Content

Appendix A - Smaller ISR USV concepts

This attachment will show different existing solutions for smaller USV concepts. All pictures and tables are gathered from the reference at the end of each description.

Saildrone Explorer USV

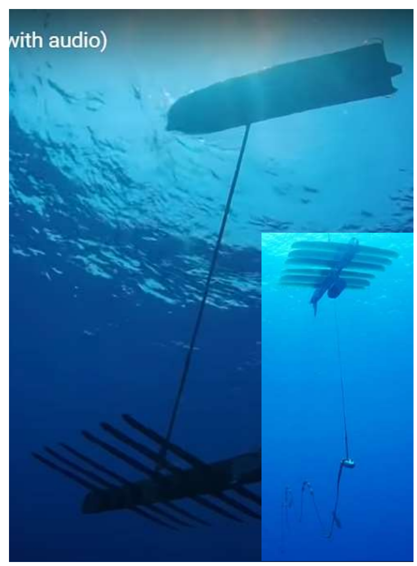
American produced USV with 1 year endurance missions. Length 7 meters with average speed of 3 knots. Autonomously collects high quality data and navigates oceans by waypoint-to-waypoint navigation. Harnessing wind and solar energy for operations. Propulsion relies on wind power. ("Saildrone Explorer USV," 2022)

Saildrone	
Length	7 meter
Average Velocity	3 knots
Endurance	1 year
Power Generation	Renewables

The Waveglider

Renewable powered USV with capabilities to endure ocean missisons. Used as a network by British Royal Navy during exercise Unmanned Warrior to report and track a submarine. Harnesses solar power, propelled by harnessing wave-motion or using a small electrical propeller. ("Waveglider," 2022)

Waveglider	
Length	2,5 m
Average Velocity	3 knots
Endurance	1 year
Power Generation	Renewables



Mariner X

Mariner X	
Length	9 m
Average Velocity	8 knots (kn), max 12 kn
Endurance	25 days
Power Generation	Diesel

Multi-purpose USV made by Maritime Robotics. Made to operate for offshore and coastal applications. ("Mariner X," 2022)

SEA-KIT H - Zero-emission vessel

SEA-KIT-H	
Length	12 / 15 meters
Average Velocity	6 knots
Endurance	23 days or 3300 nautical miles
Power Generation	-

British made USV with composite hull. The vessel is currently equipped with a diesel generator, but the company plans to install hydrogen fuel cell in 2022/2023. Made to conduct hydrographic research, seafloor mapping or maritime ISR. (Skopljak, 2022)

Protector USV

Protector USV	
Length	9 / 11 meters
Maximum Velocity	50 knots
Endurance	400 nautical miles at 30 knots
Power Generation	Diesel

The Protector is a highly independent remote controlled USV produced by Rafael Advanced Defense Systems. The vessel is currently in use by the Singapore and Israeli Navy. The USVs design is reconfigurable and enables the vessel to perform different tasks as force protection, firefighting, ISR, naval warfare, mine countermeasures and maritime harbour security missions. ("Protector USV ", 2013)

Appendix B - Choice of sensors

This thesis will not address technical solutions for sensors or its use. The choice of sensors is on the other hand fairly decisive for the design of the hull, and we therefore feel compelled to address the subject.

Selected sensors

In conversation with staff at the Royal Norwegian Naval Academy, we have opted to keep this information on a general level and rely on commercially available technology. Furthermore, it is important to understand that sonar operations and sensors are highly complicated. Implementation should not be done without careful testing and analysis by professionals.

Sonar stands for sound navigation and ranging and can be used in detecting and tracking submarines. The performance of sonar operations is heavily affected by weather, amount of biomass in the ocean, use of bandwidth, energy usage, techniques, placement and type of sensors, generic noise pollution, temperature, depth, and bottom conditions.

Sensor	**Name**	**Technical data**
Passive Variable depth sonar	Compact LF Active VDS	Weight: 1,5 tonn Maximum depth: 10-300 m
Sonar buoys		

Based on described capabilities we have chosen to go with a passive towing sonar. Our passive sonar is based on the commercially available TRAPS and Compact LF Active VDS from GeoSpectrum Technologies. The newest version is reported fitted to USVs and capable of doing unmanned missions with active sensors (Scott, 2020). Passive sonars are nothing new and equipping the USV with a passive towable sensor would provide the USV with capability to detect and track submarines.

Utilizing new sensors may pose a major risk in terms of performance. Equipping the USV with a towable new passive sonar is considered high risk with regards to performance and time for implementation.

Energy consumption

By mail, Geospectrum Technologies have defined consumption for their passive TRAPS and winching the cable as:

2-4 kW for passive sonar

7 kW for winching the cable in

Their maximum tow cable is 280 m with an 18,5 mm diameter and we estimate the passive sensor length to be a total of 250 m with 40 mm diameter. The consumption with regard to winching is to be considered an estimate as the winching is not specified at a given speed. Winching in 5 knots would provide higher total resistance and raise overall energy usage.

Calculation of drag

Towing a sonar in water poses extra resistance and we have therefore stipulated the drag force required to tow the sonar in water during 5 knots velocity. Drag force is given by the formula

$$F_d = \frac{C_d * \rho * u^2 * A}{2}$$

F_d - Drag force

C_d – Drag coefficient

ρ – Mass density of fluid

u – Flow speed of object relative to fluid

A – Area of object surface

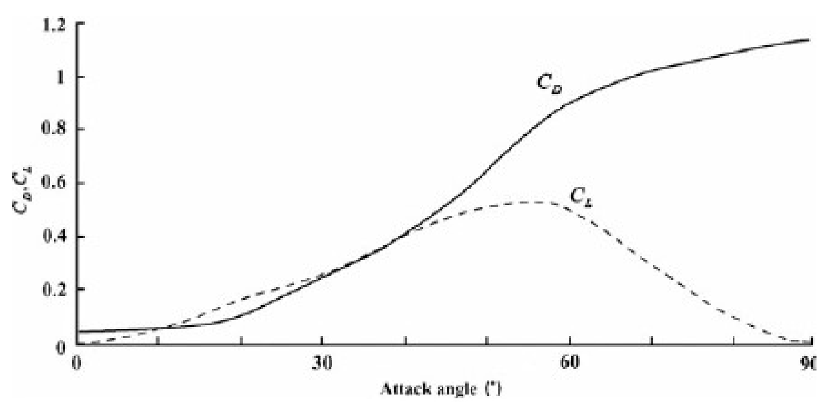


Figure 1 [kilde]

In order to estimate a drag force for the passive sensor we need the drag coefficient for the cable. If we estimate the attack angle of the tow cable is 35 degrees, we will get drag coefficient 0,4. The sensor length will have attack angle from 0-10 degrees and drag coefficient will then be 0,1.

Cd		0,1	
Tetthet		1025	kg/m^3
Speed		5	knots
Velocity		2,57	m/s
Rope diameter		45	mm
Rope circumference		0,006362	m
Length		250	m
	Area [m^2]	Fd [N]	
Sensor package	1,59	539,29	N

Table 2 Calculation of drag on sensor

Cd		0,4	
Density		1025	kg/m^3
Speed		5	knots
Velocity		2,57	m/s
Rope diameter		18,4	mm
Rope circumference		0,001064	m
	Area [m^2]	Fd [N]	
Rope Length 100 m	0,11	144,26	N
Rope Length 200 m	0,21	288,53	N
Rope Length 280 m	0,30	403,94	N

Table 1 Calculation of drag on cable

Based on given data from GeoSpectrum and estimates for drag coefficient, we have derived an Rts for the sensor to be approximately 1 kN. This drag force will be influenced by speed through water, sea states, cable attack angle on water and length of towing cable in water. Furthermore, this estimate will be good enough as a starting point for further dimensioning our vessel.

Appendix C – DELFTship data

Appendix C includes design hydrostatics rapport, hydrostatics, resistance and cross curves on both preliminary design and optimized design. Linesplan for the preliminary and optimised design is given as separate appendixes as they are dimensioned for printing in A3 sheets.

Preliminary design

Design hydrostatics report

Parent 22 - Sterntrawler

Designer	Unknown
Created by	M. van Engeland
Comment	
Filename	Parent 223.fbm

Design length	10,800 m	Midship location	5,400 m
Length over all	12,330 m	Water density	1,0250
Design beam	2,800 m	Mean shell thickness	0,0020 m
Maximum beam	2,819 m	Appendage coefficient	1,0000
Design draft	0,960 m		

Volume properties		Waterplane properties	
Moulded volume	17,033 m³	Length on waterline	11,553 m
Total displaced volume	17,107 m³	Beam on waterline	2,818 m
Displacement	17,535 t	Entrance angle	69,1 degr
Block coefficient	0,5311	Waterplane area	24,13 m²
Prismatic coefficient	0,5857	Waterplane coefficient	0,7191
Vert. prismatic coefficient	0,7353	Waterplane center of floatation	4,843 m
Wetted surface area	37,21 m²	Transverse moment of inertia	12,047 m⁴
Longitudinal center of buoyancy	5,254 m	Longitudinal moment of inertia	178,036 m⁴
Longitudinal center of buoyancy	-1,268 %		
Vertical center of buoyancy	0,547 m		
Total length of submerged body	11,905 m		
Total beam of submerged body	2,818 m		

Midship properties		Initial stability	
Midship section area	2,45 m²	Transverse metacentric height	1,254 m
Midship coefficient	0,9067	Longitudinal metacentric height	10,999 m

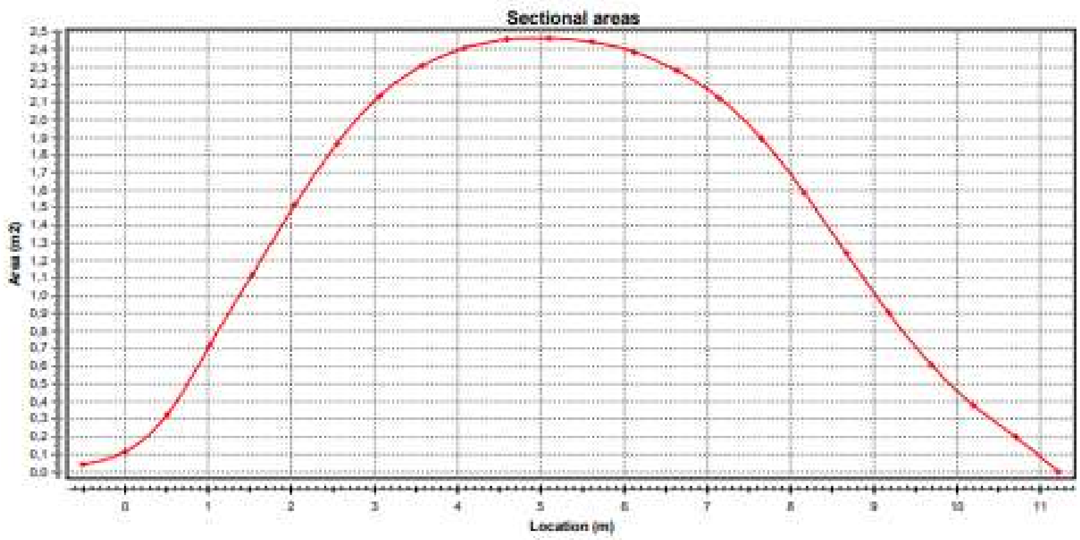
Lateral plane	
Lateral area	9,96 m²
Longitudinal center of lateral resistance	5,563 m
Vertical center of lateral resistance	0,505 m

The following layer properties are calculated for both sides of the ship

Location	Area	Thickness	Weight	LCG	TCG	VCG
	m²	m	t	m	m	m
Hull	67,13	0,040	4,565	5,500	0,000 (CL)	0,882
Superstructure	34,00	0,000	0,000	5,000	0,000 (CL)	2,188
Superstructure tower	14,70	0,000	0,000	5,448	0,000 (CL)	2,798
Towing sonar	16,11	0,000	0,000	0,220	0,000 (CL)	1,877
Battery	11,32	0,000	0,000	6,848	0,000 (CL)	0,243
Generator	6,02	0,000	0,000	7,792	0,000 (CL)	0,770
El. Engines	1,77	0,000	0,000	2,490	0,000 (CL)	0,460
Shaft	1,10	0,000	0,000	1,601	0,000 (CL)	0,456
Counter weight	0,69	0,000	0,000	10,685	0,000 (CL)	0,296
Total	152,84		4,565	5,500	0,000 (CL)	0,882

Sectional areas

Location	Area	Location	Area	Location	Area	Location	Area	Location	Area
m	m²	m	m²	m	m²	m	m²	m	m²
-0,510	0,04	2,040	1,52	4,590	2,46	7,140	2,13	9,691	0,61
0,000	0,12	2,550	1,87	5,100	2,46	7,651	1,89	10,201	0,38
0,510	0,33	3,060	2,13	5,610	2,44	8,161	1,59	10,711	0,20
1,020	0,72	3,570	2,31	6,120	2,38	8,671	1,24	11,221	0,00
1,530	1,12	4,080	2,41	6,630	2,28	9,181	0,90		



NOTE 1: Draft (and all other vertical heights) is measured from base Z=0,000
NOTE 2: All calculated coefficients based on actual dimensions of submerged body.

Hydrostatics

Water density : 1,0250
Mean shell thickness : 0,0020 m

Trim: 0,000 m

Draft	Volume	Displ FW	Displ.	LCB	VCB	TCB	Aw	LCF	KMt	KMl	MCT	TpCm
m	m³	t	t	m	m	m	m²	m	m	m	t*m	tonne/cm
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,00	0,000	0,000	0,000	0,000	0,000
0,100	0,705	0,705	0,722	5,387	0,064	0,000	11,77	5,386	3,786	78,525	0,052	0,121
0,200	2,080	2,080	2,132	5,392	0,123	0,000	15,17	5,400	2,598	35,625	0,070	0,155
0,300	3,701	3,701	3,794	5,396	0,179	0,000	17,07	5,398	2,037	23,367	0,081	0,175
0,400	5,473	5,473	5,610	5,393	0,235	0,000	18,28	5,375	1,711	17,300	0,089	0,187
0,500	7,345	7,345	7,529	5,384	0,290	0,000	19,13	5,338	1,506	13,763	0,094	0,196
0,600	9,295	9,295	9,528	5,370	0,345	0,000	19,88	5,294	1,380	11,699	0,100	0,204
0,700	11,323	11,323	11,606	5,351	0,400	0,000	20,69	5,235	1,306	10,570	0,109	0,212
0,800	13,442	13,442	13,778	5,326	0,455	0,000	21,72	5,136	1,265	10,203	0,124	0,223
0,900	15,686	15,686	16,078	5,286	0,512	0,000	23,21	4,954	1,252	10,707	0,152	0,238
1,000	18,083	18,083	18,536	5,230	0,570	0,000	24,66	4,790	1,258	11,047	0,180	0,253

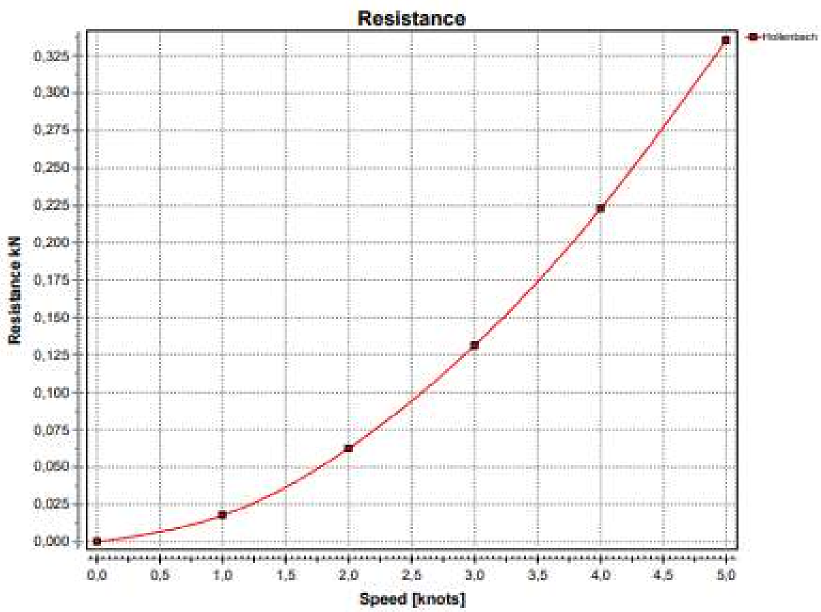
NOTE 1: Draft (and all other vertical heights) is measured from base Z=0,000
NOTE 2: All calculated coefficients based on actual dimensions of submerged body.

