Design and Comparison Report

Patrol Vessel Rijkswaterstaat

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GREEN MARITIME METHANOL

C-JOB
DEDICATED NAVAL ARCHITECTS

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Rev	Description of modifications
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DISCLAIMER

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1. INTRODUCTION

This document provides a comparison overview of the eight initial design concepts for a high-speed methanol-powered patrol vessel for Rijkswaterstaat. These design concepts serve as a starting point and enable high level evaluation and selection design with the most potential. This is followed by further development and comparison of the high potential design. The eight initial design concepts which are considered can be seen in the Table 1-1.

Table 1-1 Eight initial design concepts overview

	2 propellers	**3 propellers**
Concept 1	Monohull, planing	
Concept 2	Catamaran, planing	
Concept 3		Monohull, planing
Concept 4	Monohull, foiling	
Concept 5	Catamaran, foiling	
Concept 6		Monohull, foiling
Concept 7		Catamaran, planing
Concept 8		Catamaran, foiling

Reference documents

[1] 23.516-000-001-REV0-Design Brief
[2] 23.516-000-001-REVA-Design Brief
[3] 23.516-000-001-REVA-GENERAL ARRANGEMENT CONCEPT 1
[4] 23.516-000-001-REVA-GENERAL ARRANGEMENT CONCEPT 2
[5] 23.516-000-001-REVA-GENERAL ARRANGEMENT CONCEPT 3
[6] Report 35078-1-POW v1.3
[7] 23.516-000-001-REVD-GENERAL ARRANGEMENT CONCEPT 1
[8] 23.516-000-001-REVD-GENERAL ARRANGEMENT CONCEPT 2
[9] 23.516-000-001-REVD-GENERAL ARRANGEMENT CONCEPT 3
[10] 23.516-000-090-REVA-LSW CALCULATION

2. INITIAL DESIGN CONCEPTS

In this chapter the eight initial design concepts are introduced. Main particulars of these concepts are presented including also the weight and power estimations provided by Marin. The general arrangements of these concepts are elaborated upon as well. Initial design requirements were used to create these concept designs, see reference [1].

2.1. Concept 1

Concept 1 is a planing monohull vessel with a direct-drive two engines setup. Each of the two propellers is driven by a shaft connected to a methanol-powered engine via gearbox.

2.1.1. Main particulars

An overview of the preliminary main particulars is shown in the Table 2-1. The length is kept at the maximum requirement. The rest of the parameters are estimates based on the reference vessels (RWS 21, 22, 82).

Table 2-1 Concept 1 main particulars overview

Parameter	Value [m]
Length OA	19.95
Breadth	5.00
Draught	1.40
Depth	3.00
Freeboard aft deck	1.60
Propeller diameter	0.80

2.1.2. General arrangement

The concept general arrangement is shown below. Figure 2-1 shows the profile view of vessel's starboard and Figure 2-3 shows the top view below tank top. For the full general arrangement see reference [3].

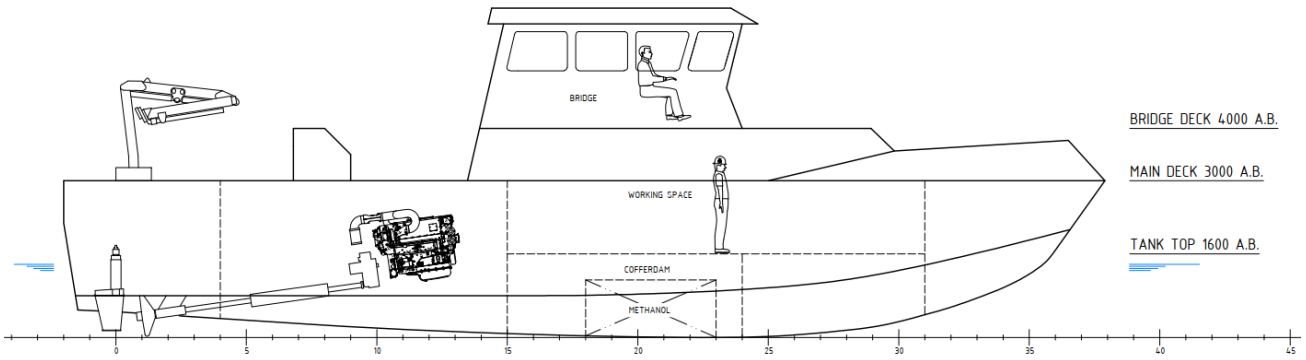

Figure 2-1 Concept 1 general arrangement (SB side view)

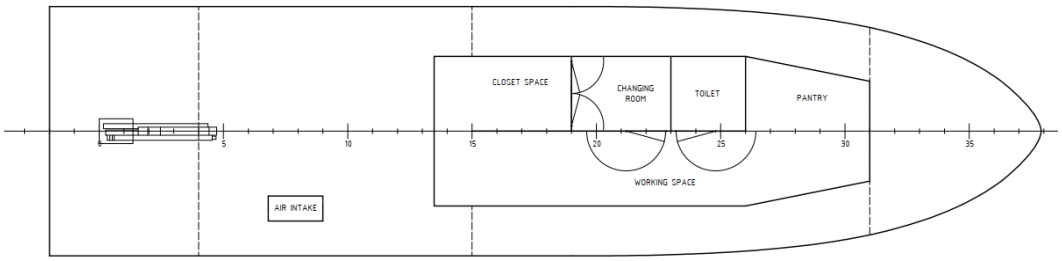

Figure 2-2 Concept 1 general arrangement (top view of main deck)

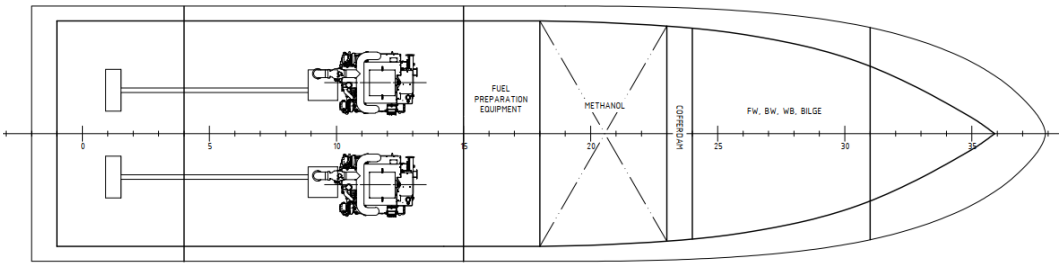

Figure 2-3 Concept 1 general arrangement (top view below tank top)

As can be seen from the general arrangement, the methanol tank is located midships as close as possible in order to limit the impact on COG and keep it in the middle of the vessel. This is a crucial criterion for a planing vessel. The methanol tank is surrounded by cofferdams except around the shell of the hull below the waterline. The aft cofferdam is extended by two frames (1 m) aft in order to accommodate methanol fuel preparation equipment. Engine room is locate aft, where two methanol engines are located. The propellers are directly driven by the engines with a gearbox in between. The propeller shaft lines are sloped 8 degrees as are the methanol engines. The fore part of the vessel below the tank top is reserved for technical tanks, such as fresh water, bilge water, black water etc. The superstructure includes the necessary working and accommodation spaces such as navigation room, closet, pantry, changing room and toilet. On the main deck aft of the superstructure the air intake/funnel is positioned above the engine room. A lifting crane is located at the aft PS of the vessel.

