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8th EMship cycle: October 2017 – February 2019

Master Thesis

Initial design of a 40 feet motorboat with experimental composite testing

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Internship tutor: Senior Lecturer Jean-Baptiste R. G. Souppez, Southampton Solent University, Southampton, UK
Reviewer: Professor Andre Hage, University of Liege, Liege, Belgium

Szczecin, January 2019

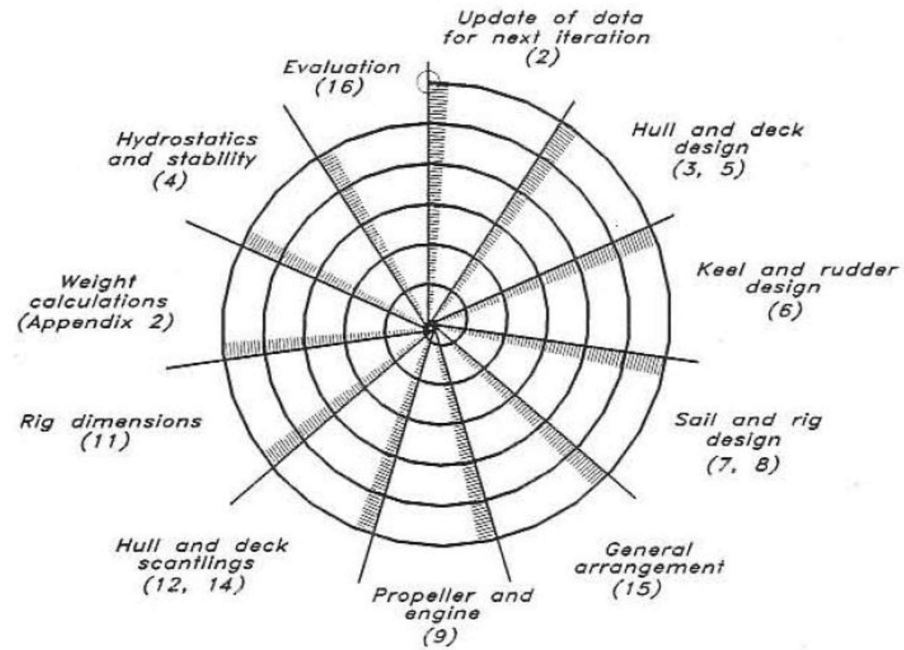
1. INTERNSHIP

- The internship took place at Southampton Solent University in UK, under guidance of Senior Lecturer Jean-Baptiste R. G. Souppez,
- During the internship were done all calculations, simulations and tests necessary to develop this project,
- I would like to thank Southampton Solent University for allowing me to use university facilities and software and to everybody who was involved to help me.

- Purpose of the project was to introduce main steps during the design process of pleasure motor yacht such as:
  - parametric study,
  - hull shape design,
  - general arrangement,
  - engine and propulsion system determination,
  - weight estimation,
  - design of structure,
  - power and stability prediction,
  - technical drawings,
  - 3D model.
- Secondary purpose was to carry out experimental fibreglass composite tests to show differences between hand layup and vacuum bagging laminates production methods and their impact on mechanical properties, as well as to help to understand production processes of such composites. Additionally results of the tests were compared with values calculated according to the ISO 12215-5 rules in order to highlight differences between practical and theoretical approach to laminate properties determination.
- Design was developed with use of Maxsurf, HullScant, AutoCad and Rhinoceros 3D software.
- Design comply with rules: ISO 12215-5, ISO 12217-1, ISO 9094, ISO 15085, RCDII.

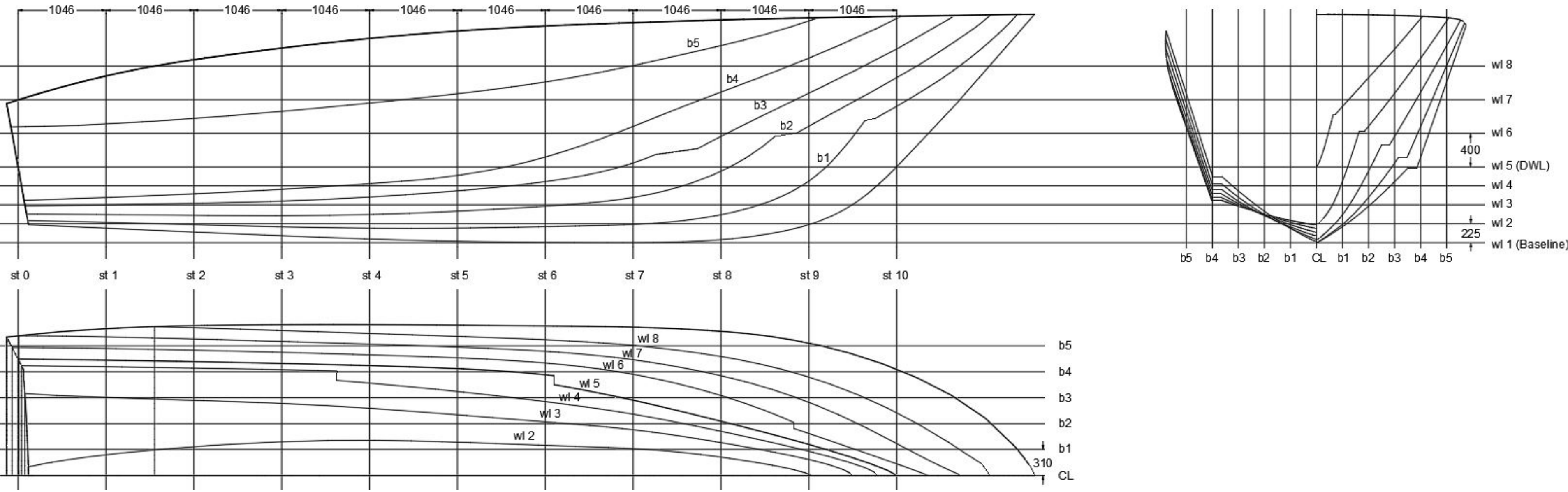
- In the design was used design spiral approach. It means that the process was iterative and based on trial and error procedure.

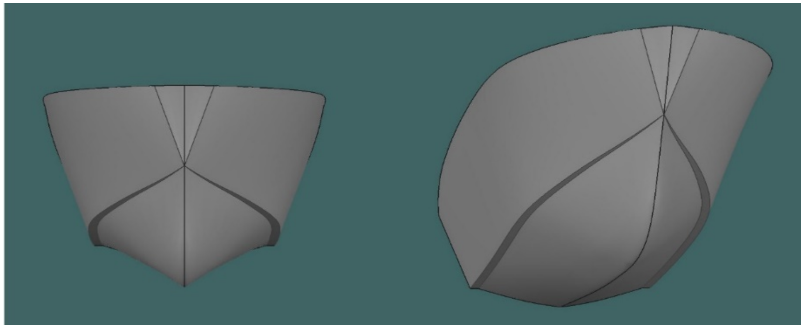
- Following steps in design loop were defined:
    - destination,
    - limitations,
    - boat's main dimensions,
    - hull shape and interior layout,
    - estimation of weight and load distribution,
    - preliminary design.