Nomenclature	
Draft	*Moulded draft, measured from baseline*
Volume	*Total displaced volume*
Displ FW	*Displacement fresh water*
Displ.	*Displacement*
LCB	*Longitudinal center of buoyancy, measured from the aft perpendicular at X=0.0*
VCB	*Vertical center of buoyancy*
TCB	*Transverse center of buoyancy*
Aw	*Waterplane area*
LCF	*Waterplane center of floatation, measured from the aft perpendicular at X=0.0*
KMt	*Transverse metacentric height*
KMl	*Longitudinal metacentric height*
MCT	*Moment to change trim one unit*
TpCm	*Weight to change the immersion with one unit*

Resistance calculations.

Hollenbach.

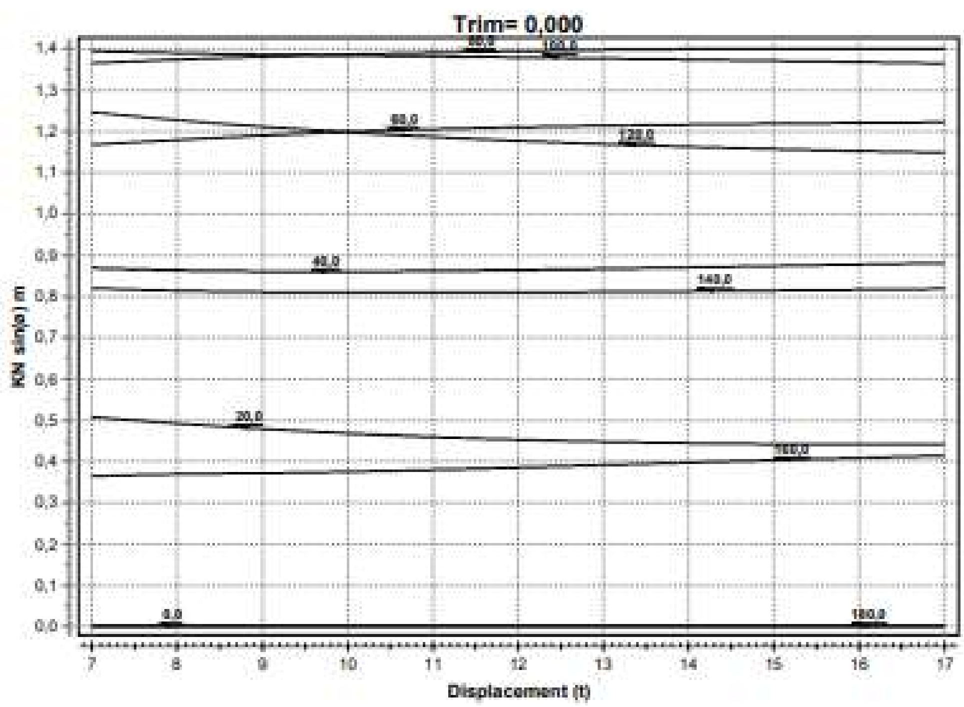
Resistance according to Hollenbach						
Speed	Speed	Froude number	Frictional resistance	Residual resistance	Total resistance	Effective power
kn	m/sec		kN	kN	kN	kW
0,00	0,00	0,000	0,0000	0,0000	0,0000	0,00
1,00	0,51	0,048	0,0177	0,0000	0,0177	0,01
2,00	1,03	0,097	0,0626	0,0000	0,0626	0,06
3,00	1,54	0,145	0,1313	0,0000	0,1313	0,20
4,00	2,06	0,194	0,2226	0,0000	0,2226	0,46
5,00	2,57	0,242	0,3354	0,0000	0,3354	0,86