2.1.3. Weight and power

Based on the reference vessels with a known displacement of 33 ton (30 ton lightship weight and 3 ton deadweight), the displacement of the methanol-powered vessel was estimated at 36 ton. It is derived that additional weight of 3 ton of methanol fuel stored on board of the vessel is required as compared to the reference diesel-driven vessels, thus resulting in 36 ton displacement.

With the data on displacement and main particulars of the vessel, the required power was estimated for a range of speeds by Marin, for the full report consult reference [6]. For the required maximum speed of 40 km/h (21.6 knots) the required shaft power is 749 kW (assuming 1% shaft losses). Taking into account the losses of the gearbox (2%) the required brake power thus equals 764 kW. This is achievable with a two engines setup as the total installed power is 830 kW.

2.2. Concept 2

Concept 2 is a catamaran with two engines, one in each hull.

2.2.1. Main particulars

An overview of the preliminary main particulars are shown in Table 2-2. The length of the vessel is the maximum specified length. The rest of the parameters are estimates based on the reverence vessels.

Table 2-2 Concept 2 main particulars overview

Parameter	Value [m]
Length OA	19.95
Breadth	6.80
Draught	1.20
Depth	2.70
Freeboard aft deck	1.50
Propeller diameter	0.80

2.2.2. General arrangement

For the full general arrangement see reference [4]. Figure 2-4 shows the profile view of the vessel's starboard, Figure 2-5 shows the top view of the main deck and Figure 2-6 shows the top view of the tank top.

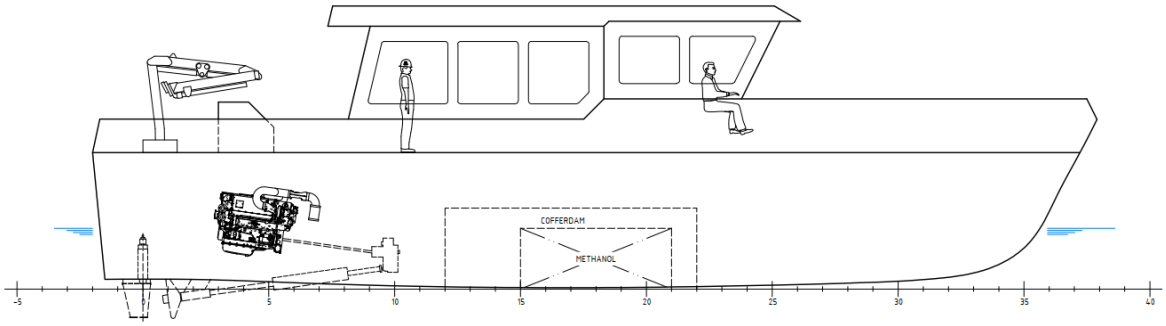

Figure 2-4 Concept 2 general arrangement (SB side view)

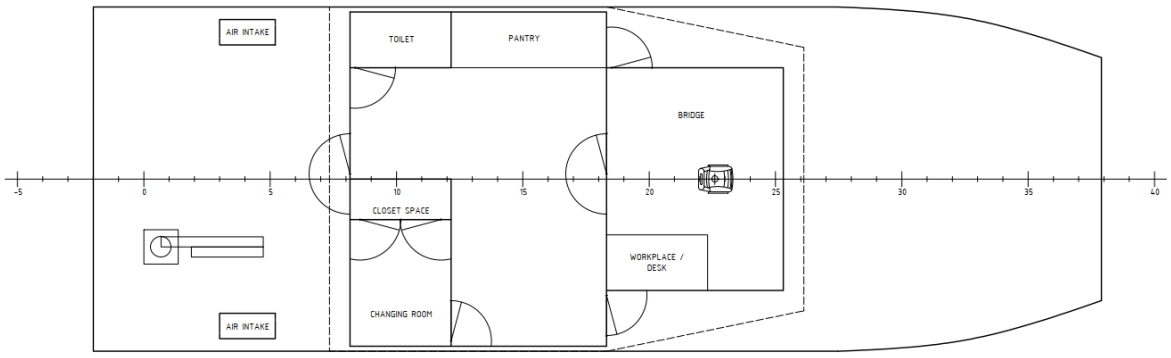

Figure 2-5 Concept 2 general arrangement (top view of main deck)

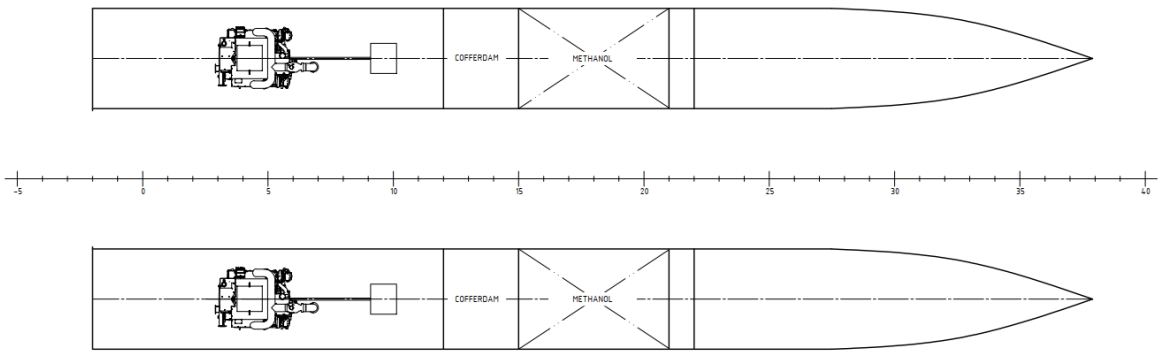

Figure 2-6 Concept 2 general arrangement (top view of tank top)

As can be seen, two methanol tanks are positioned below the waterline, one in each hull. It is located as close as possible to the midships in order to limit its impact on the COG. Each methanol fuel tank supplies one engine within each hull. The cofferdams are located fore and aft of the methanol fuel tanks. The aft cofferdam is extended by 1 m in order to accommodate fuel preparation equipment. Each engine room is located aft of each hull with a remote V-drive arrangement including input shaft from the engine to the gearbox, gearbox and output shaft connected to the propeller with a 8 degree angle. The fore part of each hull below the tank top is reserved for technical tanks, such as fresh water, bilge water, black water etc., similar as in Concept 1 and 3. The superstructure located on main deck includes the necessary working and accommodation spaces, such as bridge, workplace, pantry, toilet, closet and changing room. Two air intakes are located on PS and SB for each engine. The crane is located at the aft side of the vessel on main deck.

2.2.3. Weight and power

The same displacement of 36 ton was applied for the catamaran (30 ton lightship weight and 6 ton deadweight) based on the reference vessels. With the displacement and main particulars data the required power was estimated for a range of sailing speeds by Marin. For the full report see reference [6]. For the required speed of 40 km/h (21.6 knots) the required shaft power is 595 kW (assuming 1% shaft losses). Taking into account the losses of the gearbox (2%) the required brake power thus equals 607 kW. This is achievable with a two engine setup as the total installed power is 830 kW.