Design spiral

[Larsson L., E Eliasson R., 2000. *Principles of Yacht Design Second Edition*. London: Adlard Coles Nautical]





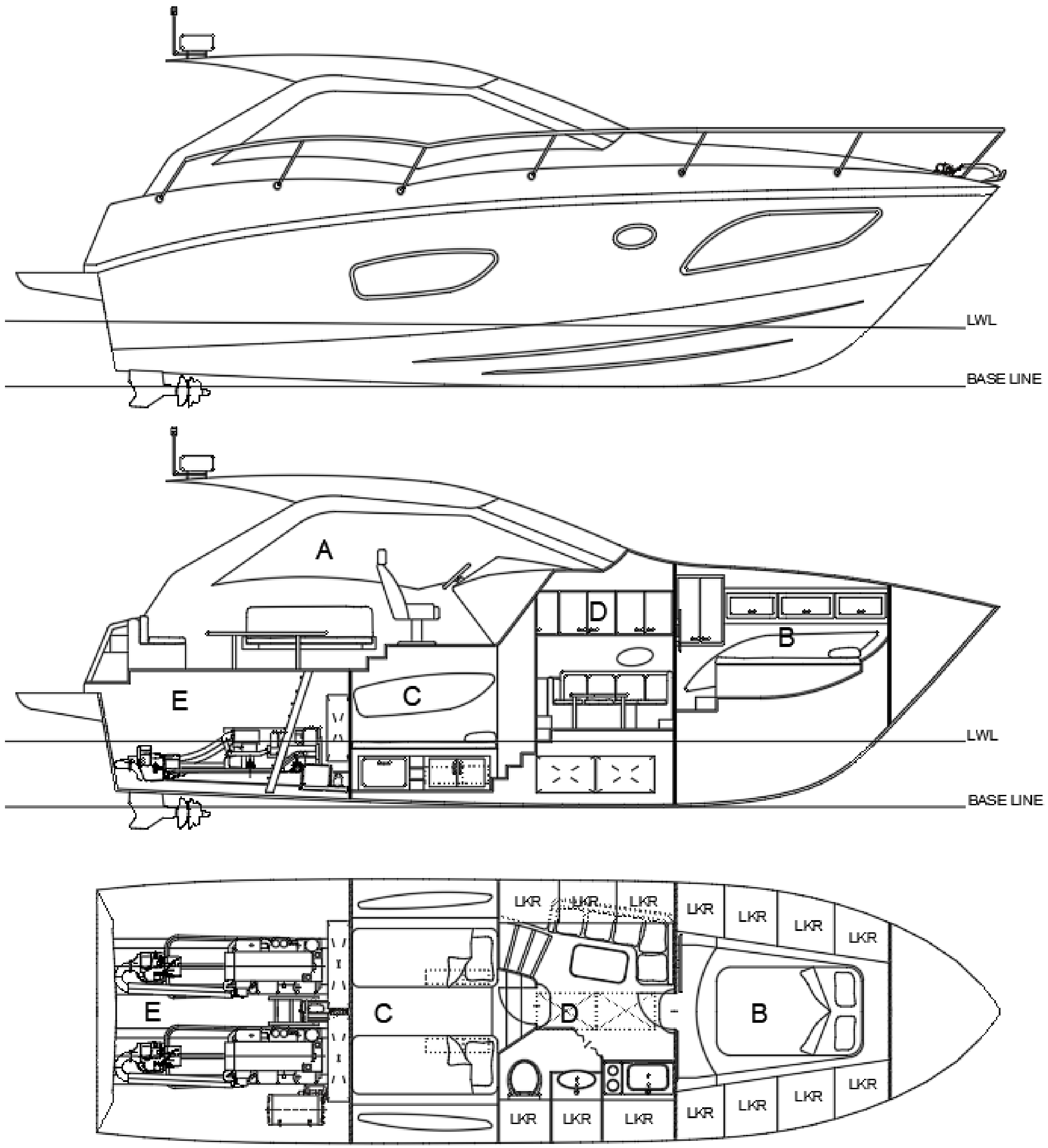
- The hull shape was developed in Maxsurf Modeller software,
- Main assumptions taken into account during hull modelling:
  - pleasure motor yacht with two engines,
  - design category B (offshore),
  - navigational area – Mediterranean Sea,
  - maximum speed 35 knots,
  - construction material – fibreglass laminate with sandwich composition,
  - length of the hull around 40 feet,
  - 6 crew members with accommodation for 4,
  - interior with owner’s cabin, guest cabin, common galley and restroom.

- Before modelling of hull shape, it was necessary to define main particulars of the boat. In order to do that, it was conducted parametric study where, were collected data of 23 parents boats. From those data with use of regression analisys and other assumptions were extracted actual parameters of the boat.

- Modelling of the hull shape was done by trial and error until following criteria for planing mode were achieved: Froude number above 1, Prismatic coeff. Cp = from 0.7 to 0.95, Longitudinal centre of buoyancy LCB around 10% measured from midship, Block coeff. Cb as small as possible, draft around 0.9 m.

Principal parameters	
Measurement	**Value**
Hull length L_H [m]	12,2
Beam B [m]	3,6
Light ship displ. Δ_{light} [t]	10,4
Fully loaded ship displ. Δ_{full} [t]	11,64
Draft T [m]	0,9
Engine power [HP]	670
Fuel tanks overall capacity [l]	650
Fresh water tank capacity [l]	200
Waste water tank capacity [l]	200
Hull material	FRP sandwich
Deck material	FRP sandwich
Max speed [knots]	35

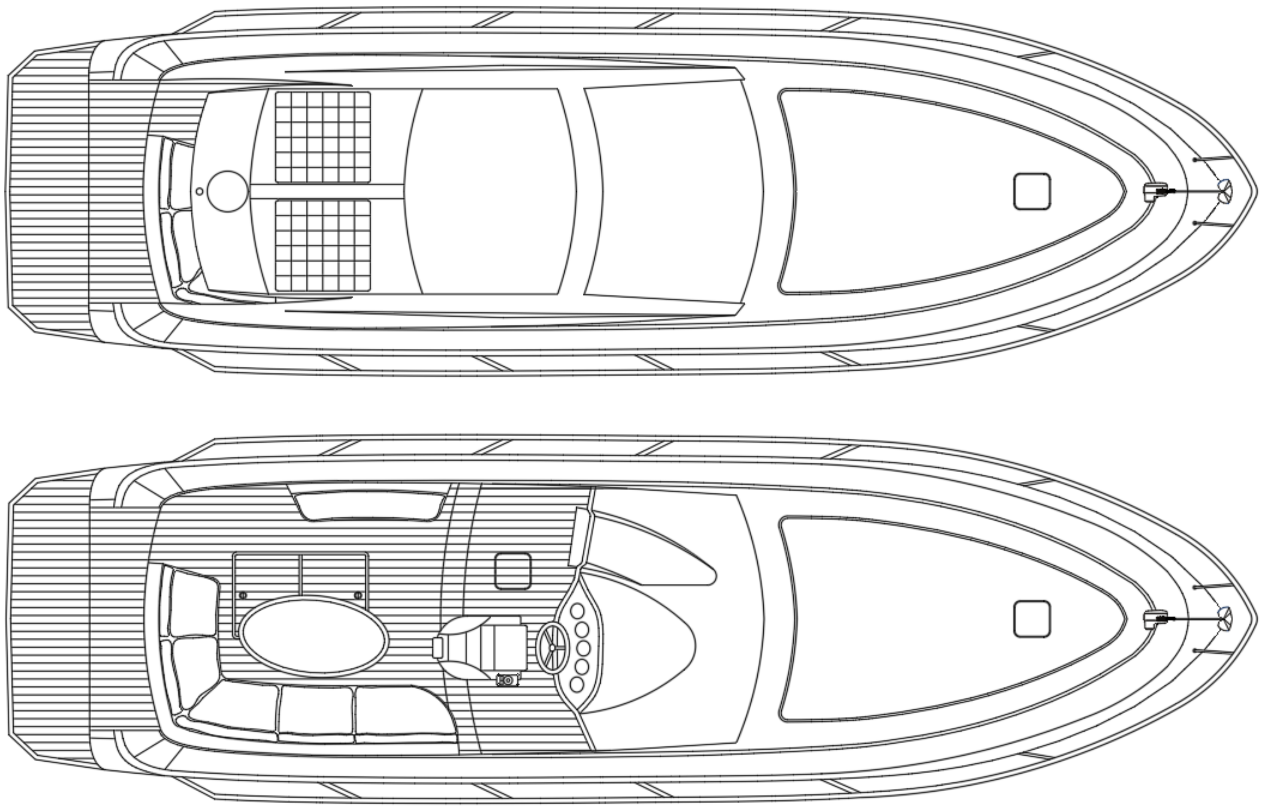
Hydrostatics			
Measurement	**Value**	**Measurement**	**Value**
Displacement Δ [t]	11,24	Waterplane area [m^2]	21,828
Displaced volume [m^3]	10,963	Prismatic coeff. C_P	0,737
Draft amidships [m]	0,9	Block coeff. C_B	0,421
Immersed depth [m]	0,9	Max sect. area coeff. C_M	0,711
L_{WL} [m]	10,457	Waterplane area coeff. C_{WP}	0,754
Beam [m]	3,6	LCB fwd from aft [m]	4,14
Beam max extents on WL [m]	2,768	LCF fwd from aft [m]	4,197
Wetted surface area [m^2]	30,304	Froude number F_N (for 35 knot)	1,77
Max sect. area [m^2]	1,422	Deadrise angle [deg]	28