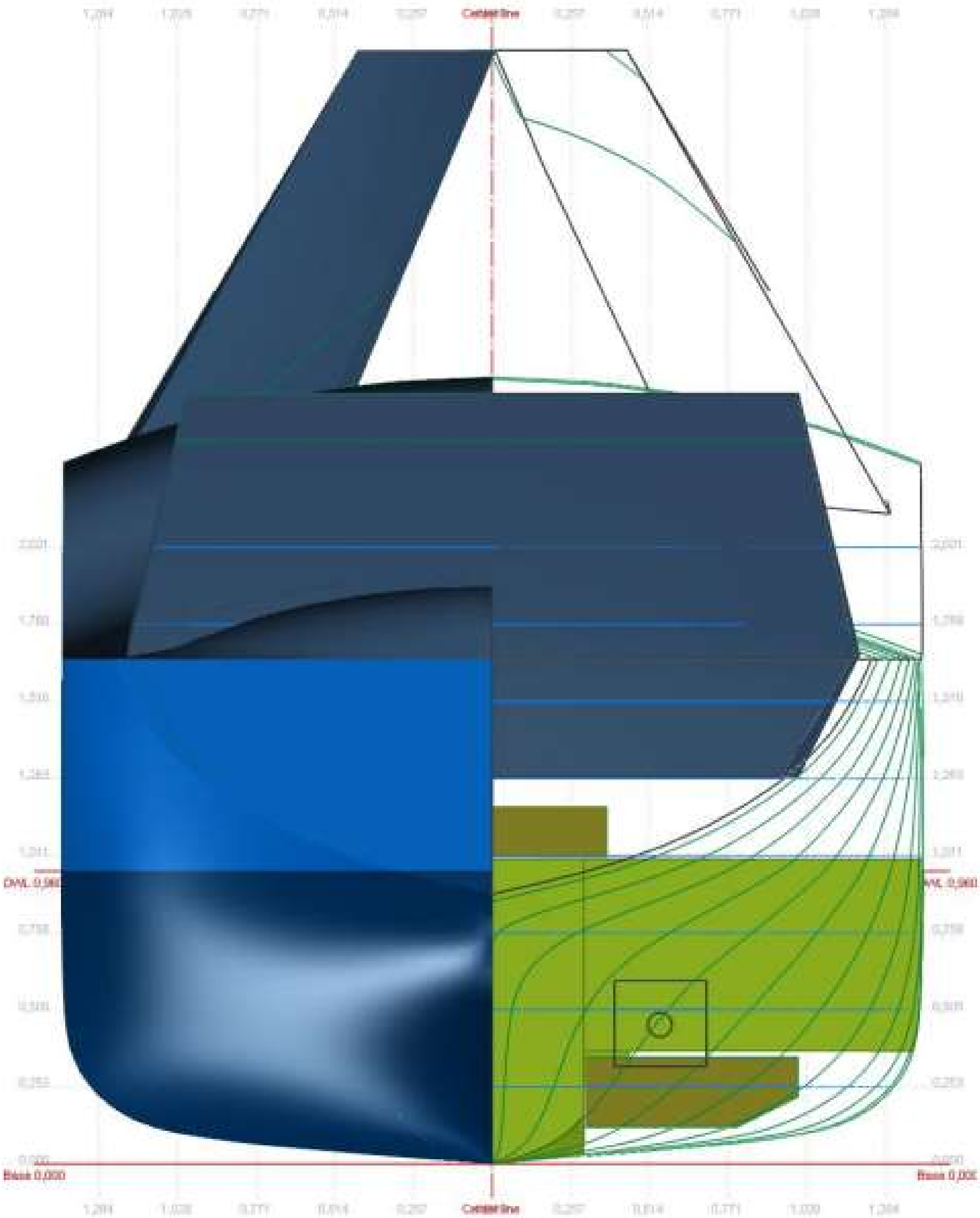


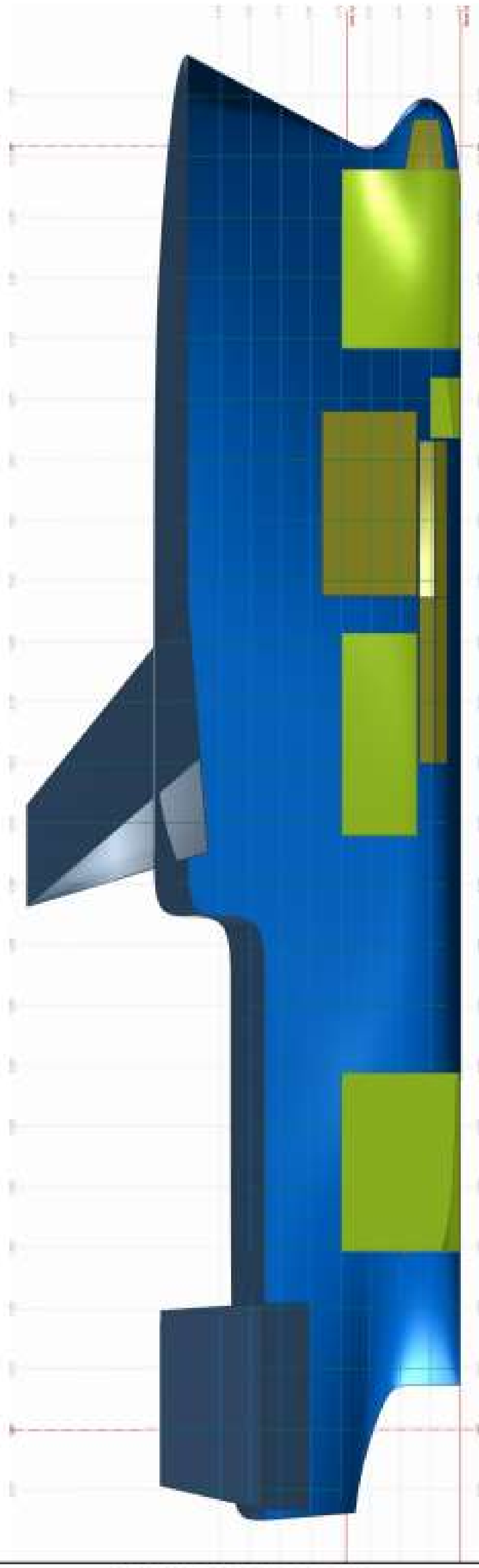
Cross curves

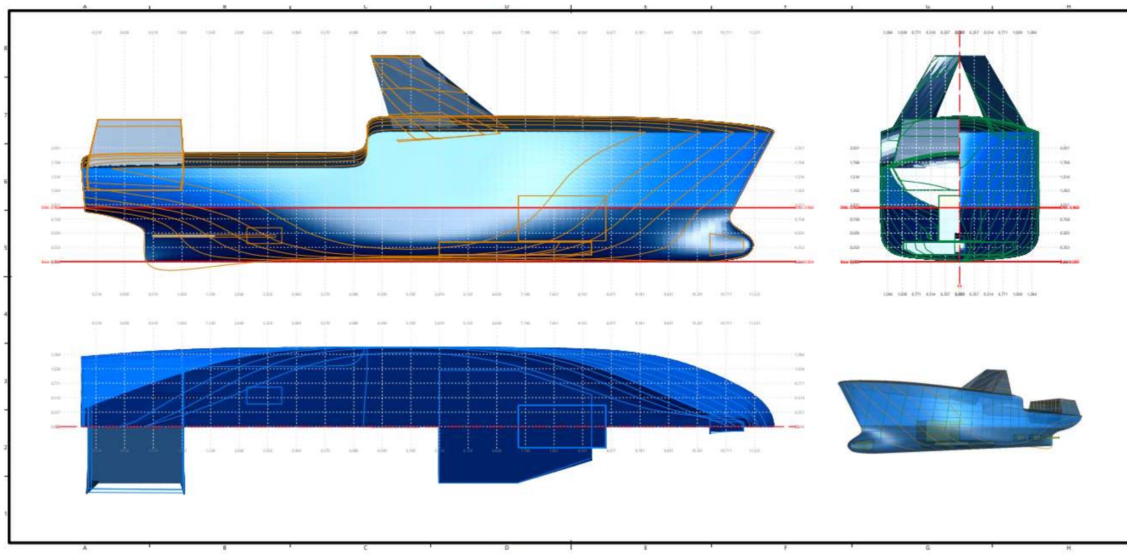
Trim= 0,000

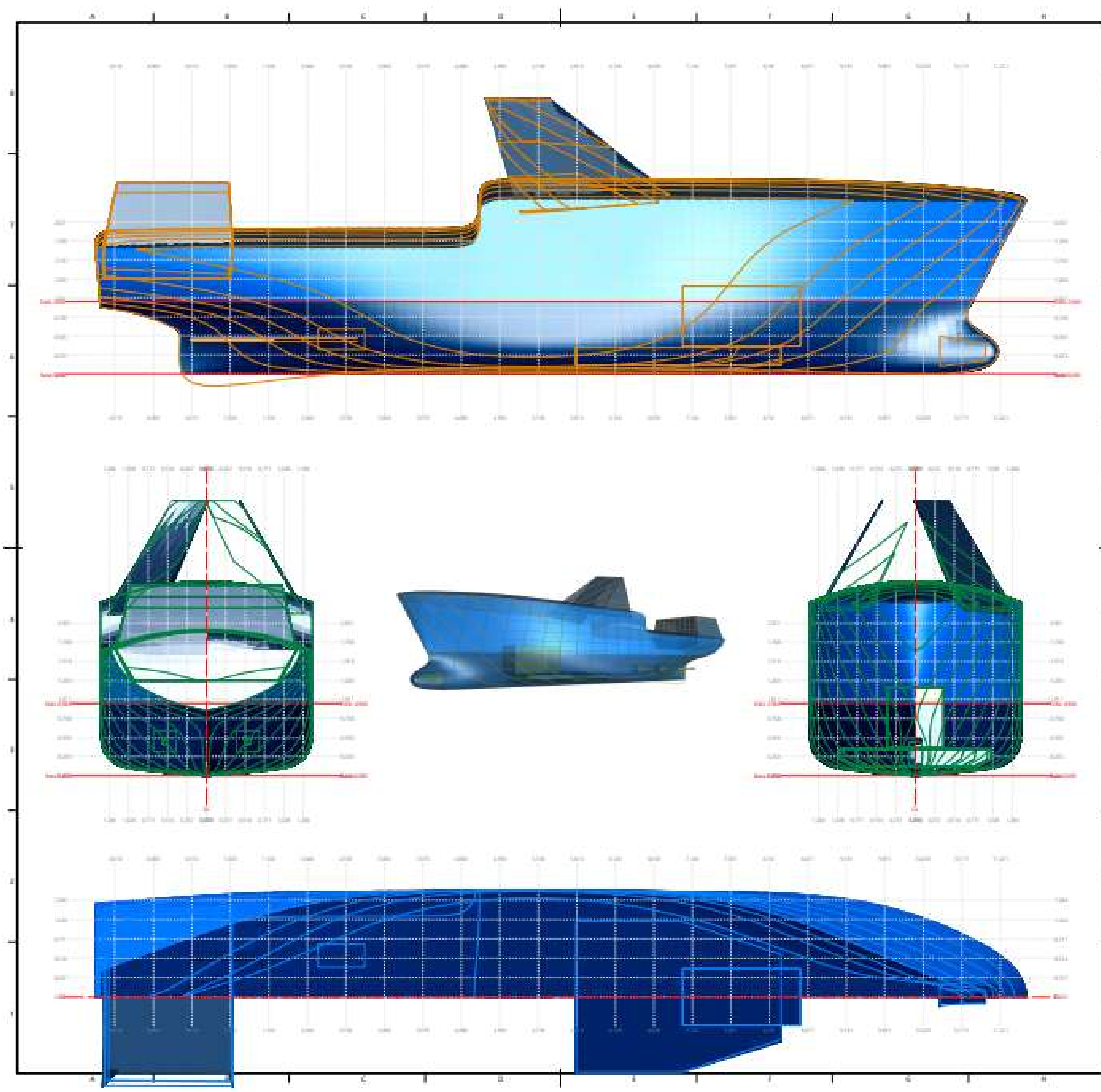
Displ.	Draft	0,0	20,0	40,0	60,0	80,0	100,0	120,0	140,0	160,0	180,0
t	m	degr	degr	degr	degr	degr	degr	degr	degr	degr	degr
7,000	0,473	0,000	0,508	0,869	1,168	1,365	1,395	1,247	0,820	0,365	0,000
8,000	0,524	0,000	0,492	0,863	1,180	1,374	1,390	1,227	0,814	0,370	0,000
9,000	0,574	0,000	0,479	0,861	1,190	1,381	1,387	1,212	0,811	0,372	0,000
10,000	0,623	0,000	0,468	0,860	1,199	1,387	1,384	1,198	0,809	0,376	0,000
11,000	0,671	0,000	0,460	0,862	1,205	1,391	1,382	1,187	0,809	0,380	0,000
12,000	0,718	0,000	0,453	0,864	1,210	1,395	1,379	1,178	0,810	0,385	0,000
13,000	0,765	0,000	0,448	0,867	1,214	1,398	1,377	1,170	0,811	0,391	0,000
14,000	0,810	0,000	0,445	0,870	1,216	1,400	1,374	1,163	0,813	0,397	0,000
15,000	0,854	0,000	0,443	0,873	1,219	1,401	1,371	1,157	0,814	0,403	0,000
16,000	0,897	0,000	0,442	0,877	1,221	1,401	1,368	1,153	0,816	0,408	0,000
17,000	0,938	0,000	0,441	0,881	1,222	1,400	1,365	1,149	0,818	0,414	0,000




Center line
DWL 0,960
Base 0,000







Optimised design

Design hydrostatics report

Parent 22 - Sterntrawler

Designer	Unknown
Created by	M. van Engeland
Comment	
Filename	Parent 22 fourth.fbm

Design length	12,000 m	Midship location	6,000 m
Length over all	13,700 m	Water density	1,0250
Design beam	2,650 m	Mean shell thickness	0,0000 m
Maximum beam	2,668 m	Appendage coefficient	1,0000
Design draft	1,077 m		

Volume properties		Waterplane properties	
Moulded volume	20,095 m³	Length on waterline	12,837 m
Total displaced volume	20,095 m³	Beam on waterline	2,667 m
Displacement	20,597 t	Entrance angle	63,6 degr
Block coefficient	0,5288	Waterplane area	25,32 m²
Prismatic coefficient	0,5852	Waterplane coefficient	0,7177
Vert. prismatic coefficient	0,7368	Waterplane center of floatation	5,381 m
Wetted surface area	42,29 m²	Transverse moment of inertia	11,347 m⁴
Longitudinal center of buoyancy	5,837 m	Longitudinal moment of inertia	231,163 m⁴
Longitudinal center of buoyancy	-1,268 %		
Vertical center of buoyancy	0,613 m		
Total length of submerged body	13,228 m		
Total beam of submerged body	2,667 m		

Midship properties		Initial stability	
Midship section area	2,60 m²	Transverse metacentric height	1,178 m
Midship coefficient	0,9036	Longitudinal metacentric height	12,117 m

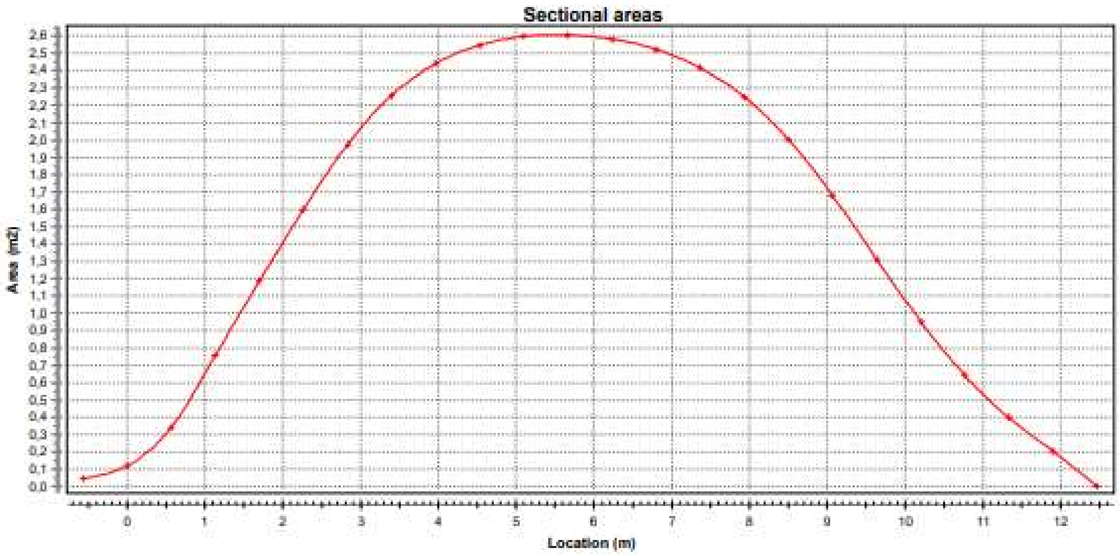
Lateral plane	
Lateral area	13,08 m²
Longitudinal center of lateral resistance	6,179 m
Vertical center of lateral resistance	0,539 m

The following layer properties are calculated for both sides of the ship

Location	Area	Thickness	Weight	LCG	TCG	VCG
	m²	m	t	m	m	m
Hull	73,01	0,035	5,111	6,123	0,000 (CL)	0,928
Hull superstructure	40,35	0,000	0,000	5,055	0,000 (CL)	2,385
Superstructure tower	5,55	0,000	0,000	8,485	0,000 (CL)	3,295
El. Engine	1,84	0,000	0,000	3,646	0,000 (CL)	0,339
Generator	6,04	0,000	0,000	8,778	0,000 (CL)	0,803
Shafts	1,45	0,000	0,000	1,651	0,000 (CL)	0,333
Propeller Nozzles	0,39	0,000	0,000	-0,055	0,000 (CL)	0,324
Counterweight	0,94	0,000	0,000	11,881	0,000 (CL)	0,342
TRAPS Sonar	15,66	0,000	0,000	0,051	0,001 (PS)	2,000
Total	145,24		5,111	6,123	0,000 (CL)	0,928

Sectional areas

Location	Area	Location	Area	Location	Area	Location	Area	Location	Area
m	m²	m	m²	m	m²	m	m²	m	m²
-0,567	0,04	2,267	1,60	5,100	2,60	7,934	2,25	10,767	0,64
0,000	0,12	2,834	1,97	5,667	2,61	8,501	2,00	11,334	0,40
0,567	0,34	3,400	2,26	6,234	2,58	9,067	1,68	11,901	0,20
1,133	0,76	3,967	2,44	6,800	2,52	9,634	1,31	12,468	0,00
1,700	1,18	4,534	2,55	7,367	2,41	10,201	0,95		



NOTE 1: Draft (and all other vertical heights) is measured from base Z=0,000
NOTE 2: All calculated coefficients based on actual dimensions of submerged body.

Hydrostatics

Water density : 1,0250

Trim: 0,000 m

Draft	Volume	Displ FW	Displ.	LCB	VCB	TCB	Aw	LCF	KMt	KMl	MCT	TpCm
m	m^3	t	t	m	m	m	m^2	m	m	m	t*m	tonne/cm
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,00	0,000	0,000	0,000	0,000	0,000
0,100	0,657	0,657	0,673	5,986	0,065	0,000	11,60	5,981	3,097	98,977	0,056	0,119
0,200	2,035	2,035	2,085	5,989	0,124	0,000	15,33	6,000	2,260	44,454	0,077	0,157
0,300	3,676	3,676	3,768	5,995	0,181	0,000	17,36	6,001	1,795	28,993	0,090	0,178
0,400	5,482	5,482	5,619	5,995	0,237	0,000	18,69	5,986	1,533	21,476	0,099	0,192
0,500	7,399	7,399	7,584	5,989	0,292	0,000	19,61	5,956	1,366	17,023	0,106	0,201
0,600	9,397	9,397	9,632	5,977	0,347	0,000	20,35	5,918	1,262	14,240	0,112	0,209
0,700	11,466	11,466	11,752	5,962	0,402	0,000	21,04	5,868	1,200	12,486	0,118	0,216
0,800	13,609	13,609	13,949	5,942	0,457	0,000	21,84	5,806	1,168	11,541	0,129	0,224
0,900	15,840	15,840	16,236	5,917	0,512	0,000	22,82	5,704	1,158	11,243	0,145	0,234
1,000	18,187	18,187	18,642	5,878	0,569	0,000	24,21	5,526	1,164	11,723	0,173	0,248

NOTE 1: Draft (and all other vertical heights) is measured from base Z=0,000

NOTE 2: All calculated coefficients based on actual dimensions of submerged body.

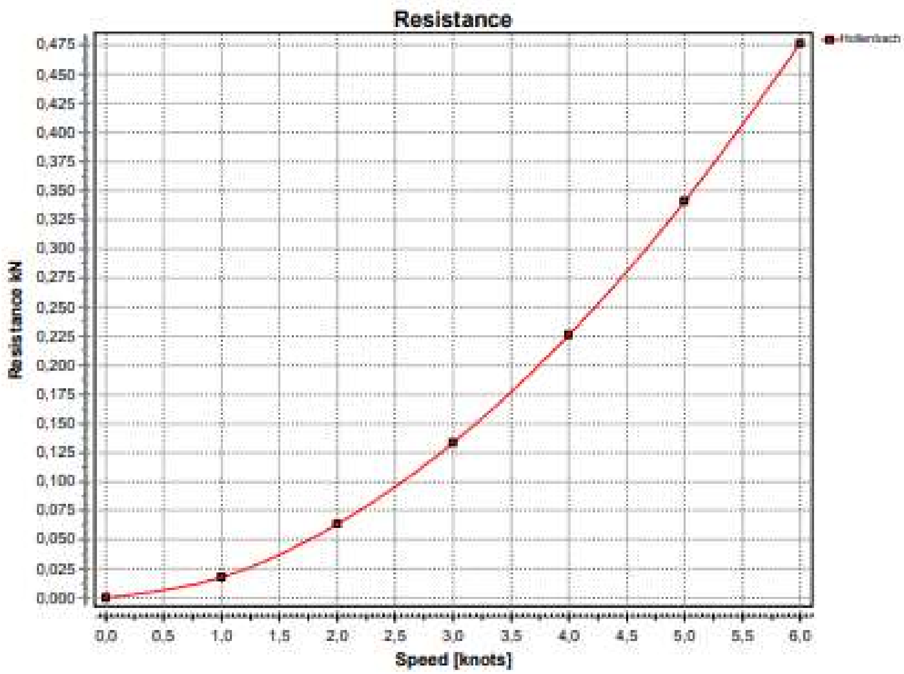
Nomenclature

Draft	*Moulded draft, measured from baseline*
Volume	*Total displaced volume*
Displ FW	*Displacement fresh water*
Displ.	*Displacement*
LCB	*Longitudinal center of buoyancy, measured from the aft perpendicular at X=0.0*
VCB	*Vertical center of buoyancy*
TCB	*Transverse center of buoyancy*
Aw	*Waterplane area*
LCF	*Waterplane center of floatation, measured from the aft perpendicular at X=0.0*
KMt	*Transverse metacentric height*
KMl	*Longitudinal metacentric height*
MCT	*Moment to change trim one unit*
TpCm	*Weight to change the immersion with one unit*

Resistance calculations.

Hollenbach.