2.3. Concept 3

Concept 3 is a planing monohull vessel with a direct-drive three engines setup. Each of the three propellers is driven by a shaft connected to a methanol-powered engine via gearbox.

2.3.1. Main particulars

An overview of the preliminary main particulars is shown in the Table 2-3. The length is kept at the maximum requirement. The rest of the parameters are estimates based on the reference vessels (RWS 21, 22, 82). The breadth was increased to 6.50 m as compared to Concept 1 with the breadth of 5.00 m. This is due to more space required to accommodate three engines in the engine room.

Table 2-3 Concept 3 main particulars overview

Parameter	Value [m]
Length OA	19.95
Breadth	6.50
Draught	1.40
Depth	3.00
Freeboard aft deck	1.60
Propeller diameter	0.80

2.3.2. General arrangement

The concept general arrangement is shown below. Figure 2-7 shows the profile view of vessel's starboard, Figure 2-8 shows the top view of the main deck and Figure 2-9 shows the top view below tank top. For the full general arrangement see reference [5].

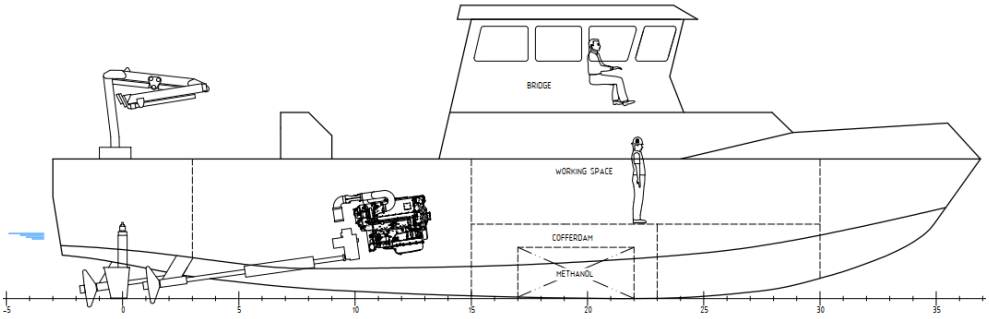

Figure 2-7 Concept 3 general arrangement (SB side view)

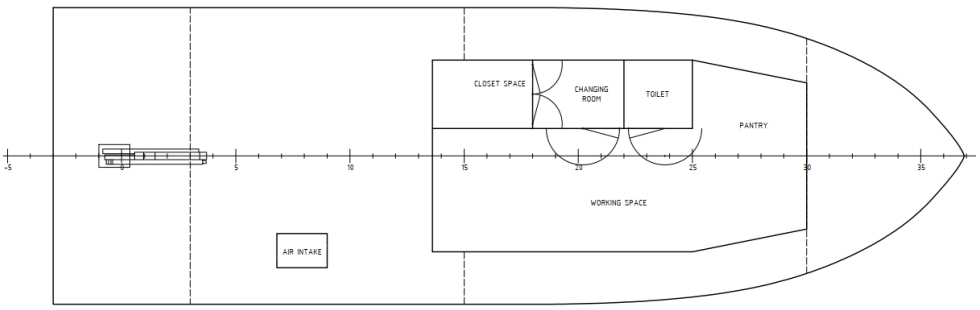

Figure 2-8 Concept 3 general arrangement (top view of main deck)

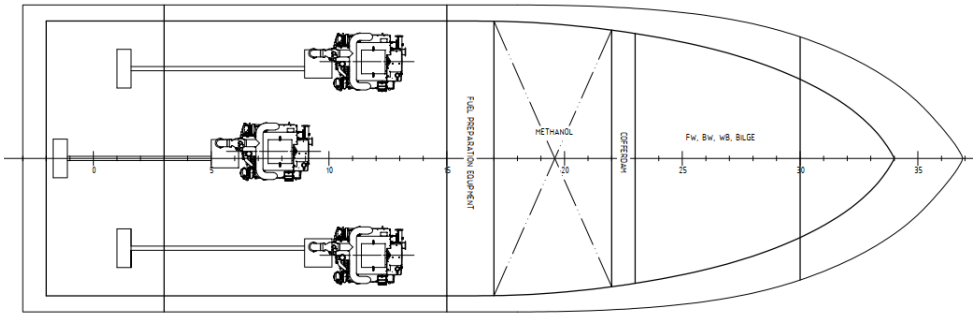

Figure 2-9 Concept 3 general arrangement (top view below tank top)

A similar arrangement of technical spaces and accommodation is kept as compared to Concept 1. The methanol tanks is located midships below the superstructure and the aft cofferdam accommodates fuel preparation equipment. In order to accommodate three engines in the engine room and ensure there is sufficient maintenance area, the breadth of the vessel was increased to 6.50 m as compared to 5.00 m for Concept 1. Rudders are located on PS and SB sides respectively to increase the manoeuvrability of the vessel. The central propeller is moved further aft and away from the side propellers in order to increase its efficiency. For this reason, the central engine is moved further aft as well and located lower than the side engines in order to keep the same shaft line angle of 8 degrees. This is feasible due to the hull shape at the centreline. Moving a centreline engine aft also allows to have more maintenance area.

2.3.3. Weight and power

The displacement is 36 ton and is estimated in the same way as for Concept 1. With this data and the main particulars data, the required power to sail at the required speed was estimated by Marin see reference [6]. It is estimated that at 21.6 knots sailing speed (40 km/h) the required shaft power is 759 kW (assuming 1% shaft losses). Taking into account the gearbox losses of 2%, the required brake power is 774 kW. This is achievable with a three engines setup as the installed power is 1245 kW.

2.4. Concept 4, 5 and 6

Concept 4, 5 and 6 are hydro foiling vessels. The initial draft arrangement has been made for Concept 4, which is a monohull vessel with two engines setup.

The patrol boat is required to occasionally reach the maximum speed of 40 km/h, for example when following another vessel entering a port. An overview of the operational profile of the reference vessel is shown in the Figure 2-10.

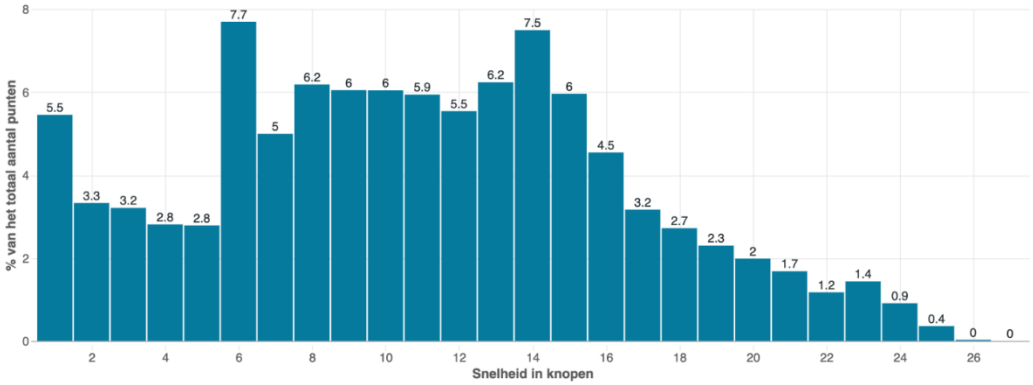

Figure 2-10 Operational profile overview of the reference vessel

The operational profile of this vessel is highly varying. Using the tool provided by Flying-Fish, it was estimated that the take-off speed would be 27 km/h (14 knots). In order to make the foils effective the patrol vessel would need to operate at speeds higher than 14 knots for continuous periods of time. As can be seen the reference vessel is not operating above 14 knots most of the time, only occasionally. At lower speeds, below 14 knots, the performance of the hydro foiling vessel is expected to be worse compared to the planing vessel due to additional resistance from the foils. This is thus considered unfavourable for this particular case.