- Superstructure type – hard top cupe

- A – deck and superstructure,
- B – owner's cabin,
- C – guest cabin,
- D – galley,
- E – engine room.

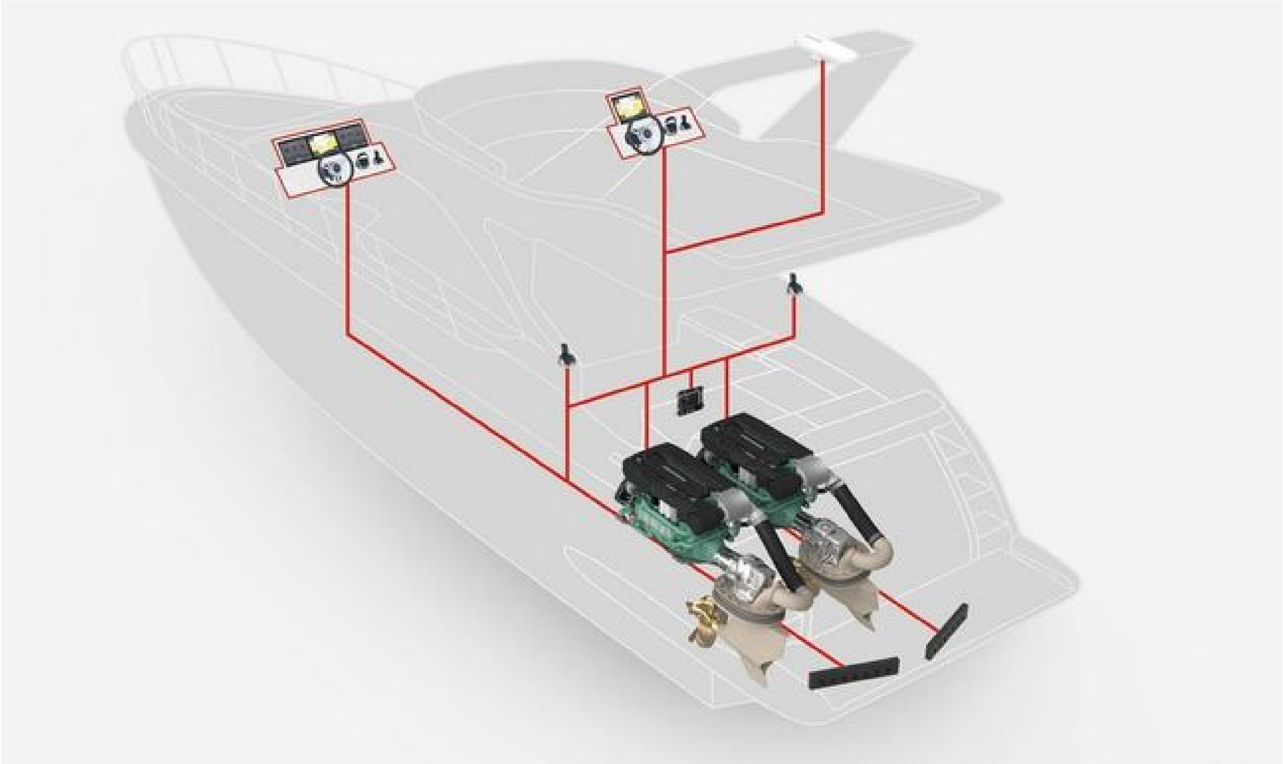
- The general arrangement was done according to the previously defined criteria given as follow:
- accommodation for 4 persons including owner's and guest cabins,
- main galley under the deck in central location with separate kitchen annex and restroom,
- hidden storage for batteries in guest room,
- deck equipped with sofa, table and additional folding seat,
- two engines in engine room with access from the deck,
- pilot seat with helm station at forvard part of cockpit,
- safety hatches in cabins according to safety rules ISO 9094,
- handrails on the deck according to safety rules ISO 15085.



- Glass window on the roof with possibility to open it,
- Solar panels on the roof,
- Swimming platform at aft part,
- Sunbathing area at forward part.

- Chosen propulsion system is Volvo Penta IPS:

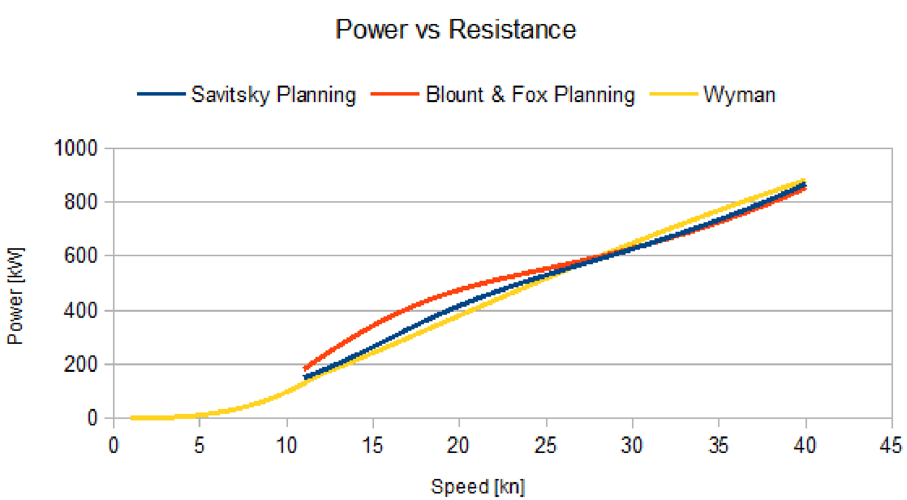
  - pod system provided in one set easy and quick to instal,
  - pod transmission with forward-facing, twin counter-rotating propellers,
  - no cavitation phenomena and less vibrations,
  - exhaust fumes directed under the water plane,
  - high maneuverability,
  - require less space in engine room,
  - system is simple to operate and user friendly.