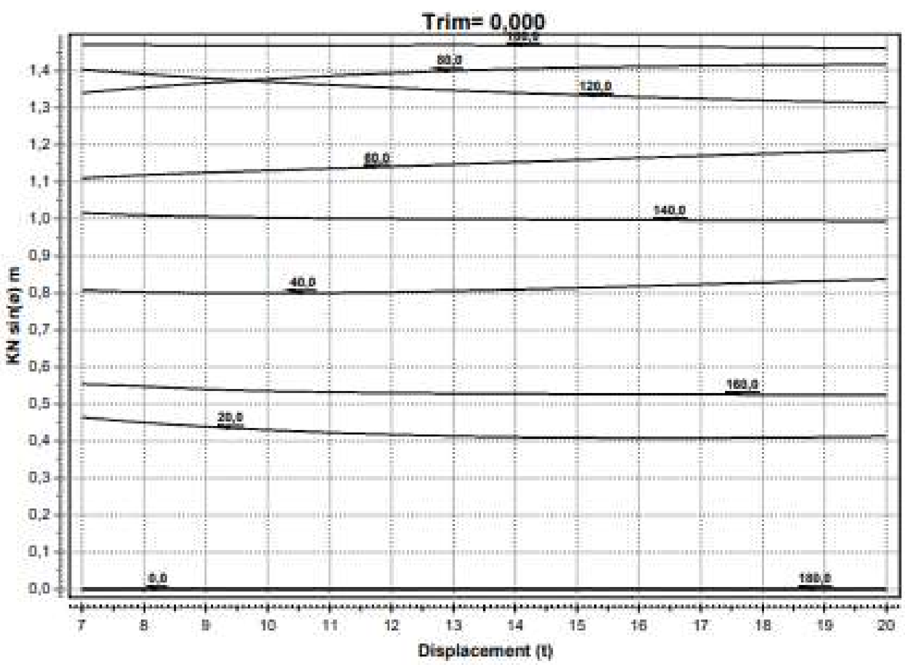
Resistance according to Hollenbach						
Speed kn	Speed m/sec	Froude number	Frictional resistance kN	Residual resistance kN	Total resistance kN	Effective power kW
0,00	0,00	0,000	0,0000	0,0000	0,0000	0,00
1,00	0,51	0,046	0,0179	0,0000	0,0179	0,01
2,00	1,03	0,092	0,0634	0,0000	0,0634	0,07
3,00	1,54	0,138	0,1333	0,0000	0,1333	0,21
4,00	2,06	0,184	0,2260	0,0000	0,2260	0,47
5,00	2,57	0,230	0,3407	0,0000	0,3407	0,88
6,00	3,09	0,275	0,4766	0,0000	0,4766	1,47

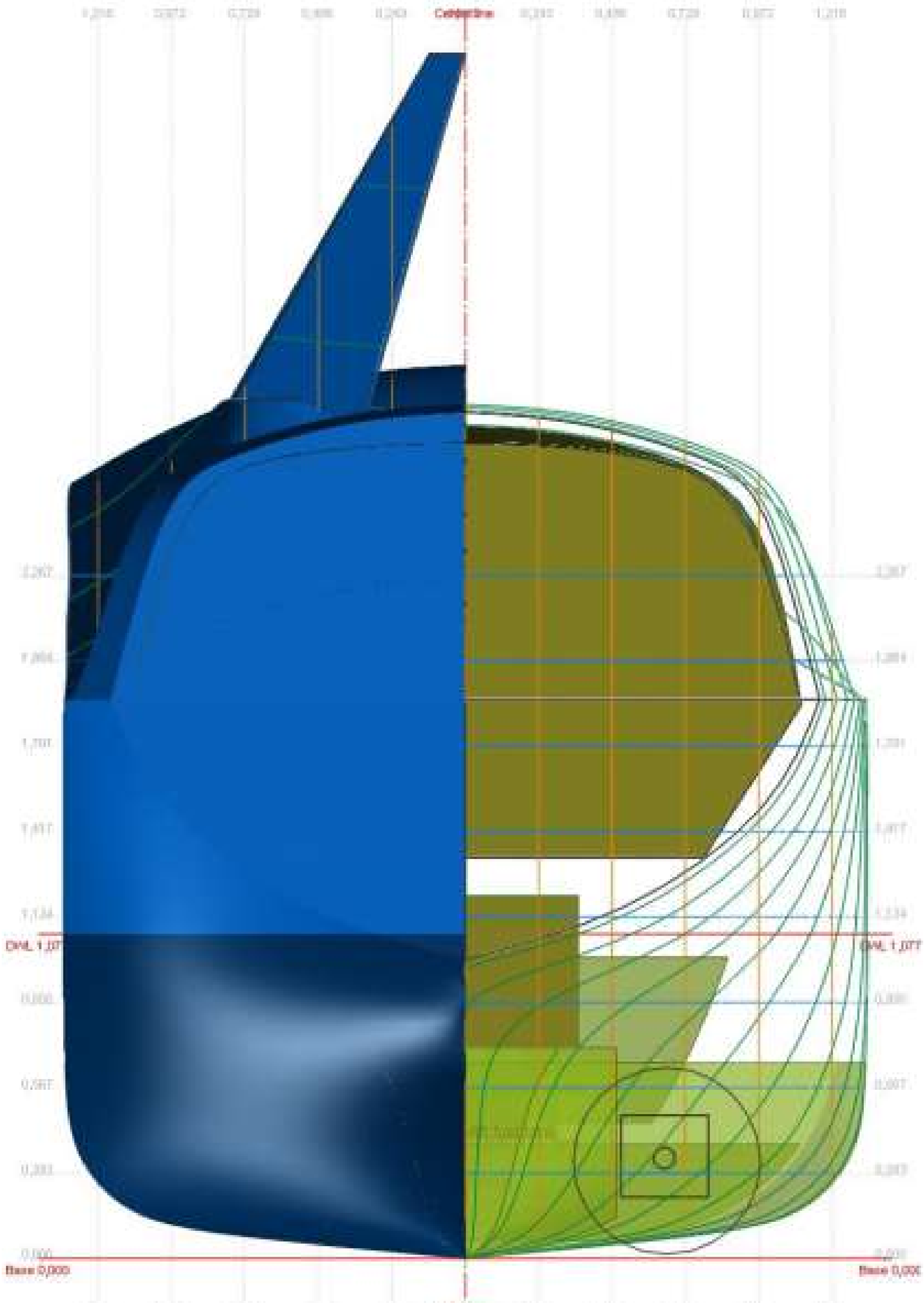


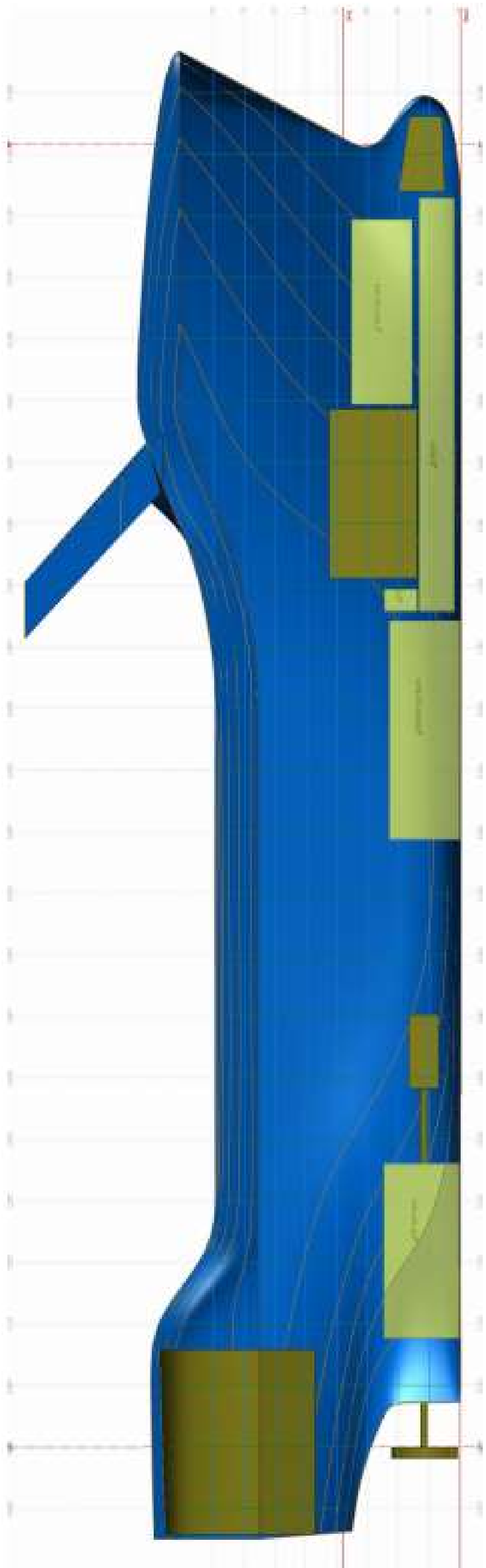
Cross curves

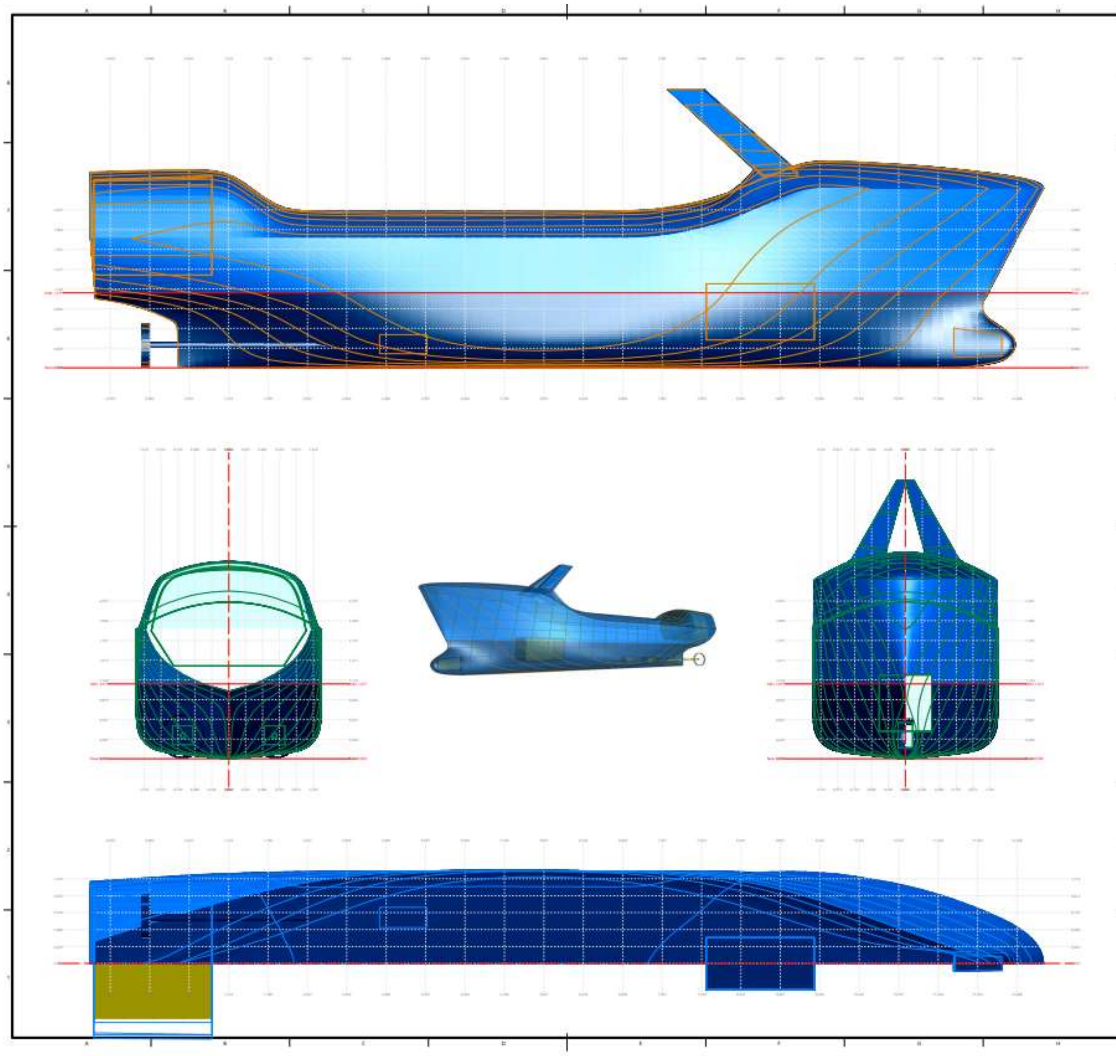
Trim= 0,000

Displ.	Draft	0,0	20,0	40,0	60,0	80,0	100,0	120,0	140,0	160,0	180,0
t	m	degr	degr	degr	degr	degr	degr	degr	degr	degr	degr
7,000	0,471	0,000	0,464	0,807	1,110	1,340	1,471	1,403	1,016	0,554	0,000
8,000	0,521	0,000	0,450	0,802	1,118	1,354	1,469	1,391	1,010	0,547	0,000
9,000	0,570	0,000	0,439	0,800	1,125	1,367	1,469	1,380	1,006	0,540	0,000
10,000	0,618	0,000	0,430	0,799	1,130	1,377	1,469	1,370	1,003	0,535	0,000
11,000	0,665	0,000	0,423	0,800	1,136	1,386	1,469	1,362	1,001	0,532	0,000
12,000	0,711	0,000	0,417	0,802	1,141	1,393	1,469	1,354	1,000	0,530	0,000
13,000	0,757	0,000	0,413	0,805	1,147	1,400	1,469	1,347	0,999	0,528	0,000
14,000	0,802	0,000	0,410	0,809	1,153	1,405	1,469	1,340	0,998	0,527	0,000
15,000	0,847	0,000	0,408	0,813	1,159	1,409	1,468	1,335	0,997	0,527	0,000
16,000	0,890	0,000	0,408	0,818	1,164	1,411	1,466	1,329	0,997	0,526	0,000
17,000	0,932	0,000	0,408	0,823	1,170	1,413	1,464	1,325	0,996	0,525	0,000
18,000	0,974	0,000	0,409	0,828	1,175	1,415	1,463	1,320	0,995	0,525	0,000
19,000	1,014	0,000	0,410	0,832	1,181	1,416	1,462	1,316	0,994	0,524	0,000
20,000	1,054	0,000	0,412	0,837	1,186	1,418	1,461	1,313	0,993	0,524	0,000




Centerline
DWL 1,077
Base 0,000
Centerline





Appendix D - Drive train, energy production and energy storage

This appendix will cover general specifications of engine, generator, fuel, lubrication oil and battery.

Engine

This section contains technical data regarding DriveMaster 15W.

Bellmarine powered by Transfluid

DriveMaster

Liquid Cooled

Including:

- Motor with mounting brackets and silent blocks
- Motor with integrated thrust bearing
- Vector control inverter IP65
- Main switch and main fuse
- DC-DC converter 12 Vdc
- 1,5m cable for display, lever, key
- Quick install / easy connect / plug and play
- Inlet and outlet liquid connections

Optional:

- NMEA2000 compatible (upon request)
- DP280 ratio i= 1.59 - 2.01 - 2.41 - 2.87 - 3.36 - 3.97 - 5.01
- Regeneration kit

			Medium & Heavy Duty			
PRODUCT CODE	DESCRIPTION	MOTOR SIZE	NOMINAL kW	INTERMITTENT kW	BATTERY Vdc	MOTOR rpm
BV101608W	DriveMaster 3W	180-4	2.5	3	48	1500
BV100854W	DriveMaster 7W	180-8	5	7	48	1500
BV100808W	DriveMaster 10W	180-12	8	10	48	1500
BV100810W	DriveMaster 15W	220-20	10	15	48	1500
BV101610W	DriveMaster 20W EVO	220-20 (*)	15	20	48	1500
BV100812W	DriveMaster 20W	220-20	15	20	96	1500
BV101288W	DriveMaster 30W	220-35	25	30	144	1500
BV101642W	DriveMaster 45W	300-50	35	45	144	1500
BV101580W	DriveMaster 55W	300-75	45	55	144	1500

(*) Special

• Complete the scope of supply by adding control throttle, display, cooling kit, coupling, shaft with propeller

Bellmarine - 2201

7

Figure 2: Drivemaster data (Bellmarine)

Master Info

1 - All motors are Permanent Magnets AC, high efficiency, IP65
2 - Intermittent kW: S3 10% - 10' (1 minute at intermittent power then reduced for 9 minutes power to return to stable temperature)
3 - Battery: 48V, 96V and 144V can be of any chemistry and brand; 288V and 384V need to be Transfluid's battery.

BATTERY	max [Vdc]	min [Vdc]
48	61	44
96	115	82
144	169	121
288	346	247
384	462	330

To evaluate the battery characteristics in case of customer's supply please use the following formula giving the max (A) current required by Transfluid's motors:

$$I\,(A) = \frac{kW \times 1000}{V} \times 2$$

4 - **RATINGS:**

- Cruising speed: 70% of rated motor rpm
- Light Duty: air cooled motor, up to 200 hours/year, intermittent kW allowed
- Medium Duty: air cooled motor, up to 500 hours/year, only nominal kW allowed
- Medium Duty: liquid cooled motor, up to 1000 hours/year, intermittent kW allowed
- Heavy Duty: liquid cooled motor, up to 3000 hours per year, intermittent kW allowed, max 80% of time at rated rpm and load

5 - Separate thrust bearing is recommended above 20 kW

6 - For Torque calculation use the formula: $T\,(Nm) = \frac{kW}{rpm} \times 9550$

Figure 3: Drivemaster data (Bellmarine)

Generator

Whisper power: M-SQ Pro 25 Maritime Generator (WhisperPower)

Estimated price from commercial dealers is 40,000 Eur.