With these insights into the required operational profile and efficient range of operation for hydro foils, the concepts involving hydro foils are disregarded for the patrol vessel.

2.5. Concept 7 and 8

Concept 7 is a planing catamaran vessel with a three propeller setup. Concept 8 is a hydro foiling catamaran vessel with a three propeller setup. These two concept designs are considered unfeasible as three propellers and two hulls are considered not realistic or practical. Therefore these are disregarded.

2.6. Conclusion

Concept 1, 2 and 3 are considered the most feasible for the listed requirements and are chosen for the further detailing, including a more detailed general arrangement and a weight estimate. The preliminary analysis shows that the required speed of 40 km/h can be reached for these three concepts despite the higher displacement due to more fuel on board compared to the reference vessels. Concepts 4,5 and 6 (with hydrofoils) are disregarded due to the varying operational profile of the vessel and therefore limited effectiveness of the hydro foil. Concepts 7 and 8 (three propeller catamarans) are considered unfeasible and are disregarded as well.

3. SELECTED DESIGN CONCEPTS

Initial design concepts 1, 2 and 3 were selected for further detailing. The new requirements summarized in reference [2] are applied for the new iteration of the selected concept designs. This chapter covers the revised general arrangements and more detailed lightship weight calculations for the 3 selected design concepts.

3.1. Concept 1

Concept 1, which is a two propeller monohull equipped with two methanol engines, was further detailed in terms of arrangement and weight estimation.

3.1.1. General arrangement

The revised general arrangement of concept 1 can be seen in the Figure 3-1 (profile view to SB) and Figure 3-2 (below tank top view). For the full general arrangement of concept 1 see reference [7].

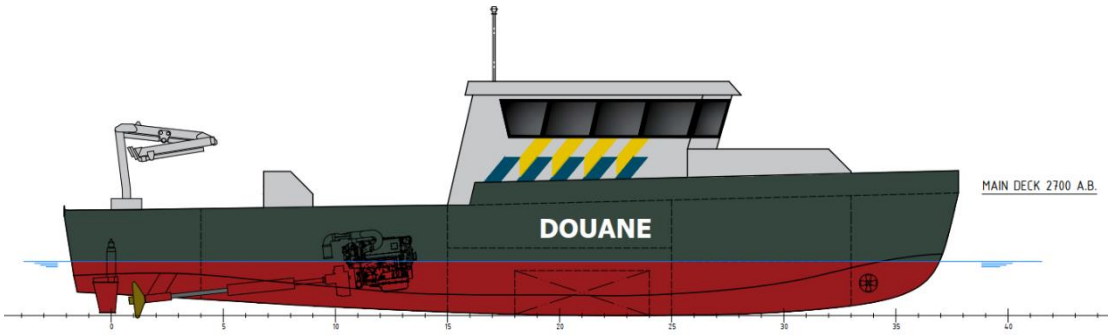

Figure 3-1 Concept 1 updated general arrangement (profile view to SB)

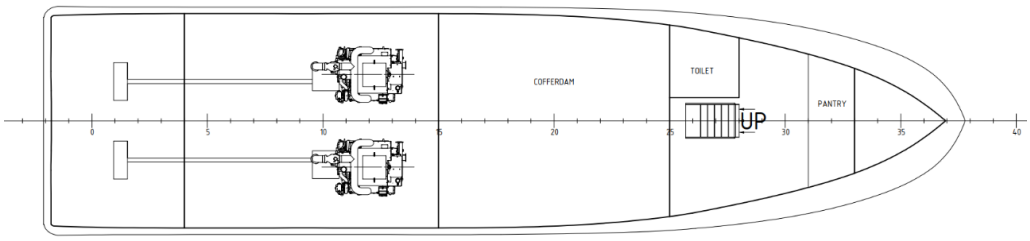

Figure 3-2 Concept 1 updated general arrangement (below tank top)

The depth and aft freeboard were updated and the hull lines used for resistance and power prediction developed by MARIN, see reference [6]. The depth of the vessel is 2.35 m and freeboard of aft deck is 1.15 m. The accommodation space was also adjusted as the previous arrangement resulted in an unpractically high superstructure. Pantry and toilet were moved fore to the tank top level with stairs from the bridge located on the main deck. Methanol tank, surrounded by 500 mm cofferdam has a capacity of 6.7 m^3 and is located below the superstructure under the waterline. Concept 1 has a draught of 1.2 m which does not comply with the minimum draught requirement of 1.3 m as stated in reference [2].

3.1.2. Weight calculation

The initial displacement estimate for Concept 1 was 30 ton of lightship weight and 6 ton of deadweight (methanol fuel). This estimate was based on the similarly sized reference vessels and methanol fuel capacity calculation. A more accurate lightship weight estimate is made in this design iteration using RWS88 vessel as reference, for which the lightship weight components are known and totals 45 ton. First the lightship weight groups of RWS88 were established based on the known equipment and hull construction calculations. The construction calculations were performed using the hull (steel) and superstructure (aluminium) 3D models. The area of steel and aluminium plates was multiplied by the known plate thickness of 5 mm for both and respective densities of steel and aluminium. Furthermore, the stiffener factor of 1.6, welding factor of 1.05 and concept factor of 1.1 were applied. The resulting lightship weight calculation of RWS88 can be seen in the Table 3-1. For the full lightship weight calculation of RWS88 see reference [10].

Table 3-1 LSW groups overview for RWS88

Lightship weight groups [ton]	**Mass**
Construction	20.2
Manoeuvring and propulsion	3.8
Piping & fittings	5.0
Power generation	4.9
Equipment	1.3
Outfitting	4.8
Joinery	2.0
Insulation, coating, vibration & noise suppression	3.0
Total LSW [ton]	45.0

The known mass of equipment such as methanol engines, crane etc. was used for concept 1 lightship weight estimation. Furthermore, the aluminium construction calculations were performed based on the preliminary hull and superstructure model. The area of the aluminium plates of the hull was multiplied by 8 mm thickness in order to reach the same specific strength as a steel hull. The superstructure plate area was multiplied by 5 mm (similar to RWS88). The same concept factors were applied for concept 1 construction as well. The resulting lightship weight estimation for concept 1 is shown in the Table 3-2. For the full lightship weight calculation of concept 1 see reference [10]. 6 ton of deadweight (5 ton fuel and 1 ton other) is applied for concept 1. This estimation is based on reference vessels and methanol conversion (see Chapter 2). This results in the displacement of 42.2 ton and is shown in the Table 3-2.