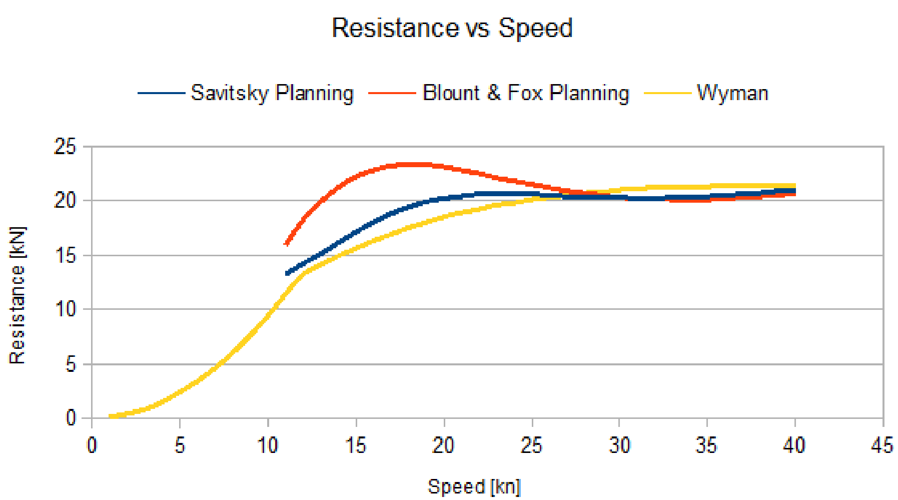


Volvo Penta IPS pod propulsion system
[www.volvopenta.com]

- Power prediction was conducted in Maxsurf Resistance software,
- Used prediction methods:
  - Savitsky resistance,
  - Blount & Fox resistance,
  - Wyman resistance.
- Assumed efficiency 50%, maximum expected speed 35 knots.

Resistance and power prediction	
Speed [kn]	35
Froude number LWL	1,778
Savitsky resisttance [kN]	20,4
Savitsky power [kW]	733,4
Blount & Fox resistance [kN]	20,1
Blount & Fox power [kW]	724,8
Wyman resistance [kN]	21,3
Wyman power [kW]	768,5





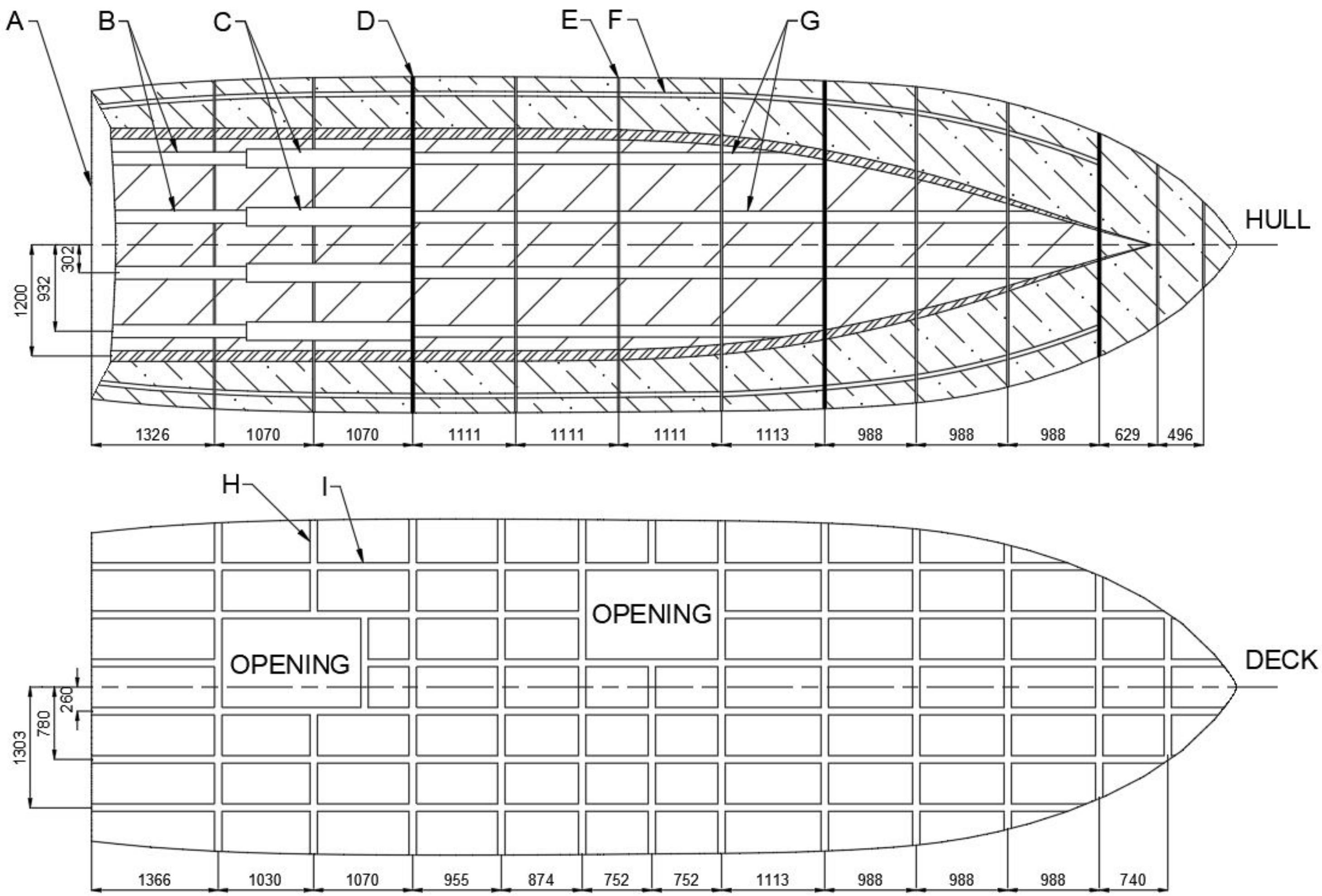
- Predicted total power: 768 kW (1044 HP) on the propeller shaft,
- Chosen engine: Volvo Penta DS-IPS700

Volvo Penta DS – IPS700 technical data	
Displacement, l	7,7
Pistons configuration	in-line 6
Crankshaft power, kW (HP)	405 (550) at 2900 rpm
Propshaft power, kW (HP)	384 (522) at 2900 rpm
Aspiration	Twin entry turbo and compressor
Dry weight (set), kg	1410
Propeller series	NS4-NS5, N1-N7
Voltage	24V
Fuel consumption, l/h	110 at 2900 rpm; 20 at 1500 rpm

Pod propulsion set Volvo Penta DS-IPS700
[www.volvopenta.com]

- Structural scantling was calculated according to the empirical formulas developed by Dave Gerr, author of book "*The Elements of Boat Strength for Builders, Designers and Owners*" ,

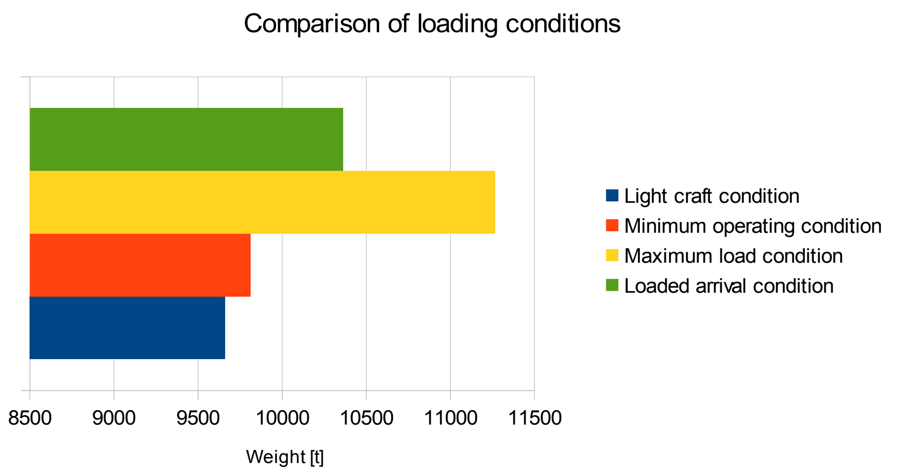
- Optimisation of scantling was done and in HullScant software developed by Wolfson Unit MTIA. This software was also used to check, if scantling structural properties meet the ISO 12215-5 rules requirements.