Figure 4: Whisper Power – M-SQ Pro 25

Specifications
M-SQ Pro 25

25-11-2022

ARTICLE NUMBER

41202005	M-SQ Pro 25, 230 VAC, 1 ph, 50 Hz (60 Hz)

MAIN SPECIFICATIONS

Intermittent Power kW at 25°C (77°F)	25 kW
Continuous Power kVA at 25°C (77°F)	27 kVA
Continuous Power kW at 25°C (77°F)	22.5 kW
Noise level	58 dB
Rpm range	1500/1800 rpm
Cooling	Indirect water cooled
Alternator voltage regulation	AVR + EBS, forced ventilation
Nominal voltage / frequency	230 VAC, 1 ph, 50 Hz (60 Hz)
Peak power 2 s	300%
Harmonic distortion	
Frequency tolerance	+/- 5 %

DIESEL ENGINE SPECIFICATIONS

Engine	WhisperPower Mitsubishi S4S - 4 cylinder
Cylinder volume	3331 cc
Bore & stroke, mm (in.)	94 x 120 (3.7 x 4.7)
Air consumption	2.8m3/min
Cooling system	indirect
Fuel consumption (no load - full load)	1-6 l/hr
starter battery charge current	12 V / 40 A

DIMENSIONS & WEIGHT

Length x width x height (cabinet), mm (in.)	1555 x 749 x 805 (61.2 x 29.5 x 31.7)
Dry weight, kg (lb.)	640 (1411)
Dry exhaust / wet exhaust	Ø 2 inch BSP / Ø 63 mm
Oil dipstick	Top & side
Max. operating angle	25º in all directions

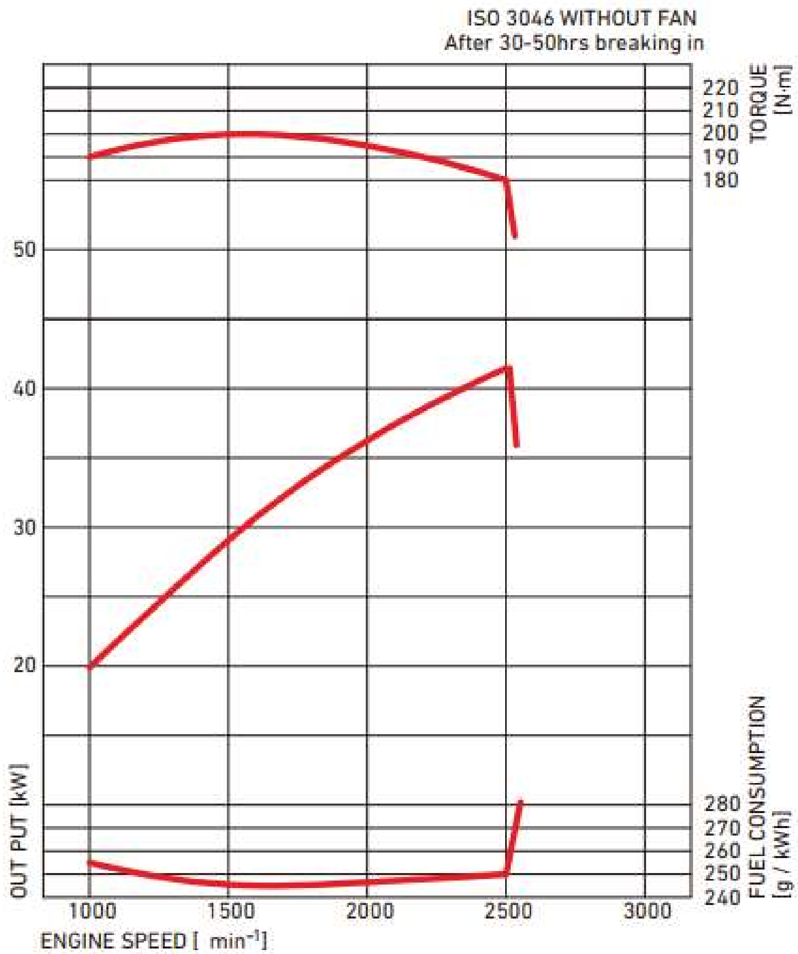


Figure 5: Performance Curve of the Mitsubishi S4S-Z365SP in Gen set

The total efficiency of the generator and combustion engine in a towing condition, 5 knots, based on the data provided by manufacturer:

$$\eta_{Gen} = \frac{P_e}{m_b * h_n} = \frac{22{,}5 * 3600}{4{,}4 * 42{,}76 * 10^{\wedge}3} = 0{,}43$$

$$\eta_{C.Eng} = \frac{P_e}{m_b * h_n} = \frac{35 * 3600}{4{,}4 * 42{,}76 * 10^{\wedge}3} = 0{,}67$$

The above values are estimated based on values of fuel consumption from the manufacturer. However, the values used in the estimation will be 0,4 for the generator and 0,55 for the combustion engine.

Fuel

The choice of fuel will be standard diesel fuel based on the below average values and standard values of Bunker Oil, the main distributer of fuel for the Royal Norwegian Navy.

Tabell 4.4 *Kjemisk sammensetning (elementæranalyse), teoretisk luftbehov, kalorimetrisk (øvre) og effektiv (nedre) brennverdi, tetthet, oktantall og cetantall for brensler raffinert av jordolje.*
Tabellen gir gjennomsnittsverdier. Avvik fra disse kan opptre, f.eks. på grunn av forskjeller i jordoljekildene

		Bensiner	Petroleum	Dieseloljer: Gassolje	Dieseloljer: Diesel oil	Tungoljer. Fyringsolje nr. 3	4	5	6
Kjemisk sammen-setning, masse-prosent	Karbon (c)	84,6	86,4	86,5	86,3	86,0	85,8	85,8	85,7
	Hydrogen (h)	14,9	13,4	12,9	12,7	11,8	11,6	11,5	11,4
	Svovel (s)	–	0,05	0,45	0,8	1,9	2,1	2,2	2,2
	Nitrogen (n) + oksygen (o)	0,5	0,15	0,15	0,15	0,1	0,1	0,1	0,1
	Vann	–	–	–	0,04	0,1	0,2	0,2	0,3
	Metalloksyder (aske)	–	–	–	0,01	0,1	0,2	0,2	0,3
Teoretisk luftbehov	Nm^3/kg	11,5	11,25	11,15	11,05	10,85	10,80	10,75	10,7
	kg/kg	14,85	14,6	14,4	14,3	14,05	14,0	13,9	13,85
Kal. brennverdi,	MJ/kg	46,9	46,5	45,6	45,2	43,5	43.1	42,7	42,3
	kcal/kg	11 200	11 100	10900	10800	10400	10300	10200	10100
Eff. brennverdi,	MJ/kg	43,5	43,3	42,7	42,3	41,0	40,6	40,2	39,8
	kcal/kg	10400	10350	10200	10100	9800	9700	9600	9500
Tetthet, kg/dm^3		0,73	0,78	0,83	0,85	0,93	0,95	0,96	0,97
Oktantall (research)		90, 100	50						
Cetantall			40	53	45	35	30	30	25

Table 3: Average value of chemical composition and properties of relevant fuel types. (Lundby, 1979)

Parameter	Data
Type	Marine Gas Oil
Dencity [ρ]	855 kg/m^3
Lower heating value [h_n]	42,7 MJ/kg

Figure 6 : Estimation of average Marine Gas oil values (BunkerOil, 2021).

Lubrication Oil

Description:

"49 NORTH ARCTIC SYNTHETIC HEAVY DUTY ENGINE OIL Is specially formulated from low volatility synthetic fluids and a specialized additive system to provide excellent fluidity for extreme cold weather (-40°C) start up, while maintaining the vicosity required to provide the necessary protection of critical parts during high temperature operations." (Lubricants).

TYPICAL PROPERTIES

SAE Viscosity Grade	0W-30
Product Code	1403
API Service	CJ-4 / SN
API Gravity	35.8
Density, lbs / gallon	7.042
Viscosity, Kinematic	
cSt @ 40°C	59.34
cSt @ 100°C	10.92
Viscosity Index	178
Cold Crank Simulator	
P @ -35°C	4475
Pour Point, °C	-51
Flash Point, °C	226
Colour,	3.0
TBN, ASTM D2896	10.0

Figure 7: 49 North Arctic Synthetic heavy duty engine oil, 0W-30.

Battery

Tesla 4680 Battery-Cell, Model-Y

Energy density estimation

Item	Data	Remark
Cathode areal capacity	To be determined	
Anode areal capacity	5.5 mAh/cm² (half cell second cycle)	11 mAh/cm² for double side
Total electrode area	~330cm * 7.2 cm = 2376 cm²	Roughly measured inside the glovebox
Total capacity	11 mAh/cm² *2376 cm² = 26.136 Ah	
Total energy	26.136 Ah * (3.7 ~3.8 V) ≈ 96~99 Wh	Estimated average voltage
Cell weight	355 g	From lab balance
Energy density	272 Wh/kg ~ 296 Wh/kg	

Table 4: Energy Density of Tesla 4680-Type Cylindrical Lithium-Ion Battery Cell (Kane, 2022).

Model Y Battery Packs with 4680 cells		
	Long Range	Standard Range
Columns	69	69
Rows	12	10
Cells	828	690
Wh per cell	98	98
Wh per pack	81,144	67,620
kWh per pack	81.1	67.6

@TroyTeslike, 9 Apr 2022

69*12=828 cells
828*98Wh= 81,144 Wh = 81,1 kWh

Table 5: Estimated values of Model-Y 2022 battery pack from twitter post by Troy Teslike, published on Insideevs (Kane, 2022).

Appendix E – Weight breakdown and cross curves

Preliminary design

Weight breakdown

The preliminary design provides an initial approximation to distribution of weight on the vessel. The weight breakdown is a rough estimation and will have to be confirmed by more detailed calculations on a different stage. Knowledge of simple stability calculations and its abbreviation is expected from readers.

The hulls initial data from Delftship Pro is plotted in the table below.

Vessel statistics			Abbreviation
Loa	12,33	m	Length over all
Lpp	10,8	m	Length between perpendiculars
B	2,8	m	Beam
T	0,96	m	Draught
LCG	5,621	m	Longitudinal centre of gravity
TCG	0	m	Transverse centre of gravity
VCG	0,949	m	Vertical centre of gravity
Total displaced volume	17,033	m^3	

All components in the vessel is plotted with their placement in the hull. Origo is in the aft perpendicular where the keel starts. The x-axis is parallel to the keel, y-axis is to the side and z-axis is height. Negative y-axis is representing the starboard side. Summing up all the components and their weights produces the vessels total weight and its new centre of gravity in three directions.

In order to secure positive stability in the vertical axis the new VCG is checked against the hulls KMt from hydrostatics. KMt is obtained from Delftship hydrostatics for that hull by means of interpolation of values. When KMt minus VCG is a positive value, it ensures the vessel will stay upright for that specific loading condition.

Trim in the longitudinal and transverse axis is also checked to make sure the vessel doesn’t have unwanted trim. Some positive forward trim is desirable to ensure better waterflow around the propeller.

The transverse centre of gravity will stay 0 because of components cancelling each other out.

Lightweight

Weight breakdown all components with internal fluids, additional fuel is excluded. Added 10 % design margin and 5 % building margin.

						Placement			Trimming moment		
Components	Quantity	Density [tonn/m^3]	Degree of filling [%]	Volume [m^3]	Weight [tonn]	LCG [m]	TCG [m]	VCG [m]	LCG * W [tonnm]	TCG * W [tonnm]	VCG * W [tonnm]
Main Hull	1				4,565	5,5	0	0,882	25,108	0,000	4,026
Hull Superstructure	1				0,7	5	0	2,188	3,500	0,000	1,532
Superstructure tower	1				0,2	5,448	0	2,798	1,090	0,000	0,560
Electrical engines	2				0,15	2,49	0	0,46	0,374	0,000	0,069
Generator	1				0,65	7,792	0	0,77	5,065	0,000	0,501
Battery	1				1,5	6,848	0	0,243	10,272	0,000	0,365
Shaft	1				0,2	1,6	0	0,456	0,320	0,000	0,091
Counter weight	1				0,5	10,685	0	0,296	5,343	0,000	0,148
TRAPS Slepesonar	1				1,50	0,22	0	1,877	0,330	0,000	2,816
Sonar Buoys	10				0,17	5	0	1,6	0,850	0,000	0,272
Lightweight					10,135						
Design margin		10 % addition design margin			11,15						
Building margin		5 % additon building margin			11,71						
Corrected Lightweight					11,71						
Sum					11,71				52,25	0,00	10,38

Centre of gravity	LCG	TCG	VCG
	5,16	0,00	1,02

Stability requirements		GM > 0	
KMt from Hydrostatics		1,287	m
GM loaded		0,26	m

Demand for 0-trim		LCG = LCB	
LCB from hydrostatics		5,34	m
Difference LCG-LCB		0,18	POS = forward trim

0-Yaw requirement		TCG = 0	
TCG =	0,00	m	POS = babord

Standard weight

Weight breakdown for vessel with 50 % fuel.