Table 3-2 Weight overview for concept 1

Weight groups	Mass
Lightship weight [ton]	36.2
Construction	13.0
Manoeuvring and propulsion	3.7
Piping & fittings	4.5
Power generation	5.2
Equipment	1.3
Outfitting	4.0
Joinery	2.0
Insulation, coating, vibration & noise suppression	2.5
Deadweight [ton]	6.0
Fuel	5.0
Crew, provisions and other	1.0
Displacement [ton]	42.2

The total lightship weight of concept 1 results in 36.2 ton, which is less than of a similarly sized RWS88, mostly due to a lighter aluminium hull. With 6 ton deadweight, the displacement of the vessel is 42.2 ton.

3.2. Concept 2

Concept 2, which is a two propeller catamaran equipped with two methanol engines, one in each demi hull, was further detailed in terms of arrangement and weight estimation.

3.2.1. General arrangement

The revised general arrangement of concept 2 can be seen in the Figure 3-1 (profile view to SB) and Figure 3-2 (below tank top view). For the full general arrangement of concept 2 see reference [8].

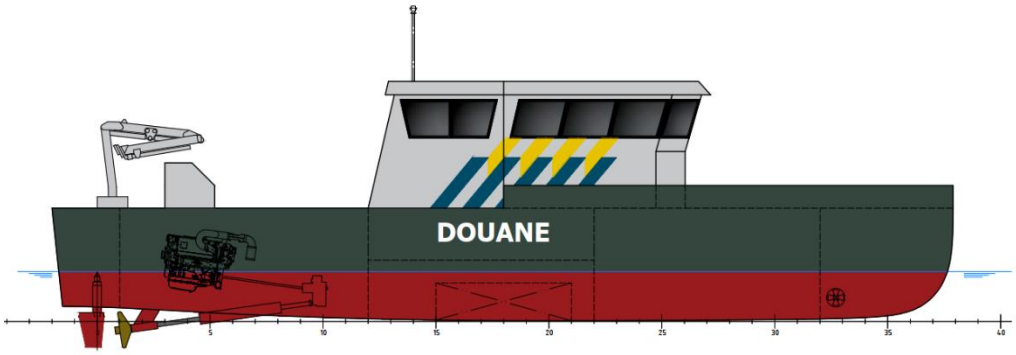

Figure 3-1 Concept 2 updated general arrangement (profile view to SB)

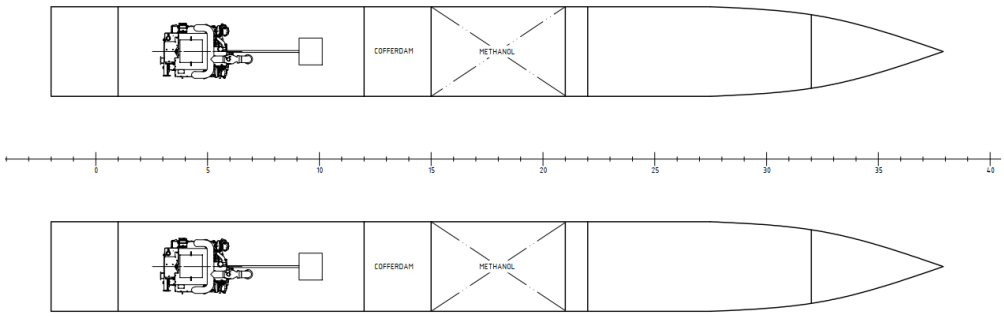

Figure 3-2 Concept 2 updated general arrangement (below tank top)

The length and breadth of the catamaran are kept the same as in the first iteration, 19.95 m and 6.8 m respectively, the depth was decreased to 2.5 m to match it with the catamaran model provided by MARIN. The accommodation and bridge spaces were reduced in length in order to keep more aft deck space. Methanol tanks are located below the superstructure and below the waterline. The remote V-drive arrangement of propulsion is kept the same within both demi hulls with two methanol engines. It should be noted that this concept does not comply with the minimum draught requirement of 1.3 m and the maximum breadth requirement of 6.0 m as stated in reference [2], concept 2 has a draught of 1.1 m and a breadth of 6.8 m.

3.2.2. Weight calculation

A reference catamaran of similar dimensions and known lightship weight components was used to estimate the lightship weight of several components of concept 2, such as outfitting, joinery, piping and fittings. The aluminium construction calculations were performed based on the 3D model of the demi hulls, intermediate structure and superstructure. Area of the plates was multiplied by 8 mm thickness for demi hulls, bulkheads and intermediate structure. The area of the superstructure plates was multiplied by 5 mm thickness respectively. Furthermore, the stiffener factor of 1.6, welding factor of 1.05 and concept factor of 1.1 were applied. An overview of the lightweight ship components of concept 2 can be seen in the Table 3-3. 6 ton of deadweight (5 ton fuel and 1 ton other) is applied for concept 2. This estimation is based on reference vessels and methanol conversion (see Chapter 2). This results in the displacement of 49.6 ton and is shown in the Table 3-3.

Table 3-3 Weight overview for concept 2

Weight groups	**Mass**
Lightship weight [ton]	43.6
Construction	22.4
Manoeuvring and propulsion	3.7
Piping & fittings	3.0
Power generation	5.2
Equipment	1.3
Outfitting	4.5
Joinery	2.0
Insulation, coating, vibration & noise suppression	1.5
Deadweight [ton]	6.0
Fuel	5.0
Crew, provisions and other	1.0
Displacement [ton]	49.6

The total lightship weight of concept 2 results in 43.6 ton. This is higher than for two monohulls (concept 1 and 3). This is due to the heavier aluminium construction with the two demi hulls and an intermediate structure. Lower and less conservative thickness for the demi hulls and intermediate structure can be investigated for a potential weight reduction. With 6 ton deadweight the displacement of the vessel is 49.6 ton.

3.3. Concept 3

Concept 3, which is a three propeller monohull equipped with three methanol engines, was further detailed in terms of arrangement and lightship weight estimation.

3.3.1. General arrangement

The revised general arrangement of concept 3 can be seen in the Figure 3-3 (profile view to SB) and Figure 3-4 (below tank top view). For the full general arrangement of concept 3 see reference [9].

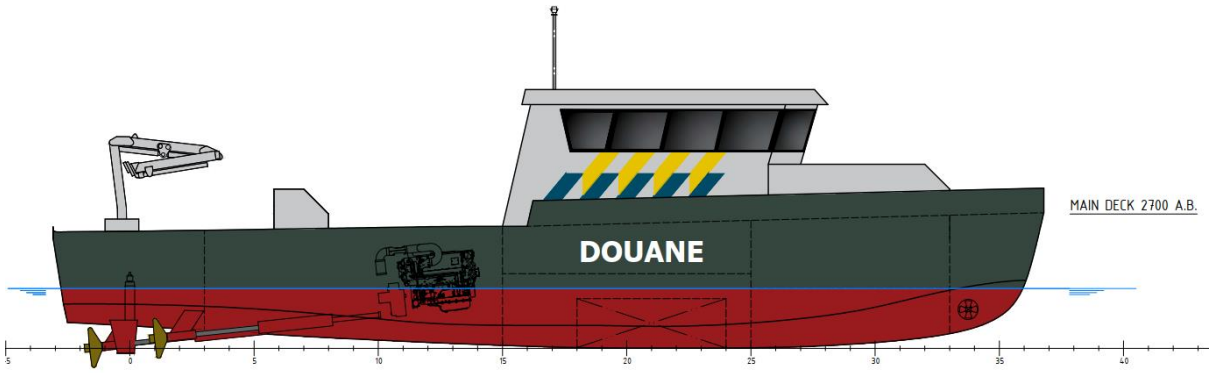

Figure 3-3 Concept 3 updated general arrangement (profile view to SB)