REFERENCE TABLE	
A	Transom
B	Girder not at the engine mount
C	Girder at the engine mount
D	Watertight bulkhead
E	Transverse frame
F	Side longitudinal stringer
G	Hull longitudinal stringer
H	Deck transverse stringer
I	Deck longitudinal stringer
	Bottom
	Chine
	Topsides

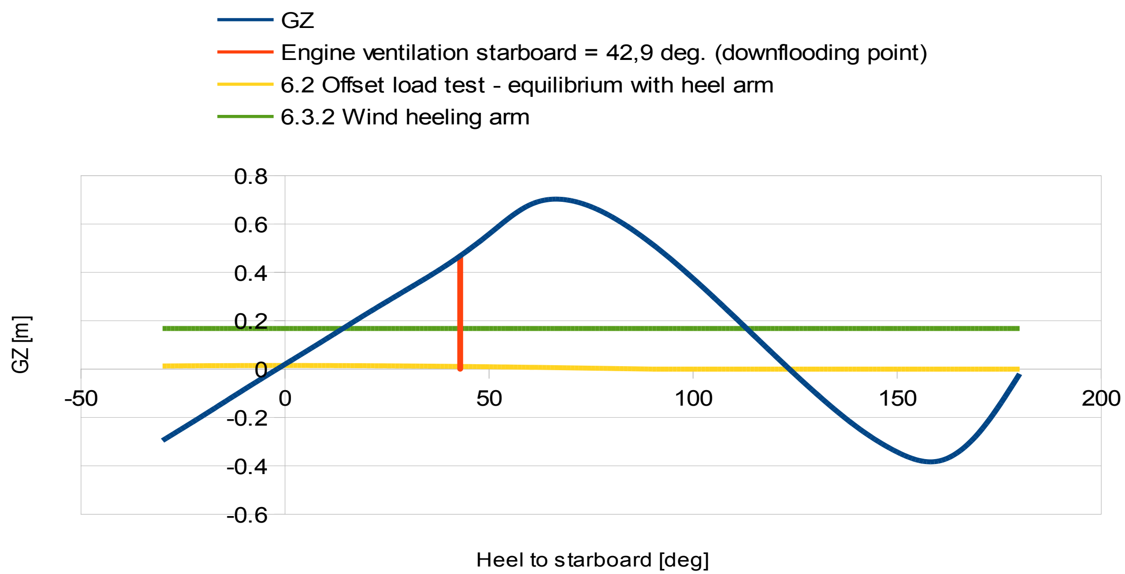
- Weight estimation was done in order to define center of gravity of ship which is required for stability assessment,
- Because it is initial design, the weights were approximated with use of safety margins,
- Load conditions were defined according to ISO 12217-1 rules:
    - light craft condition – empty craft condition plus standard equipment,
    - minimum operating condition – boat in the light craft condition plus crew and non-edible stores,
    - maximum load condition – boat in the light craft condition with the added maximum load,
    - loaded arrival condition – boat in the maximum load condition minus 85% of maximum capacity of tanks and minus 90% of edible stores.

Condition	Light craft	Minimum operating	Maximum load	Loaded arrival
Weight [kg]	7572,05	7722,05	9135,05	8261,55
Weight with margin [kg]	9661,40	9811,40	11267,40	10360,80
LCG [m]	3,33	3,33	3,63	3,51
TCG [m]	-0,02	-0,01	-0,01	-0,01
VCG [m]	1,02	1,04	1,06	1,07



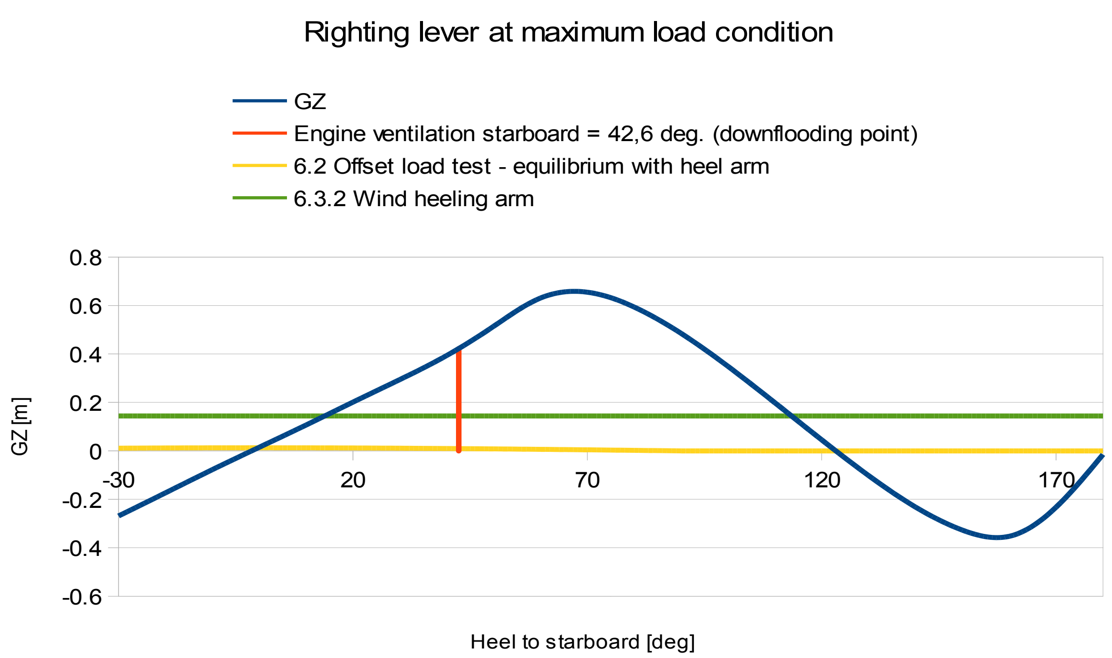
Stability results at light craft condition					
Criteria	**Value**	**Units**	**Actual**	**Status**	**Margin %**
6.1.2 Downflooding height at equilibrium	0,750	m	0,875	Pass	+16,67
6.2 Offset load test (heel at equilibrium)	15,0	deg	-2,0	Pass	+113,15
6.2 Offset load test (required freeboard at equilibrium)	0,750	m	0,875	Pass	+16,67
6.2 Offset load test (equilibrium with heel arm)	15,0	deg	-0,5	Pass	+103,29
6.3.2 Rolling in beam waves and wind	100	%	137,39	Pass	+37,39
6.3.3 Resistance to waves (Value of GZ)	0,200	m	0,330	Pass	+65,0
6.3.3 Resistance to waves (value of RM)	7000	Nm	31275,7	Pass	+346,8