						Placement			Trimming moment		
Components	Quantity	Density [tonn/m^3]	Degree of filling [%]	Volume [m^3]	Weight [tonn]	LCG [m]	TCG [m]	VCG [m]	LCG * W [tonnm]	TCG * W [tonnm]	VCG * W [tonnm]
Main Hull	1				4,565	5,5	0	0,882	25,108	0,000	4,026
Hull Superstructure	1				0,7	5	0	2,188	3,500	0,000	1,532
Superstructure tower	1				0,2	5,448	0	2,798	1,090	0,000	0,560
Electrical engines	2				0,15	2,49	0	0,46	0,374	0,000	0,069
Generator	1				0,65	7,792	0	0,77	5,065	0,000	0,501
Battery	1				1,5	6,848	0	0,243	10,272	0,000	0,365
Shaft	1				0,2	1,6	0	0,456	0,320	0,000	0,091
Counter weight	1				0,5	10,685	0	0,296	5,343	0,000	0,148
TRAPS Slepesonar	1				1,50	0,22	0	1,877	0,330	0,000	2,816
Sonar Buoys	10				0,17	5	0	1,6	0,850	0,000	0,272
Lightweight					10,135						
Design margin		10 % addition design margin			11,15						
Building margin		5 % additon building margin			11,71						
Corrected Lightweight					11,71						
Aft Fueltank	0,5	0,855	0,95	0,858	0,35	2,255	0	0,513	0,786	0,000	0,179
Fore Fueltank	0,5	0,855	0,95	0,86	0,35	9,686	0	0,59	3,383	0,000	0,206
Middel Fueltank	0,5	0,855	0,95	2,897	1,18	5,843	0	0,687	6,875	0,000	0,808
Service Oil	0,5	0,843	0,95	0,063	0,03	7,749	0	0,133	0,195	0,000	0,003
Sum					13,61				63,49	0,00	11,57

Centre of gravity	LCG	TCG	VCG
	5,28	0,00	0,96

Stability requirements		GM > 0	
KMt from Hydrostatics		1,264	m
GM loaded		0,30	m

Demand for 0-trim		LCG = LCB	
LCB from hydrostatics		5,323	m
Difference LCG-LCB		0,05	POS = forward trim

0-Yaw requirement		TCG = 0	
TCG =	0,00	m	POS = babord

Fully loaded

Weight breakdown for a fully loaded vessel

						Placement			Trimming moment		
Components	Quantity	Density [tonn/m^3]	Degree of filling [%]	Volume [m^3]	Weight [tonn]	LCG [m]	TCG [m]	VCG [m]	LCG * W [tonnm]	TCG * W [tonnm]	VCG * W [tonnm]
Main Hull	1				4,565	5,5	0	0,882	25,108	0,000	4,026
Hull Superstructure	1				0,7	5	0	2,188	3,500	0,000	1,532
Superstructure tower	1				0,2	5,448	0	2,798	1,090	0,000	0,560
Electrical engines	2				0,15	2,49	0	0,46	0,374	0,000	0,069
Generator	1				0,65	7,792	0	0,77	5,065	0,000	0,501
Battery	1				1,5	6,848	0	0,243	10,272	0,000	0,365
Shaft	1				0,2	1,6	0	0,456	0,320	0,000	0,091
Counter weight	1				0,5	10,685	0	0,296	5,343	0,000	0,148
TRAPS Slepesonar	1				1,50	0,22	0	1,877	0,330	0,000	2,816
Sonar Buoys	10				0,17	5	0	1,6	0,850	0,000	0,272
Lightweight					10,135						
Design margin		10 % addition design margin			11,15						
Building margin		5 % additon building margin			11,71						
Corrected Lightweight					11,71						
Aft Fueltank	1	0,855	0,95	0,858	0,70	2,255	0	0,513	1,572	0,000	0,358
Fore Fueltank	1	0,855	0,95	0,86	0,70	9,686	0	0,59	6,766	0,000	0,412
Middel Fueltank	1	0,855	0,95	2,897	2,35	5,843	0	0,687	13,749	0,000	1,617
Service Oil	1	0,843	0,95	0,063	0,05	7,749	0	0,133	0,391	0,000	0,007
Full weight					15,50						
Future growth margin		5 % future growth margin			16,28						
Corrected Full Weight					16,28						
Sum					16,28				74,73	0,00	12,77

Centre of gravity	LCG	TCG	VCG
	5,36	0,00	0,92

Stability requirements	GM > 0	
KMt from Hydrostatics	1,253	m
GM loaded	0,34	m

Demand for 0-trim	LCG = LCB	
LCB from hydrostatics	5,273	m
Difference LCG-LCB	-0,09	POS = forward trim

0-Yaw requirement		TCG = 0	
TCG =	0,00	m	POS = babord

Cross curves and stability

In order to calculate stability and the vessels righting arm crosscurved are used to get information of KN SIN(Ø) in regard to vessel displacment and healingangle. These values are then used to calculate GZ-arm for each case and plotted in a graph.

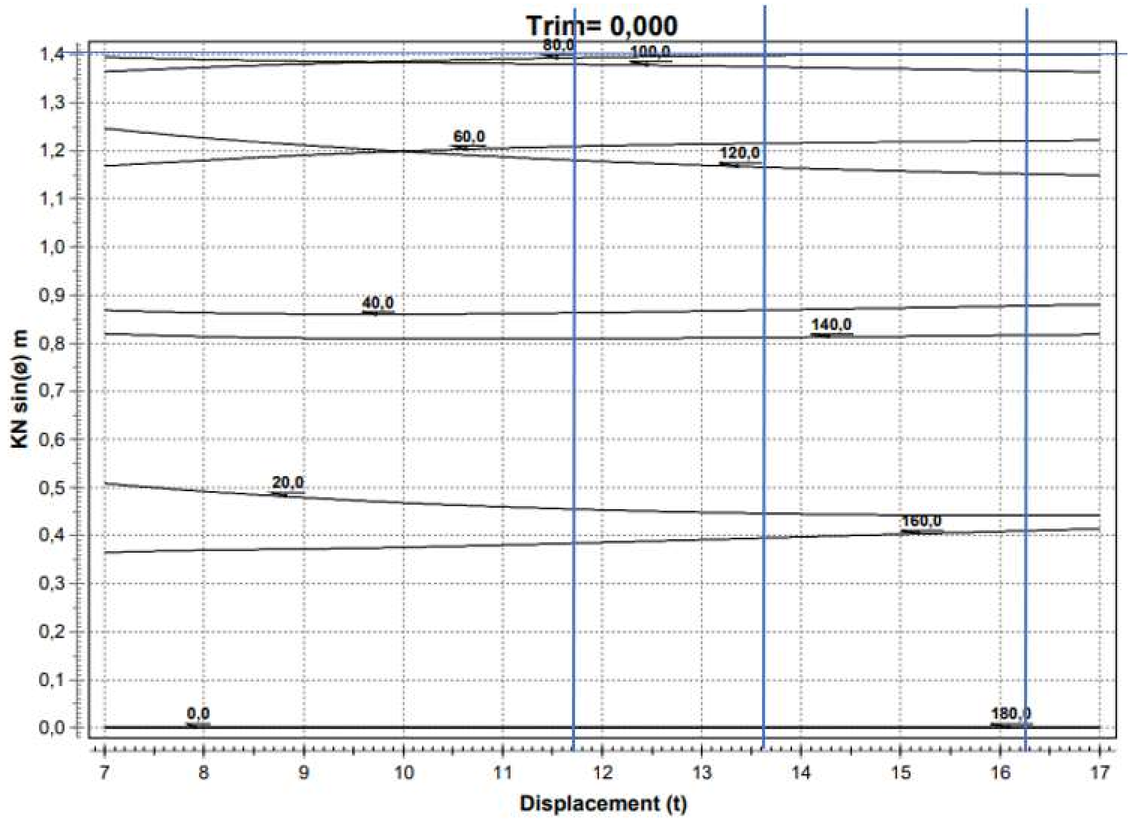


Figure 8: Preliminary vessel crosscurves

Lightweight	GZ	Standard	GZ	Full weight	GZ
0	0,000	0	0,000	0	0,000
20	0,460	20	0,460	20	0,450
40	0,865	40	0,870	40	0,870
60	1,210	60	1,210	60	1,225
80	1,400	80	1,400	80	1,405
100	1,375	100	1,380	100	1,365
120	1,189	120	1,185	120	1,160
140	0,815	140	0,810	140	0,820
160	0,385	160	0,400	160	0,410
180	0,000	180	0,000	180	0,000

Table 6: Data provided from Figure 1

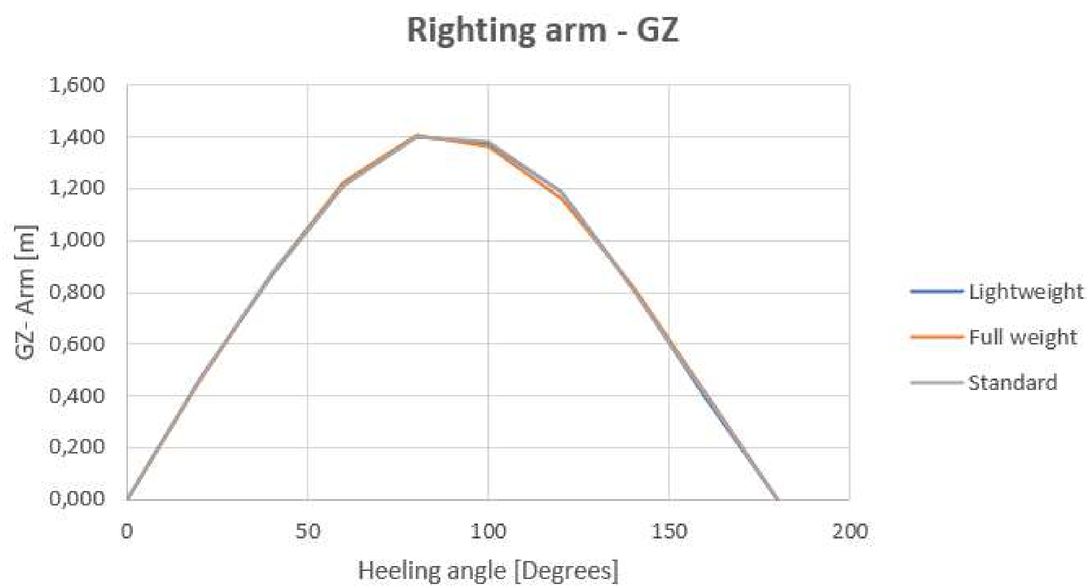


Figure 9: Heeling angle and positive GZ

Optimized design

Weight breakdown

Vessel statistics			Abbreviation
Loa	13,7	m	Length over all
Lpp	12	m	Length between perpendicular
B	2,65	m	Beam
T	1,077	m	Draught
LCG	6,162	m	Longitudinal centre of gravity
TCG	0	m	Transverse centre of gravity
VCG	1,018	m	Vertical centre of gravity
Total displaced volume	20,095	m^3	

Lightweight

Weight breakdown all components with internal fluids, additional fuel is excluded. Added 10 % design margin and 5 % building margin.

						Placement			Trimming moment		
Components	Quantity	Density [tonn/m^3]	Degree of filling [%]	Volume [m^3]	Weight [tonn]	LCG [m]	TCG [m]	VCG [m]	LCG * W [tonnm]	TCG * W [tonnm]	VCG * W [tonnm]
Main Hull	1				5,111	6,123	0	0,928	31,295	0,000	4,743
Hull Superstructure	1				0,7	5,055	0	2,385	3,539	0,000	1,670
Superstructure tower	1				0,2	8,485	0	3,295	1,697	0,000	0,659
Electrical engines	2				0,15	3,646	0	0,339	0,547	0,000	0,051
Generator	1				0,65	8,778	0	0,803	5,706	0,000	0,522
Battery	1				1,5	9,032	0	0,238	13,548	0,000	0,357
Shaft	2				0,2	1,651	0	0,333	0,660	0,000	0,133
Propeller Nozzles	2				0,2	-0,055	0	0,324	-0,022	0,000	0,130
Counter weight	1				0,5	11,873	0	0,342	5,937	0,000	0,171
TRAPS Slepesonar	1				1,50	0,051	0	2	0,077	0,000	3,000
Sonar Buoys	10				0,17	5	0	1,6	0,850	0,000	0,272
Lightweight					10,881						
Design margin		10 % addition design margin			11,97						
Building margin		5 % additon building margin			12,57						
Corrected Lightweight					12,57						
Sum					12,57				63,83	0,00	11,71

Centre of gravity	LCG	TCG	VCG
	5,87	0,00	1,08

Stability requirements	GM > 0	
KMt from Hydrostatics	1,184	m
GM loaded	0,11	m

Demand for 0-trim	LCG = LCB	
LCB from hydrostatics	5,952	m
Difference LCG-LCB	0,09	POS = forward trim

0-Yaw requirement		TCG = 0	
TCG =	0,00	m	POS = babord

Standard Weight

						Placement			Trimming moment		
Components	Quantity	Density [tonn/m^3]	Degree of filling [%]	Volume [m^3]	Weight [tonn]	LCG [m]	TCG [m]	VCG [m]	LCG * W [tonnm]	TCG * W [tonnm]	VCG * W [tonnm]
Main Hull	1				5,111	6,123	0	0,928	31,295	0,000	4,743
Hull Superstructure	1				0,7	5,055	0	2,385	3,539	0,000	1,670
Superstructure tower	1				0,2	8,485	0	3,295	1,697	0,000	0,659
Electrical engines	2				0,15	3,646	0	0,339	0,547	0,000	0,051
Generator	1				0,65	8,778	0	0,803	5,706	0,000	0,522
Battery	1				1,5	9,032	0	0,238	13,548	0,000	0,357
Shaft	2				0,2	1,651	0	0,333	0,660	0,000	0,133
Propeller Nozzles	2				0,2	-0,055	0	0,324	-0,022	0,000	0,130
Counter weight	1				0,5	11,873	0	0,342	5,937	0,000	0,171
TRAPS Slepesonar	1				1,50	0,051	0	2	0,077	0,000	3,000
Sonar Buoys	10				0,17	5	0	1,6	0,850	0,000	0,272
Lightweight					10,881						
Design margin		10 % addition design margin			11,97						
Building margin		5 % additon building margin			12,57						
Corrected Lightweight					12,57						
Aft Fueltank	0,5	0,855	0,95	0,795	0,32	1,909	0	0,404	0,616	0,000	0,130
Fore Fueltank	0,5	0,855	0,95	0,856	0,35	10,281	0	0,745	3,574	0,000	0,259
Middel Fueltank	0,5	0,855	0,95	2,756	1,12	6,577	0	0,367	7,362	0,000	0,411
Service Oil	0,5	0,843	0,95	0,035	0,01	7,8	0	0,55	0,109	0,000	0,008
Sum					14,37				75,49	0,00	12,52

Centre of gravity	LCG	TCG	VCG
	5,95	0,00	0,99

Stability requirements		GM > 0	
KMt from Hydrostatics		1,165	m
GM loaded		0,18	m

Demand for 0-trim		LCG = LCB	
LCB from hydrostatics		5,933	m
Difference LCG-LCB		-0,02	POS = forward trim

0-Yaw requirement		TCG = 0	
TCG =	0,00	m	babord

Full weight

Components	Quantity	Density [tonn/m^3]	Degree of filling [%]	Volume [m^3]	Weight [tonn]	Placement LCG [m]	TCG [m]	VCG [m]	Trimming moment LCG * W [tonnm]	TCG * W [tonnm]	VCG * W [tonnm]
Main Hull	1				5,111	6,123	0	0,928	31,295	0,000	4,743
Hull Superstructure	1				0,7	5,055	0	2,385	3,539	0,000	1,670
Superstructure tower	1				0,2	8,485	0	3,295	1,697	0,000	0,659
Electrical engines	2				0,15	3,646	0	0,339	0,547	0,000	0,051
Generator	1				0,65	8,778	0	0,803	5,706	0,000	0,522
Battery	1				1,5	9,032	0	0,238	13,548	0,000	0,357
Shaft	2				0,2	1,651	0	0,333	0,660	0,000	0,133
Propeller Nozzles	2				0,2	-0,055	0	0,324	-0,022	0,000	0,130
Counter weight	1				0,5	11,873	0	0,342	5,937	0,000	0,171
TRAPS Slepesonar	1				1,50	0,051	0	2	0,077	0,000	3,000
Sonar Buoys	10				0,17	5	0	1,6	0,850	0,000	0,272
Lightweight					10,881						
Design margin		10 % addition design margin			11,97						
Building margin		5 % additon building margin			12,57						
Corrected Lightweight					12,57						
Aft Fueltank	1	0,855	0,95	0,795	0,65	1,909	0	0,404	1,233	0,000	0,261
Fore Fueltank	1	0,855	0,95	0,856	0,70	10,281	0	0,745	7,148	0,000	0,518
Middel Fueltank	1	0,855	0,95	2,756	2,24	6,577	0	0,367	14,723	0,000	0,822
Service Oil	1	0,843	0,95	0,035	0,03	7,8	0	0,55	0,219	0,000	0,015
Full weight					16,18						
Future growth margin		5 % future growth margin			16,98						
Corrected Full Weight					16,98						
Sum					16,98				87,15	0,00	13,32