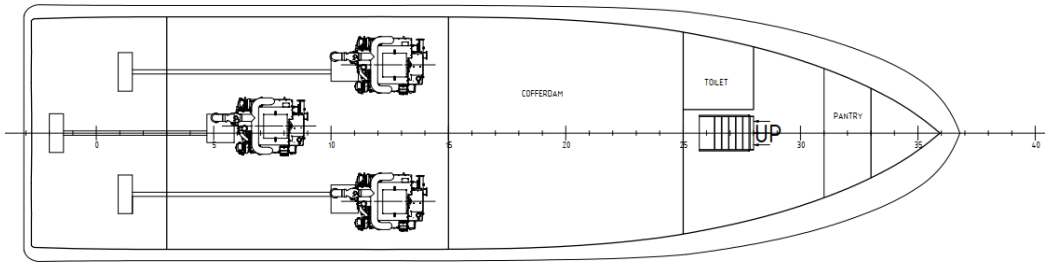

Figure 3-4 Concept 3 updated general arrangement (below tank top)

Similar arrangement is applied for concept 3 as for concept 1. The breadth is increased by 0.5 m to 5.5 m in order to accommodate three methanol engines. Two rudders are installed on PS and SB. The freeboard and depth of the vessel are kept the same as concept 1. Two side methanol engines are located closer to the midships and the middle engine is located aft and lower due to the hull shape and angle of the propeller and shaft. The accommodation space arrangement is kept similar to concept 1 and no changes to the superstructure are made. Concept 3 has a draught of 1.2 m which does not comply with the minimum draught requirement of 1.3 m as stated in reference [2].

3.3.2. Weight calculation

The same approach was used for lightship weight calculation for concept 3 as for concept 1. RWS88 was used as reference for determining weight of lightship weight groups. Construction calculations were performed using the hull and superstructure 3D model. The areas of the plates were multiplied by the respective thickness of 8 mm and 5 mm for the hull and superstructure respectively. Furthermore, the stiffener factor of 1.6, welding factor of 1.05 and concept factor of 1.1 were applied. The resulting lightship weight overview for concept 3 can be seen in the Table 3-4. For the full lightship weight calculation of concept 3 see reference [10]. 6 ton of deadweight (5 ton fuel and 1 ton other) is applied for concept 3. This estimation is based on reference vessels and methanol conversion (see Chapter 2). This results in the displacement of 46.7 ton and is shown in the Table 3-4.

Table 3-4 Weight overview for concept 3

Weight groups	Mass
Lightship weight	40.7
Construction	13.7
Manoeuvring and propulsion	4.7
Piping & fittings	5.5
Power generation	7.0
Equipment	1.3
Outfitting	4.0
Joinery	2.0
Insulation, coating, vibration & noise suppression	2.5
Deadweight [ton]	6.0
Fuel	5.0
Crew, provisions and other	1.0
Displacement [ton]	46.7

The total lightship weight of concept 3 results in 40.7 ton. An increase in weight compared to concept 1 is due to the larger breadth of the vessel and an additional methanol engine, gearbox, shaft, propeller and rudder. Furthermore, more piping and fittings would be required to handle methanol fuel for an operation of the additional methanol engine. With 6 ton deadweight the displacement of the vessel is 46.7 ton.

3.4. Weight overview

Table 3-5 presents an overview of the lightship weight, deadweight and displacement for concepts 1,2 and 3. This data is used as input for the second iteration of power estimation and subsequent tank capacity calculation.

Table 3-5 Weight overview for concepts 1,2 and 3

Weight group	Concept 1	Concept 2	Concept 3
Lightship weight [ton]	36.2	43.6	40.7
Deadweight [ton]	6.0	6.0	6.0
Displacement [ton]	42.2	49.6	46.7

3.5. Power and speed prediction

Marin was consulted to determine the speed power curves of all three concepts. Based on the general arrangements and main particulars, Marin created three 3D hull models to determine the resistance of the concepts. Table 3-6 shows the main particulars of the 3D models of the three concepts.

Table 3-6 Input power and speed prediction

Description	Symbol	Catamaran 2 propellers	Mono hull 2 propellers	Mono hull 3 propellers	Unit
Length over all	L_{PP}	19.950	19.950	19.950	m
Length on waterline	L_{WL}	19.950	18.380	18.372	m
Length overall submerged	L_{OS}	19.950	18.380	18.372	m
Breadth extreme	B_m	6.800	5.000	5.500	m
Breadth moulded on WL	B_{WL}	2.000*	4.635	4.622	m
Draught moulded on FP	T_F	1.080	1.180	1.200	m
Draught moulded on AP	T_A	1.080	1.180	1.200	m
Displacement volume moulded	∇	25.2	42.0	46.7	m^3
Displacement mass in seawater**	Δ_1	25.2*	43.1	47.8	t
Wetted surface area bare hull	S	57.8	89.5	92.5	m^2
Wetted surface area appended	S_{TOT}	60.3	94.5	100.0	m^2
LCB position forward of ½ L_{PP}	LCB	-2.4	-4.9	-3.9	%
Block coefficient	C_B	0.585	0.423	0.419	-
Midship section coefficient	C_M	0.914	0.558	0.558	-
Prismatic coefficient	C_P	0.640	0.758	0.751	-
Water plane coefficient	C_{WP}	0.798	0.788	0.787	-
Length-Breadth ratio	L_{wl}/B_{wl}	9.975	3.918	3.554	-
Breadth-Draught ratio	B_{wl}/T	1.852	3.928	4.258	-
Area exposed to wind	A_V	25.0	17.5	17.5	m^2

*Catamaran hull data based on a single hull with distance from CL to CL of 4.8m.

**Hull shape displacement not exactly as specified due to 3D model margins and constraints, modelled displacement slightly higher than shown in Table 3-5, making it a conservative approach.

Using the DESP computer program (which is based on the empirical Holtrop-Mennen method) the speed-power curves of all three concepts are determined. Because the propeller load of the monohull with two propellers was too high, a fourth case was added with a larger propeller diameter of 0.9 meter instead of 0.8 meter. The resulting curves are shown in Figure 3-5.