Righting lever GZ at light craft condition

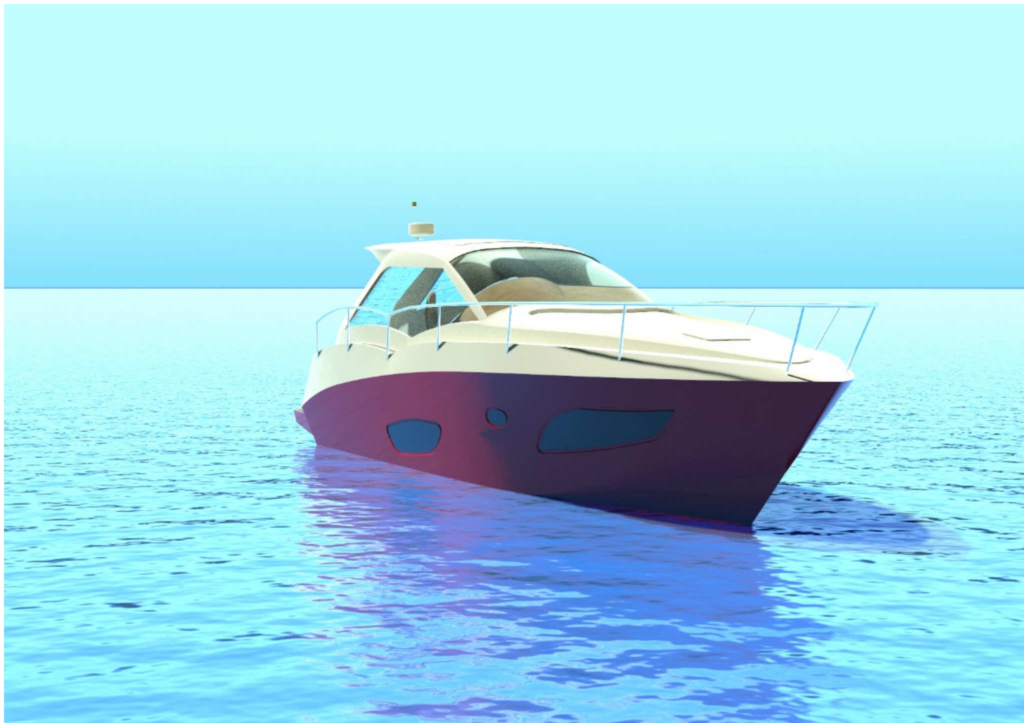


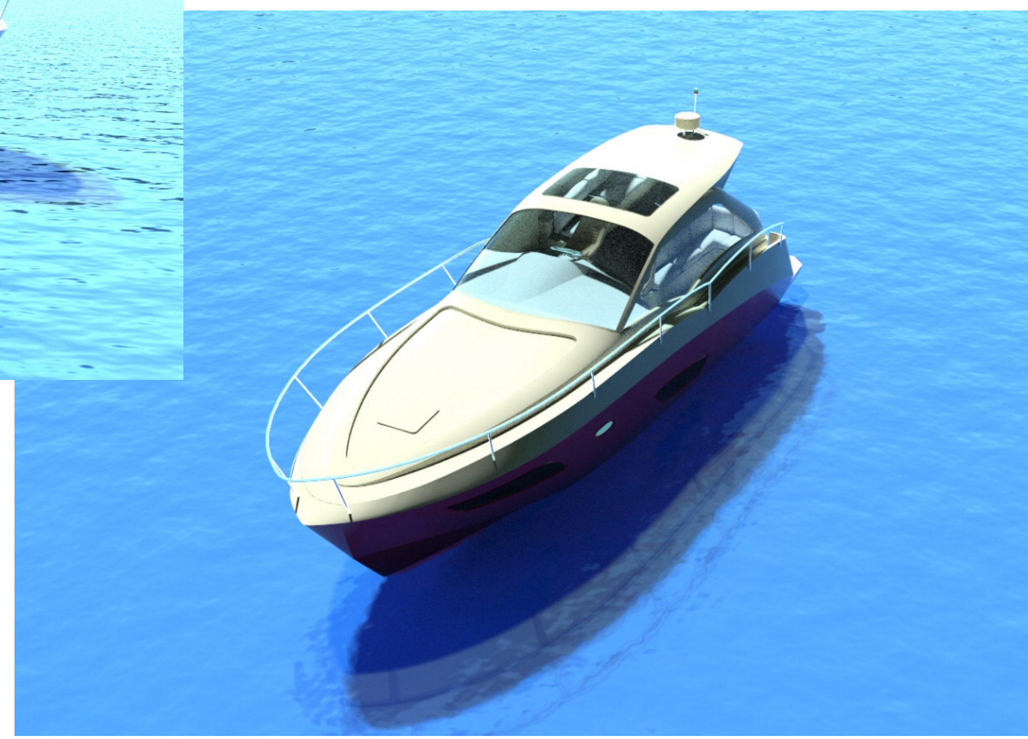
- Stability was assessed with use of Maxsurf Stability software,
- Assesment was done according to ISO 12217-1 rules requirements for four load cases specified previously,
- Required tests by rules:
  - 6.1.2 – Downflooding height test,
  - 6.2 – Offset load test,
  - 6.3 – Resistance to waves and wind.

Stability results at maximum load condition					
Criteria	**Value**	**Units**	**Actual**	**Status**	**Margin %**
6.1.2 Downflooding height at equilibrium	0,750	m	0,853	Pass	+13,73
6.2 Offset load test (heel at equilibrium)	15,0	deg	-1,6	Pass	+110,84
6.2 Offset load test (required freeboard at equilibrium)	0,750	m	0,853	Pass	+13,73
6.2 Offset load test (equilibrium with heel arm)	15,0	deg	-0,2	Pass	+101,48
6.3.2 Rolling in beam waves and wind	100	%	142,18	Pass	+42,18
6.3.3 Resistance to waves (Value of GZ)	0,200	m	0,294	Pass	+47,0
6.3.3 Resistance to waves (value of RM)	7000	Nm	32520,5	Pass	+364,58