Centre of gravity	LCG	TCG	VCG
	6,02	0,00	0,92

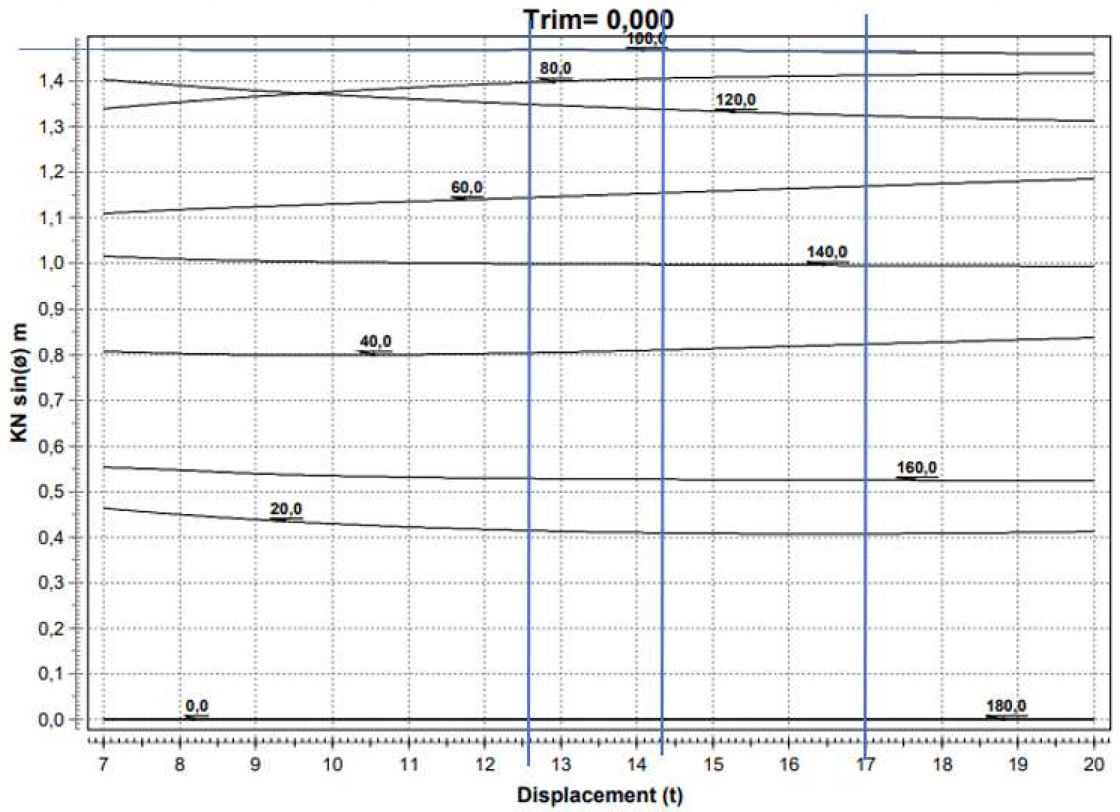
Stability requirements		GM > 0	
KMt from Hydrostatics		1,161	m
GM loaded		0,24	m

Demand for 0-trim		LCG = LCB	
LCB from hydrostatics		5,898	m
Difference LCG-LCB		-0,12	POS = forward trim

0-Yaw requirement		TCG = 0	
TCG =	0,00	m	POS = babord

Cross curves and stability

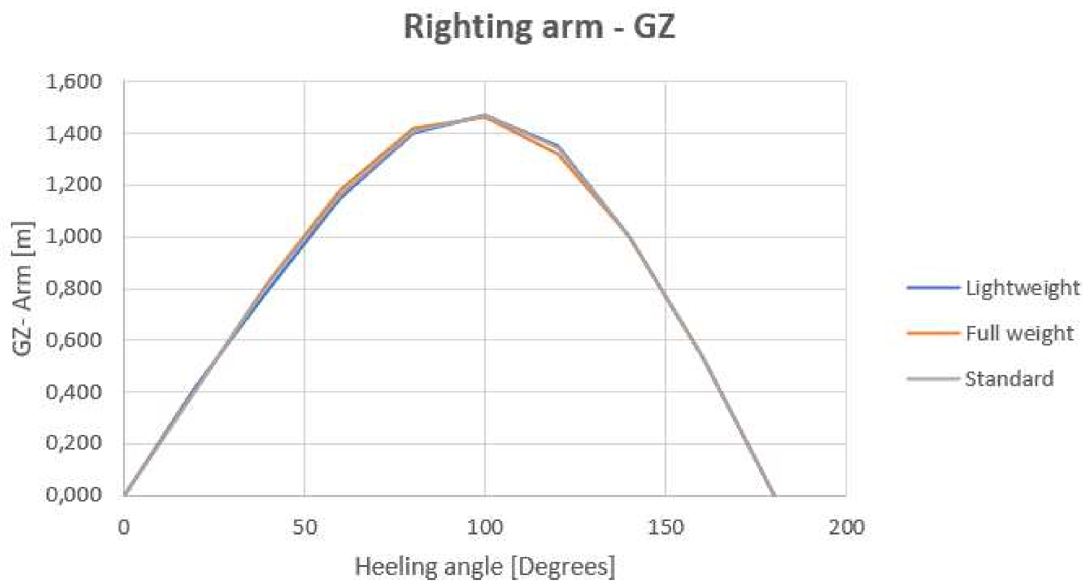
In order to calculate stability and the vessels righting arm crosscurved are used to get information of KN SIN(Ø) in regard to vessel displacment and healingangle. These values are then used to calculate GZ-arm for each case and plotted in a graph.



Lightweight	GZ
0	0,000
20	0,420
40	0,800
60	1,150
80	1,400
100	1,470
120	1,350
140	1,000
160	0,530
180	0,000

Standard	GZ
0	0,000
20	0,410
40	0,820
60	1,160
80	1,410
100	1,470
120	1,345
140	1,000
160	0,530
180	0,000

Full weight	GZ
0	0,000
20	0,410
40	0,830
60	1,180
80	1,420
100	1,465
120	1,320
140	1,000
160	0,530
180	0,000



Righting arm - GZ
1,600
1,400
1,200
1,000
0,800
0,600
0,400
0,200
0,000
GZ- Arm [m]
0
50
100
150
200
Heeling angle [Degrees]
Lightweight
Full weight
Standard

Appendix F - Parametric study

The following parametric study shall seek to identify the possible parameters in the design spiral in order to further optimize the vessel. Due to scope and time, certain limitations have been made, and will be addressed as “Not applicable”, see list of limitations.

Parameter	Description	Adjustment
Complement	Not applicable, unmanned vessel.	Not applicable, unmanned vessel.
Mass	A lot of space available and buffer with respect to draft may allow for more weight. Possibility to adjust the hull thickness in order to reduce weight.	Smeared hull thickness adjusted from 0,04m to 0,035m.
Enclosed volume	A lot of space available, may allow for more fuel storage or other components. Increased space may allow the vessel to become a test subject for other fuel types.	No additional fuel storage or components added. Testing of other fuel types in this phase will not be conducted.
Linear dimensions	Length of the vessel may be increased by changing shape of bow to go straight down to the bulb.	Beam adjusted from 2,8m to 2,667m Lpp adjusted from 10,8m to 12m.
Length/beam	L/B ratio to be adjusted for better stability properties.	Adjustments in linear dimensions. L/B ratio adjusted from 4,125 to 4,813 as product of change in linear dimensions.
Draught	Adjusted based on linear dimensions.	Adjusted from 0,96m to 1,077m.

Volume of displacement	Not applicable	Not applicable
Underwater form	Not applicable	Not applicable
Speed, power	Operating speed of tow may be subject of change in order to save fuel.	Operating speed not adjusted.
Propulsion machinery	Consider further optimizing the choice of engine based on propeller performance curve.	Synergy of propeller and engine will not be addressed at this stage, is currently sufficient for an initial design.
Propulsor	Hull limits propeller diameter to 0,5m without nozzle, and 0,625 with nozzle Optimize maximum load of propeller	Adjust the maximum allowed propeller diameter to 0,5m. Max load adjusted from 10 to 6 kN/m^2.
LCG, LCB, Balance	Maximum allowed trim of +/- 5°	Within limit, will not be addressed.
Transverse stability	Option to address sections in the fuel tanks in order to limit free-surface-effect.	Sections in the fuel tanks will be addressed.
Safety, survivability (Redundans)	Consider the application of two generators Consider the application of a split Bus Bar for redundancy	Not changed.
Architecture layout	The lower deck on the aft may be extended in order to prevent instability. In general rounder edges will allow for better waterflow over deck.	Changed the overall layout of the superstructure to account for better waterflow over deck and stability.

Seakeeping	Sufficient, will not be directly addressed.	Sufficient, will not be directly addressed.
Manoeuvring	Not applicable, see limitations.	Not applicable, see limitations.
Structural strength	Not applicable, see limitations.	Not applicable, see limitations.
Ease of production	Adjusting drivetrain complexity may allow for easier production. Adjust the chosen battery packages in order to avoid a development phase.	Change to 6 x Transfluid 48V, 41kWh batteries. (Transfluid, 2020).
Cost	Not applicable in this phase	Not applicable on this phase.
Signatures	Consider the application of 4-bladed 0,55 BAR ducted propeller in order to reduce noise.	Not changed.
Electrical, heating loading	Not applicable	Not changed
Reliability, maintainability, availability, logistics	Possible to adjust drivetrain complexity in order to ease maintenance and reliability. Alternative battery package in order to avoid a development phase with Tesla 4680 battery cells (Kane, 2022). Possibility to add 1 more generator in order to increase redundancy.	Drivetrain not changed. Change to 6 x Transfluid 48V, 41kWh batteries. (Transfluid, 2020). No additional generators will be added.
Payload or cargo characteristics	Option to adjust the amount of fuel represented in the vessel.	Adjust fuel to 4100 litres of fuel.

	4615 Litres of fuel does satisfy the operational requirement of 1400 Nm operations in a 5-knot towing condition with 35% limit 4615 litres of fuel do satisfy the operational requirement of 20 days of operation in a 5-knot towing condition with 35% limit.	Adjust to 4350 litres of storage, which equals to 4,35m^3.

Table 7: Parametric study with description and adjustments made.

Appendix G - Energy consumption and operational profile

The following tables are extracts from the energy consumption and operational profile calculations in a separate spreadsheet. The tables are separated into a preliminary design and an optimized design.

Preliminary design

Vessel				
Knots	3	5	7	
Drag	0,13	0,34	1,27	**kN**
Speed	5,56	9,26	12,96	**km/h**
Speed	1,54	2,57	3,60	**m/s**
Pe = Effect towards water	0,20	0,87	4,57	**kW**
Resistance from towing cable	1,54	2,57	3,60	**kW**
Prop. Efficiency	0,388	1,675	8,754	**kW**
Prop Efficiency with tow	3,34	6,603	15,65	**kW**

20 % addition	0,5	2,0	10,5	**kW**
20 % Tow	4,014	7,924	18,78289885	**kW**

Estimated power need		
Hotel	10	**kWh**
Passive sonar	(2-4)	**kWh**
Passive sonar	2	**kWh**
Winch	7	**kWh**
Towing cable	1,0	**kN**

Fuel

Fuel total	4400	liter

Effect [kW]	0-5	25	50	75	100	%
Fuel [l/h]	1	2,25	3,5	4,75	6	

Scenario	Total Load	Generator load	Fuel [l/h]	Hours of operation	Nm	Days
Transitt 3 kn	6,44	0,29	2,43	1809,76	5429,29	75,4
Transitt 7 kn	12,01	0,53	3,67	1199,24	8394,67	50,0
Passiv son, 5 kn	19,92	0,89	5,43	810,69	4053,45	33,8
Winching in, 3 kn	20,99	0,93	5,66	776,82	2330,46	32,4

35 % remaining fuel		
Hours. Of ops	**nm**	**days**
1176,35	3529,04	49,01
779,51	5456,54	32,48
526,95	2634,74	21,96
504,93	1514,80	21,04

Operational profile	Speed [kn]	Distance [Nm]	Hours [h]	Fuel [l/h]	Fuel [l]
Transit	7	350	50,00	3,67	183,45
Transit	3	10	3,33	2,44	8,12
Winching	3	1	0,33	5,67	1,89
Towing	5	1000	200,00	5,43	1085,49
Winching	3	1	0,33	5,67	1,89
Transit	3	10	3,33	2,44	8,12
Transit	7	350	50,00	3,67	183,45
Total		1722	307,33		1472,42

Battery

Battery capasity	170	Wh/kg
Battery in weight	1470	kg
Total capasity	250	kWh

Scenario	kWh	El. Energy [kWh]	Total	Battery [h]	Length [Nm]
Passiv son, 0 kn	0,00	8	8,00	31,3	0,0
Transitt 3 kn	0,47	6	6,47	38,7	116,0
Transitt 7 kn	2,0	10	12,01	20,8	145,7
Passiv son, 5 kn	7,9	12	19,92	12,5	87,8
Winching in, 3 kn	4,01	17	21,01	-	-

Optimized design

Vessel				
Knots	3	5	7	
Drag	0,13	0,34	0,64	kN
Speed	5,56	9,26	12,96	km/h
Speed	1,54	2,57	3,60	m/s
Pe = Effect towards water	0,21	0,88	2,30	kW
Resistance from towing cable	1,54	2,57	3,60	kW
Prop. Efficiency	0,381	1,623	4,268	kW
Prop Efficiency with tow	3,24	6,386	10,94	kW

20 % addition	0,5	1,9	5,1	kW
20 % Tow	3,887	7,664	13,12404938	kW

Estimated powerneed		
Hotel	10	kWh
Passive sonar	(2-4)	kWh
Passive sonar	2	kWh
Winch	7	kWh
Towing cable	1,0	kN

Fuel

Fuel total	4100	liter

Effect [kW]	0-5	25	50	75	100	%
22,5	1	2,25	3,5	4,75	6	

Scenario	Total Load	Generator load	Fuel [l/h]	Hours of operation	Nm	Days
Transitt 3 kn	6,46	0,29	2,43	1683,83	5051,49	70,2
Transitt 7 kn	11,95	0,53	3,65	1121,75	7852,28	46,7
Passiv son, 5 kn	19,66	0,87	5,37	763,55	3817,74	31,8
Winching in, 3 kn	20,89	0,93	5,64	726,76	2180,27	30,3

35 % remaining fuel		
Hours. Of ops	**nm**	**days**
1094,49	3283,47	45,60
729,14	5103,98	30,38
496,31	2481,53	20,68
472,39	1417,17	19,68

Operation	Speed [kn]	Distance [Nm]	Hours [h]	Fuel [l/h]	Fuel [l]
Transit	7	350	50,00	3,65	182,75
Transit	3	10	3,33	2,43	8,12
Winching	3	1	0,33	5,64	1,88
Towing	5	1000	200,00	5,37	1073,93
Winching	3	1	0,33	5,64	1,88
Transit	3	10	3,33	2,43	8,12
Transit	7	350	50,00	3,65	182,75
Total		1722	307,33		1459,43

Battery

Battery capasity	170	Wh/kg
Battery in weight	1470	kg
Total capasity	250	kWh

Scenario	kWh	El. Energy [kWh]	Total [kWh]	Battery [h]	Length [Nm]
Passiv son, 0 kn	0,00	8	8,00	31,3	0,0
Transitt 3 kn	0,46	6	6,46	38,7	116,1
Transitt 7 kn	1,9	10	11,95	20,9	146,5
Passiv son, 5 kn	7,7	12	19,66	12,7	89,0
Winching in, 3 kn	3,89	17	20,89	-	-

Appendix H - Optimization of propeller

This appendix will represent the extracts from the spreadsheet used in the estimation of optimal propeller diameter, rpm, effect, and torque. The appendix will be split into a preliminary design, and an optimized design based on the parametric study in appendix F.