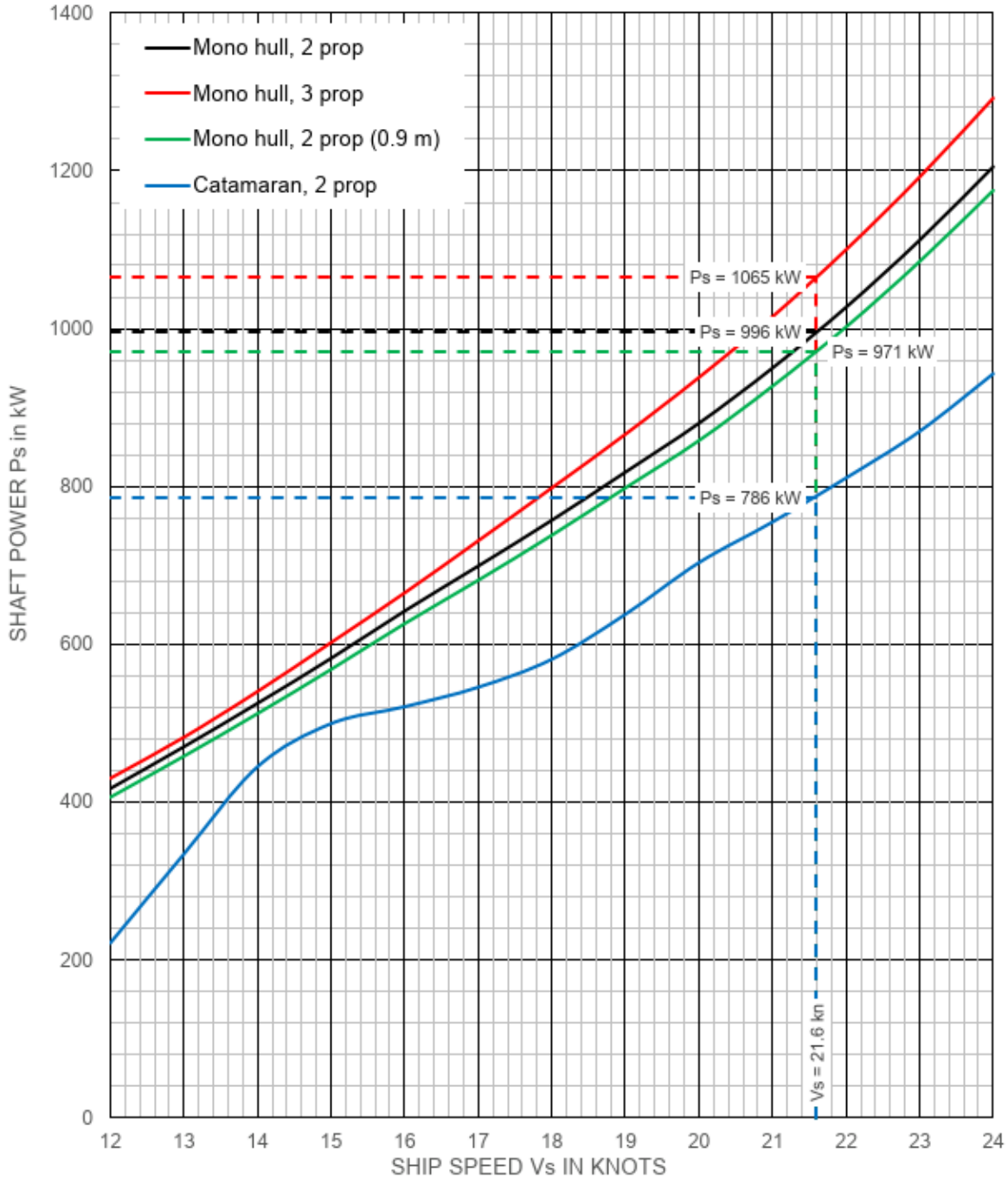

Figure 3-5 Speed power curves

Table 3-7 Speed power prediction results

Ship power at 40 km/h			
Concept	**Shaft power [kW]**	**Brake power [kW]**	**Installed brake power [kW]**
Catamaran 2 propellers	786	802	830
Mono hull 2 propellers D=0.8m	996	1016	830
Mono hull 2 propellers D=0.9m	971	991	830
Mono hull 3 propellers	1065	1087	1245

Table 3-7 shows the shaft power, brake power (based on 98% gearbox efficiency), and the installed brake power. From Table 3-7 it can concluded that a speed of 40 km/h is only possible for the catamaran and the monohull with three propellers. The monohull with two propellers has insufficient installed power to reach the required speed. With an installed brake power of 830 kW the monohull with two propellers has a maximum speed of 35 km/h. The monohull with 2 propellers can however be feasible when more powerful engines become available. Therefore, in section 3.6 a concept with two more powerful dual fuel engines is investigated as alternative for the ScandiNAOS engines. Alternatively, it could be considered to accept a reduced speed of 35 km/h.

From required power point of view, the catamaran appears to be the most attractive. Furthermore, now that the actual power requirements of the concepts are known the fuel requirements and corresponding deadweight estimates can be checked and where needed updated, which is done in section 0.

3.6. Concept 1B: Dual-fuel

Based on the power and speed predictions performed with the given displacement and main particulars, it was concluded that for concept 1 (2 propeller monohull) the power provided by two methanol ScandiNAOS engines would not be sufficient to reach the required 40 km/h speed. The required shaft power for this speed is 996 kW (0.8 m propeller diameter) or 971 kW (0.9 m propeller diameter). As a larger propeller (diameter of 0.9 m) offers a better performance in terms of efficiency, it is further applied for Concept 1. As power of these engines is limited to maximum 415 kW (so 830 kW maximum installed power), a dual-fuel power generation option is investigated for Concept 1 with more powerful dual-fuel engines and thus more installed power on board.

As a reference for a dual-fuel engine Volvo Penta D13-700 is taken with the maximum continuous rating of 515 kW. This dual-fuel engine is currently in development, but not yet commercially available. Concept 1B has two Volvo Penta engines, making the installed power 1030 kW. The required brake power to sail at 40 km/h is 991 kW. Therefore, concept 1B with dual fuel engines has sufficient power to reach the required speed.

3.7. Fuel capacity and autonomy

The required autonomy for each concept is 12 hour sailing at a speed of 40 km/h. With the estimated power requirement to sail at this speed for all three concept vessels, the fuel tank capacities are calculated and the weight of fuel is checked with the first estimate of 5 ton in this new iteration.

3.7.1. Concept 1A

Concept 1A uses two ScandiNAOS engines, with a total installed power of 830 kW. The maximum speed this concept can reach is 35 km/h, which does not comply with the 40 km/h requirement. Based on the specific fuel consumption of the ScandiNAOS engines the autonomy of Concept 1A is exactly 12 hours at 35 km/h.

3.7.2. Concept 1B

Concept 1B has two high-speed dual-fuel engines (based on Volvo Penta D13-700). The Volvo Penta engines are slightly lighter than the ScandiNAOS engines. However, because of the additional weight of the dual fuel system the lightweight difference between concept 1A and 1B is considered neglectable. Therefore, this weight difference is not further addressed.

The diesel efficiency of the Volvo Penta engine is 0.40 (based on 212 g/kWh at high load). Assuming that the same efficiency can be reached with a dual-fuel option and applying 5% in terms of mass of diesel as pilot fuel, the specific fuel consumption is 409 g/kWh of methanol and 22 g/kWh of diesel as pilot fuel. The required fuel mass capacity is 4.9 ton of methanol and 0.3 ton of diesel, thus a total of 5.2 ton. This is more than the initially estimated 5.0 ton of fuel. Therefore, an additional design iteration is required.