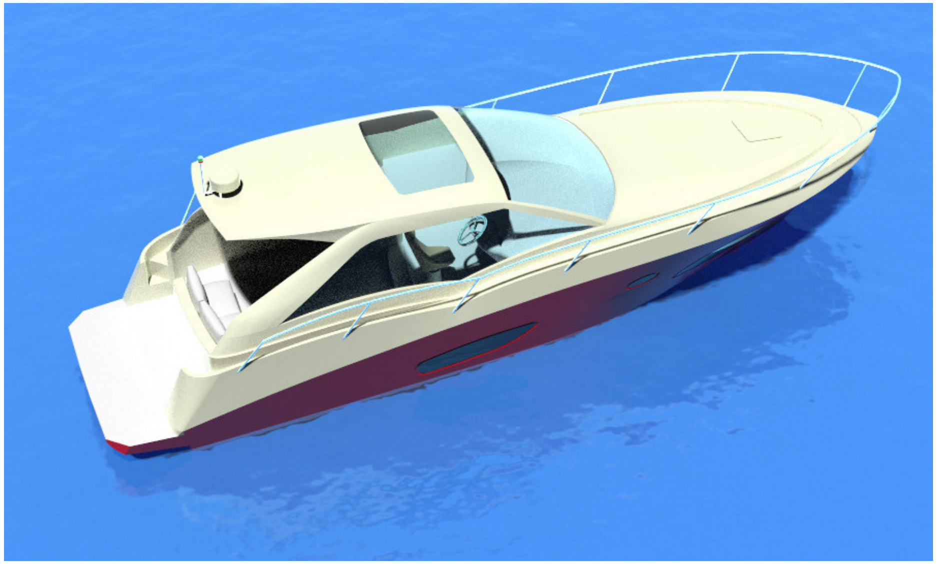


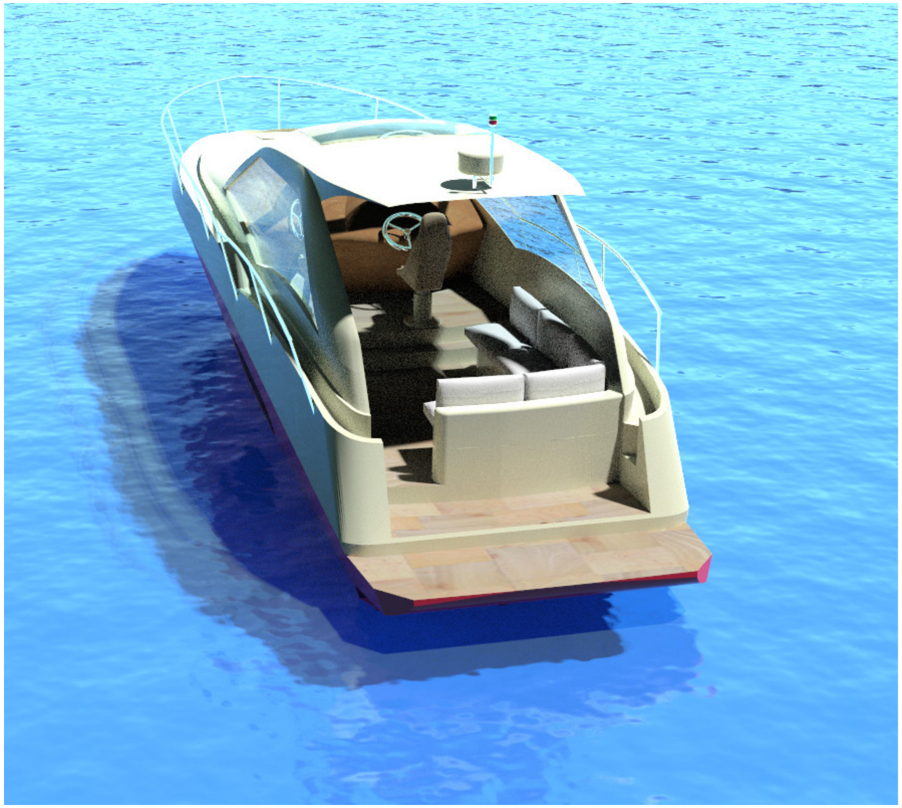
- 3D model was done in Rhinoceros 3D software with use of rendering engine Flamingo nXt



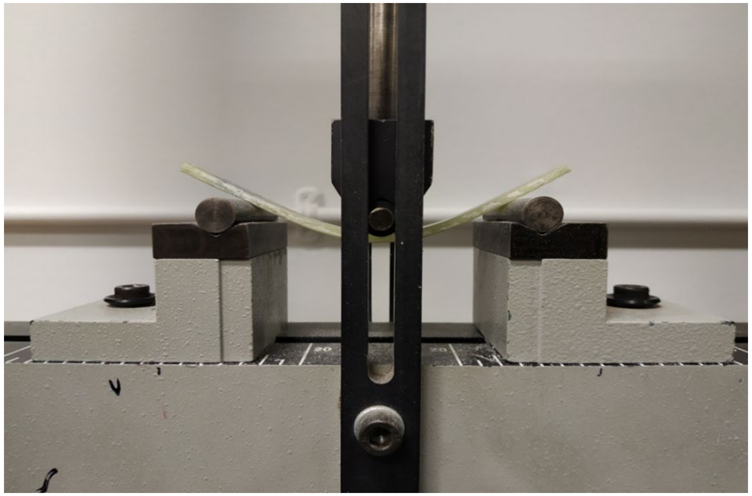


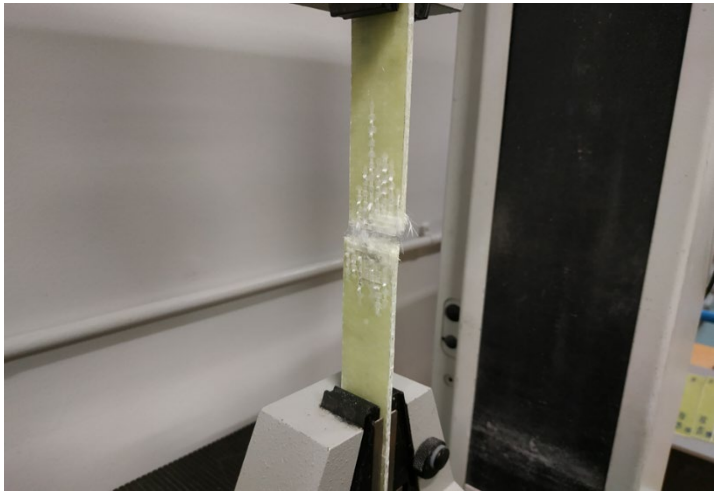
Initial design of a 40 feet motorboat with experimental composite testing





- Purpose of destructive tests was to determine mechanical properties of fibreglass laminates and then check their compliance with theoretical values calculated according to the ISO 12215-5 rules. Additionally the laminates were distinguished according to the production method on hand laminated and vacuum bagged. The tests were conducted for flexure, tensile and compression. To carry out them it was used a universal testing machine LLOYD LR 30K with maximum allowable load 5 kN.





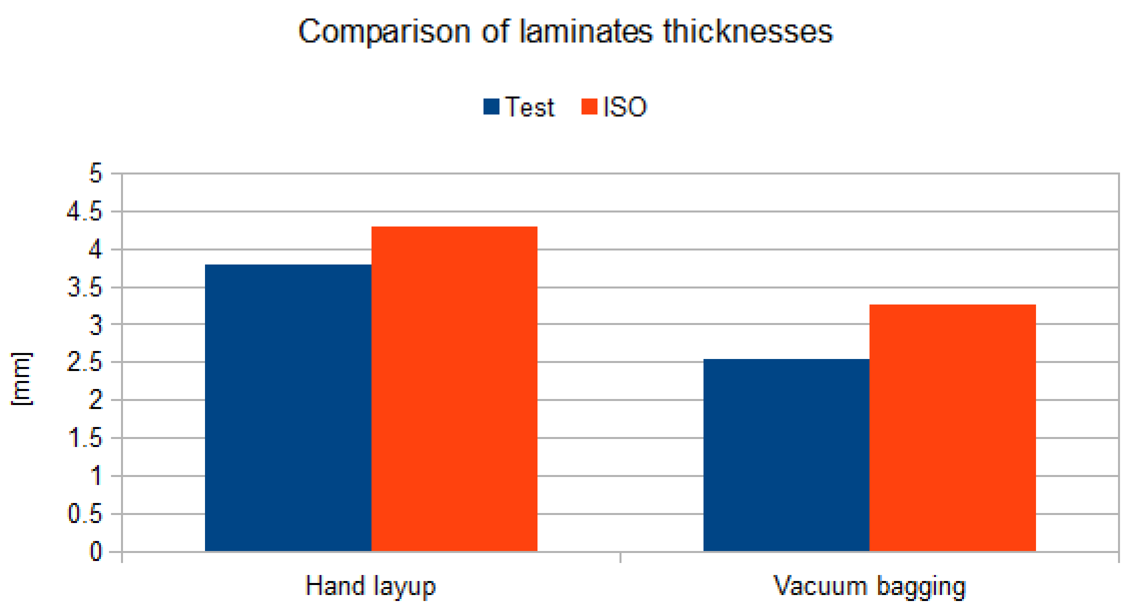
	CSM M 300	Woven-roving RE 290
Weight [g/m^2]	300	290
Thickness [mm]	0,8	0,35
Glass content by mass ψ (hand layup)	0,30	0,48
Glass content by mass ψ (vacuum bagged)	0,38	0,58
Density (wet) [kg/m^3]	1565	1816