Preliminary Design

Towing 5 knots	FPP		Comments
BAR	0,65		From propeller series
Lwl	11,553		From hydrostatic data
T	0,960	m	From hydrostatic data
Bwl	2,818		From hydrostatic data
B/L	0,244		4,099716111
R_{ts}	1,34	kN	From Appendix G
Blades	3		From propeller series
Propeller shaft	2		Estimation
Max load	10	KN/m^2	60 / 80 (max)
ρ	1025	kg/m^3	standard
C_b	0,5288		From hydrostatic data
V_s	5	knop	From hydrostatic data
	2,57	m/s	From hydrostatic data
w	0,0790		Wake fraction coefficient
t	0,1153		Thrust deduction coefficient
J	0,6		Advance Coefficient
P/D	1,2		Pitch/Diameter ratio
η_0	0,60		Propeller efficiency
η_R	0,995		Relative Rotational efficiency
η_m	0,91		Mechanical Efficiency

Calculations

T_{aksel}	= Rts/[(1-t)*antall antall aksler	0,757	KN/screw
A_E	= T_{aksel}/T_{max}	0,076	m^2/screw
D	= √[(4*AE)/(π*B.A.R)]	0,385	m
V_A	= V_s*(1-w)	2,369	m/s
K_{T/J^2}	= (T*J^2/(ρ*D^2*V_A^2)	0,887	
w	= 2*C_b^5*(1-C_b)+0,04	0,079	Wake Fraction
t	= 0,7*w + 0,06	0,115	Thrust deduction
n	= V_A/(J*D)	615	rpm
P.C	= η_0 * ((1-t)/(1-w)) * η_R * η_m	0,522	Propeller Coefficient
PE	= R_{TS}*V_s	3,447	KW
P_c	= P_E/P.C	6,605	KW
Q	= (P_c*1000*60)/(2*π*n)	102,54	Nm
P_c + 20% servi	= P_E/P.C	7,926	kw
Q + 20% servic	= (P_c*1000*60)/(2*π*n)	123,05	Nm
		61,52	Nm/screw
		3,96	kW/screw

Figure 10 : Extract from the initial propulsion spreadsheet.

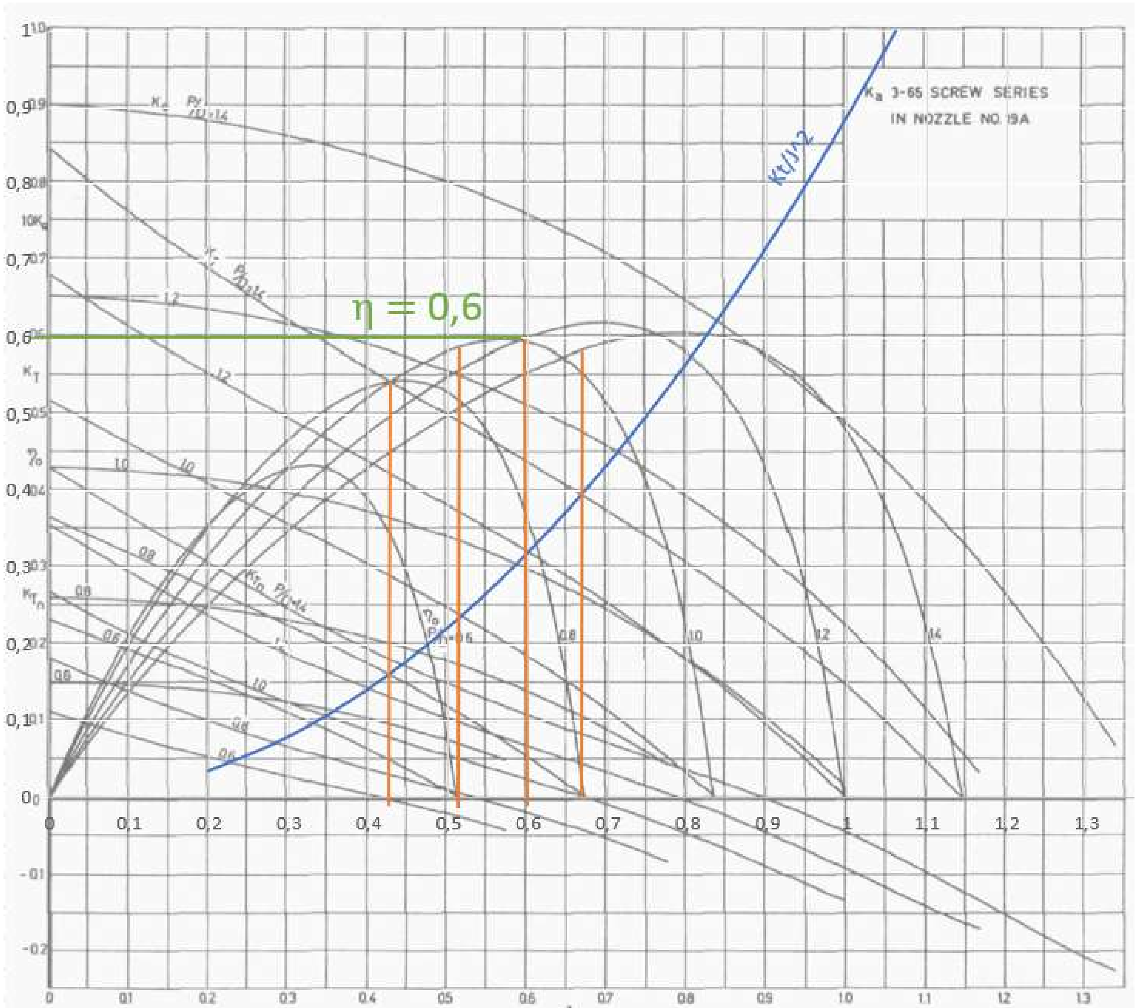


Figure 11 : Values of Kt plotted in Wageningen Ka 3-65 propeller series data.

J	0	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1	1,1	1,2	1,3	1,4	1,5
K_T		0,035	0,080	0,142	0,222	0,319	0,435	0,568	0,719	0,887	1,074	1,278	1,500	1,739	1,997

Table 8 : Relation between Kt and J for the initial parameters.

Optimized Design

Towing 5 knots	FPP		Comments
BAR	0,65		From propeller series
Lwl	12,837		From hydrostatic data
T	1,077	m	From hydrostatic data
B	2,667		From hydrostatic data
B/L	0,207758822		4,813273341
R_{ts}	1,3407	kN	From Appendix G
Blades	3		From propeller series
Propeller shafts	2		Estimation
Max load	6	KN/m^2	60 / 80 (max)
ρ	1025	kg/m^3	standard
C_b	0,5288		From hydrostatic data
V_s	5	knop	From hydrostatic data
	2,57	m/s	From hydrostatic data
w	0,0790		Wake fraction coefficient
t	0,1153		Thrust deduction coefficient
J	0,700		Advance Coefficient
P/D	1,20		Pitch/Diameter ratio
η_0	0,620		Propeller efficiency
η_R	0,995		Relative Rotational efficiency
η_m	0,91		Mechanical Efficiency

Calculations

T_{aksel}	= Rts/[(1-t)*antall antall aksler]	0,758	KN/screw
A_E	= T_{aksel}/T_{max}	0,126	m^2/screw
D	= √[(4*AE)/(π*B.A.R)]	0,497	m
V_a	= V_s*(1-w)	2,369	m/s
K_T/J^2	= (T*J^2/(ρ*D^2*V_A^2)	0,532	
w	= 2*C_b^5*(1-C_b)+0,04	0,079	Wake Fraction
t	= 0,7*w + 0,06	0,115	Thrust deduction
n	= VA/(J*D)	408	rpm
P.C	= η_0 * ((1-t)/(1-w)) * η_R * η_m	0,539	Propeller Coefficient
PE	= R_{TS}*V_s	3,449	KW
P_c	= Pd/P.C	6,395	KW
Q	= (P_c*1000*60)/(2*π*n)	149,57	Nm
P_c + 20% servic	= Pd/P.C	7,674	kw
Q + 20% servic	= (P_c*1000*60)/(2*π*n)	179,49	Nm
		89,74	Nm/screw
		3,84	kW/screw

Figure 12: Extract from the optimized propulsion spreadsheet.

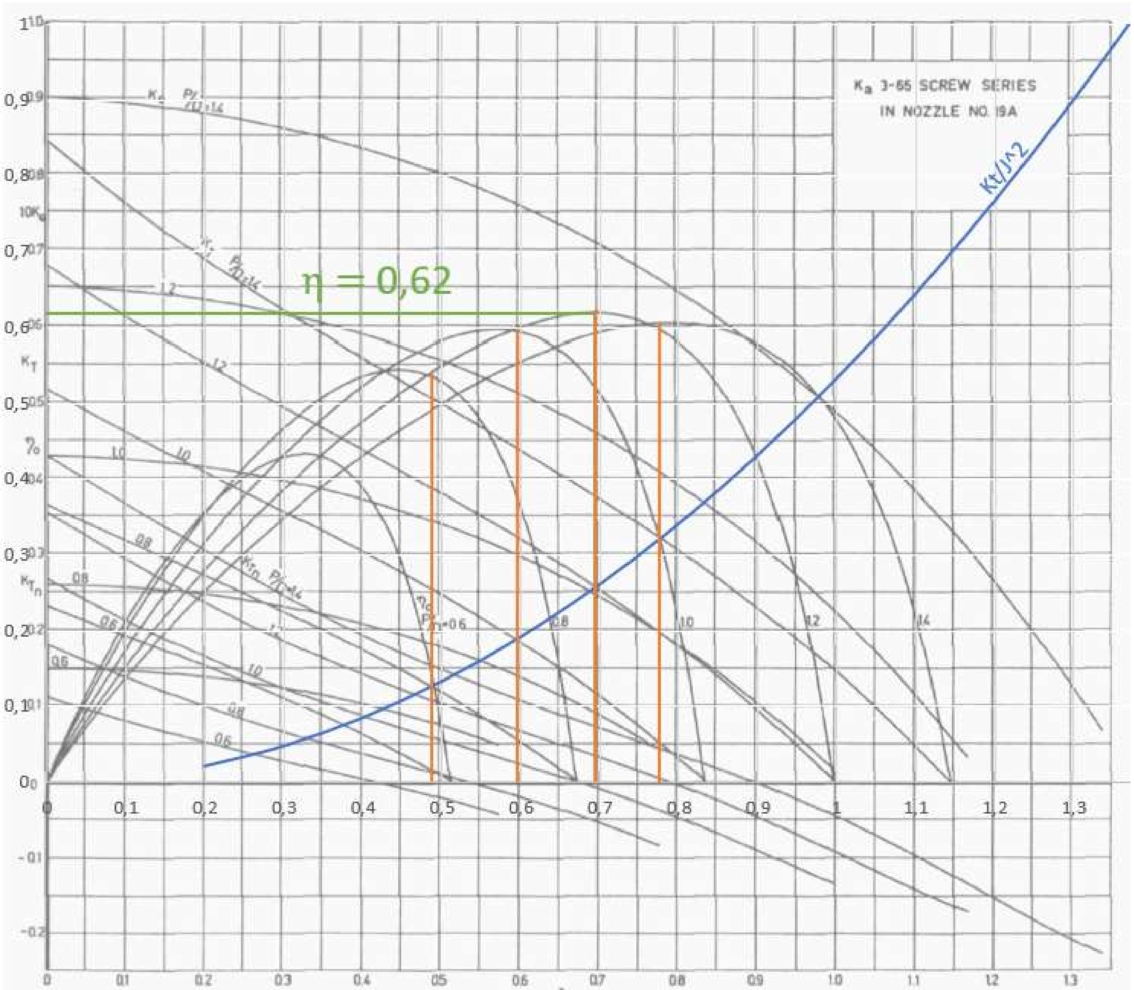


Figure 13: Values of Kt plotted in Wageningen Ka 3-65 propeller series data.

J	0	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1	1,1	1,2	1,3	1,4	1,5
KT		0,021	0,048	0,085	0,133	0,192	0,261	0,341	0,431	0,532	0,644	0,767	0,900	1,044	1,198

Table 9: Relation between Kt and J for the optimized parameters

References

Bellmarine. Drivemaster. *Drivemaster.* Retrieved from https://www.bellmarine.tech/pdf/?path=/var/www/vhosts/bellmarine.tech/httpdocs/wp-content/uploads/2022/01/BELLMARINE_GB_Jan-2022_LQ.pdf&filename=BELLMARINE_GB_Jan%202022_LQ&productname=drivemaster&page=6-7

BunkerOil. (2021). Marine Gas Oil (MGO). Retrieved from https://www.bunkeroil.no/no/kategori/mgo

Kane, M. (2022). Tesla's 4680-Type Battery Cell Teardown: Specs Revealed. Retrieved from https://insideevs.com/news/598656/tesla-4680-battery-cell-specs/

Lubricants, N. ARCTIC SYNTHETIC HEAVY DUTY ENGINE OIL. Retrieved from http://oilmart.com/data/products/pds/1723/TDS%2049N%20Arctic%20Synthetic%200W-30.pdf

Mariner X. (2022). Retrieved from https://www.maritimerobotics.com/_files/ugd/a0d8a5_3998cfeab939480a814bbf1ae778b29f.pdf

Protector USV (2013). Retrieved from https://www.naval-technology.com/projects/protector-unmanned-surface-vehicle/

Saildrone Explorer USV. (2022). *Naval technology.* Retrieved from https://www.naval-technology.com/projects/saildrone-explorer-unmanned-surface-vessel-usv-usa/

Scott, R. (2020). GeoSpectrum Launches Scaled down TRAPS sonar for USVs. Retrieved from https://www.janes.com/defence-news/news-detail/geospectrum-launches-scaled-down-traps-sonar-for-usvs

Skopljak, N. (2022). SEA-KIT eyes zero-emission vessels with latest USV design. Retrieved from https://www.offshore-energy.biz/sea-kit-eyes-zero-emission-vessels-with-latest-usv-design/

Transfluid. (2020). Battery Pack- innovative energy system for marine application. Retrieved from https://www.transfluid.eu/wp-content/uploads/2021/01/batterie-tf_gb_20.10_lq_rev2.pdf

Waveglider. (2022). Retrieved from https://www.liquid-robotics.com/wave-glider/how-it-works/

WhisperPower. Specifications M-SQ Pro 25. *M-SQ.* Retrieved from https://www.whisperpower.com/diesel-generators/m-sq-generators/m-sq-pro-25