By adding an additional 0.5 ton to the fuel deadweight the displacement of concept 1 is increased from 42.2 ton to 42.7 ton. Using the Admiralty coefficient the required power to sail 40 km/h with the increased displacement is calculated. Based on a total displacement of 42.7 ton, the brake power required to sail 40 km/h is increased from 991 kW to 999 kW. Using the same efficiencies and fuel share ratios as in previous calculations the required fuel mass capacity is 4.9 ton of methanol and 0.3 ton of diesel. This required fuel deadweight increase of 0.1 ton is less than the 0.5 ton. Therefore, having a fuel deadweight of 5.5 ton is sufficient.

3.7.3. Concept 2

To sail at 40 km/h the catamaran requires 802 kW brake power. Therefore, the two ScandiNAOS engines deliver sufficient power to reach 40 km/h. The specific fuel consumption of the methanol engine is 470 g/kWh according to the ScandiNAOS specification. Using the required autonomy and specific fuel consumption, the required methanol capacity is 4.5 ton. This complies with the initial estimate of 5.0 ton of fuel.

3.7.4. Concept 3

Concept 3 with the three methanol ScandiNAOS engines requires 1087 kW brake power to sail 40 km/h. Using the same specific fuel consumption of the methanol engine as in Concept 2, the required methanol capacity is 6.3 ton. This is more than the initially estimated 5.0 ton of fuel. Therefore, an additional design iteration is required.

The required power to sail 40 km/h with 1.5 ton additional fuel deadweight is calculated using the Admiralty coefficient. The additional displacements increases the required brake power from 1087 kW to 1110 kW. Based on the fuel consumption specified by ScandiNAOS, and the required

autonomy, the required methanol fuel capacity is 6.3 ton. Therefore, having a fuel deadweight of 6.5 ton is sufficient.

3.8. Concepts comparison

Table 3-8 shows an overview of the main particulars and weight comparison of the three selected concepts. Concept 1 and 3 are monohulls with two and three engines respectively and similar main particulars. Concept 3 is 0.5 m wider than concept 1 in order to accommodate three engines. Concept 2 is a catamaran with two engines. It has the same length overall as the other two concepts. It has a higher breadth of 6.8 m and a slightly higher depth of 2.5 m.

For the lightship weight calculation aluminium is assumed for the hull structure of all 3 concepts. Concept 1 has the lowest lightship weight since it has the smallest hull as well as accommodating two engines and two propellers. Concept 2 has the highest lightship weight due to a higher aluminium construction weight consisting of two demi hulls, intermediate structure, bulkheads and superstructure. Concept 3 has a higher lightship weight compared to concept 1 due to additional weight of the hull construction due to increased breadth as well as an additional methanol engine, shaft, gearbox and propeller.

Table 3-8 Concepts 1,2 and 3 design iteration overview

Parameter	Concept 1A	Concept 1B	Concept 2	Concept 3
Main particulars				
Length OA [m]	19.95	19.95	19.95	19.95
Breadth [m]	5.00	5.00	6.80	5.50
Depth [m]	2.35	2.35	2.50	2.35
Draught [m]	1.20	1.20	1.10	1.20
Number of engines [-]	2	2	2	3
Lightship weight [ton]	36.2	36.2	43.6	40.7
Construction	13.0	13.0	22.4	13.7
Manoeuvring and propulsion	3.7	3.7	3.7	4.7
Piping & fittings	4.5	4.5	3.0	5.5
Power generation	5.2	5.2	5.2	7.0
Equipment	1.3	1.3	1.3	1.3
Outfitting	4.0	4.0	4.5	4.0
Joinery	2.0	2.0	2.0	2.0
Insulation, coating, vibration & noise	2.5	2.5	1.5	2.5
Deadweight [ton]	6.0	6.5	6.0	7.5
Fuel	5.0	5.5	5.0	6.5
Crew, provisions and other	1.0	1.0	1.0	1.0
Displacement [ton]	42.2	42.7	49.6	48.2

Table 3-9 shows the comparison of the three concepts in terms of the required power and energy to sail 12 hour at 40 km/h speed as well as overview of the required fuel capacity and storage volume. The calculation was based on the resistance estimations, engine specific fuel consumption and required autonomy.

Table 3-9 Required fuel capacity and operational overview of the three concepts

Parameters	Concept 1A	Concept 1B	Concept 2	Concept 3
Required autonomy [h]	12.0			
Required speed [km/h]	40.0			
Design speed [km/h]	35.0	40.0	40.0	40.0
Autonomy at design speed [h]	12.0	12.1	13.3	12.7
Brake power at design speed [kW]	830	999	802	1110
Installed brake power [kW]	830	1030	830	1245
Methanol capacity [ton]	5.0	5.0	5.0	6.5
Diesel capacity* [ton]	-	0.5	-	-

*Only applied for concept 1, which includes dual-fuel engines

As can be seen, the catamaran (Concept 2) offers the highest fuel efficiency as compared to the other concepts. Due to a significantly lower resistance at higher speeds, fuel consumption of the catamaran is reduced by approximately 20-25% as compared to monohull concepts.

4. CONCLUSIONS AND RECOMMENDATIONS

This feasibility study explored eight initial design concepts for a high-speed methanol-powered patrol vessel tailored to the operational requirements of Rijkswaterstaat.

The initial analysis demonstrated that, despite methanol's lower energy density and the resulting need for greater fuel storage (and thus increased displacement), Concepts 1, 2, and 3 have the potential to achieve the target operational speed of 40 km/h. Concepts incorporating hydrofoils (4, 5, and 6) were deemed unsuitable due to their limited benefit in the vessel's varied operational profile. Meanwhile, Concepts 7 and 8 (three-propeller catamarans) were eliminated due to practical (technical feasibility) constraints.

Based on this concepts 1, 2, and 3 were selected as the most promising candidates. These designs were subjected to further refinement, including a further developed general arrangements and lightship weight calculation.

Based on the speed power analysis of Marin, concept 2 (catamaran) requires 802 kW brake power to sail 40 km/h and has an installed power of 830 kW, concept 3 (3 propeller monohull) requires 1110 kW to sail 40 km/h and has an installed power of 1245 kW. Therefore, concept 2 and concept 3 have sufficient installed power to reach the required speed.

Concept 1 (2 propeller monohull), had insufficient power with the ScandiNAOS methanol engines, and was therefore upgraded with more powerful dual-fuel alternatives (concept 1B). This consisted of replacing the ScandiNAOS engines with dual-fuel Volvo Penta D13-700 units (each offering 515 kW) provides a total installed power of 1030 kW, which is sufficient to meet the power demand of 1010 kW for 40 km/h. However, high speed dual-fuel engines, like Volvo Penta, are still under development and not yet commercially available.

Alternatively, it could be considered to accept a lower maximum speed of 35 km/h and select concept 1A, with two ScandiNAOS engines.

In summary, the feasibility of a methanol-powered patrol vessel is technically sound within the constraints analysed. While challenges remain, particularly in engine availability, this study confirms that with appropriate design choices and propulsion configurations, a high-speed, methanol-fuelled patrol vessel can meet operational performance targets. The catamaran shows the best performance and is the recommended design for further development and optimization.

It should be noted that the design requirements where changed by RWS during the design process. Therefore, some concepts deviate from the minimum draught of 1.3 m and the maximum breadth of 6.0 m.