- Reinforcement materials used in tested laminates

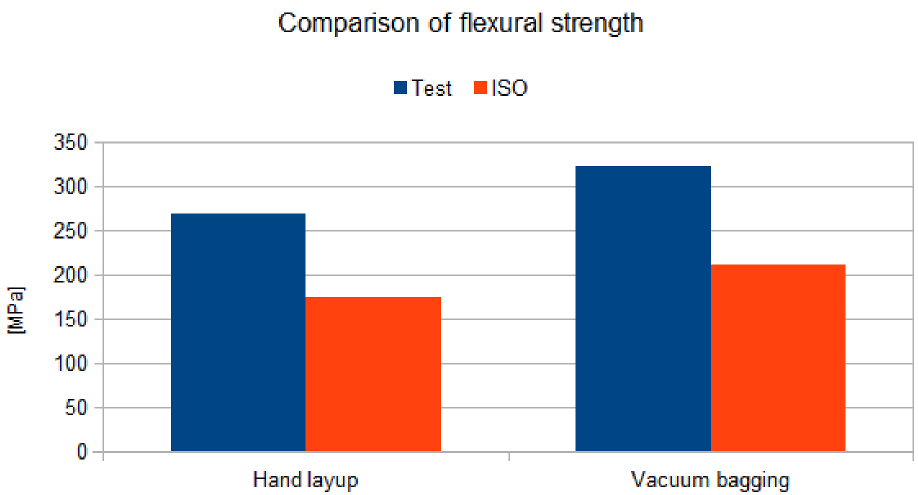
	Material	Number of layers	Layer thickness [mm]	Laminate thickness [mm]
Outer skin	RE 290	1	0,35	2,3
	Mat 300	1	0,8	
	RE 290	1	0,35	
	Mat 300	1	0,8	
Inner skin	RE 290	1	0,35	2,3
	Mat 300	1	0,8	
	RE 290	1	0,35	
	Mat 300	1	0,8	
			Total thickness [mm]	4,6

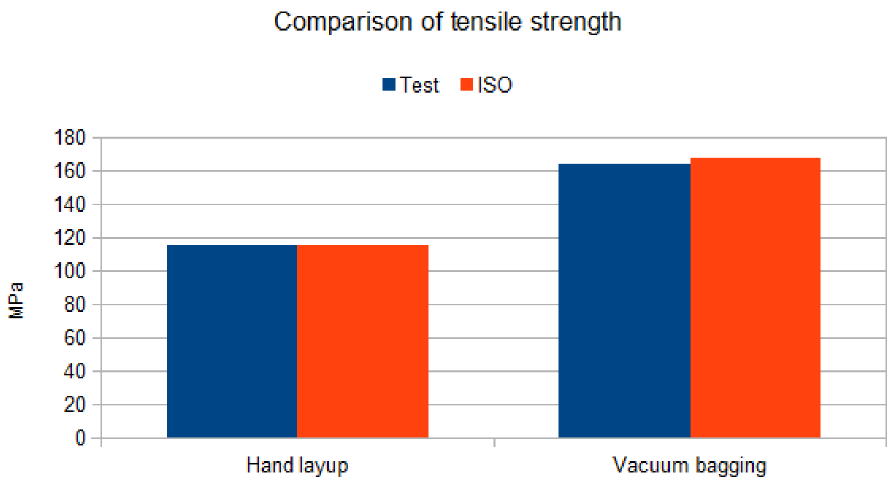
- Layout of tested laminate

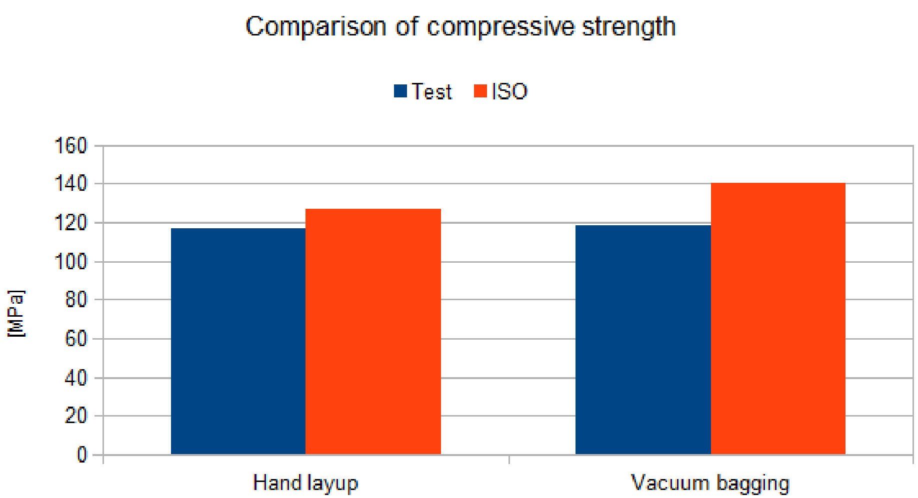
Comparison of laminates mechanical properties				
	Test		ISO 12215-5	
	Hand layup	Vacuum bagging	Hand layup	Vacuum bagging
Thickness [mm]	3,78	2,55	4,3	3,25
Flexural strength [MPa]	269,76	322,83	174,91	212,1
Tensile strength [MPa]	115,56	164,47	115,79	167,88
Compressive strength [MPa]	117,07	118,75	127,17	140,63



- Hand layup laminate is around 30% thicker than vacuum bagging







- Flexural strength of vacuum bagging laminate is higher around 16%,
- Tensile strength of vacuum bagging laminate is higher around 30%,
- Compressive strength almost similar for vacuum bagging and hand layup laminates.

- The designed boat meet ISO 12215-5 and ISO 12217-1 criteria for structure and stability,
- Design comply with safety rules ISO 15085 and fire protection rules ISO 9094,
- Design criteria are fulfiled (maximum speed 35 knots, 40 feet hull length, allowable 6 persons on board, 4 accommodation places, design category B, two engines),
- The design consist of all necessary aspects at initial stage such as hull form design, general arrangement, engine and propulsion system selection, main systems determination, structure calculations, weight estimation, stability assessment, technical drawings and 3D visualisation,
- The vacuum bagging method give around 30 % stronger laminate comparing to hand layup laminate at same layout of fabric,
- Vacuum bagging laminate can help to reduce weight of vessel and improve its performance, wherein the strength remain same or higher than for hand layup laminate,
- Values of compressive strength of tested laminate are lower than expected, because of problems with buckling occurring during the test,
- ISO rules give very close results to the reality.

Thank you