UNIVERSITÀ DEGLI STUDI DI GENOVA

Structural Design of a High Speed Motor Yacht in GRP by Rules and direct FEM analysis

"EMSHIP"

Erasmus Mundus Master Course

in "Integrated Advanced Ship Design"

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Developed at: Intermarine Spa

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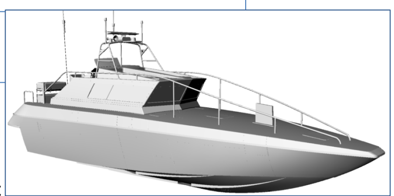
La Spezia, 03.02.2012

INTRODUCTION

GOAL

Develop a high speed motor yacht –type: "open"
Top speed - 55 knots

REFERENCE PROJECT



Intermarine, 13.2 meter, Fast Patrol Vessel
Top speed – 45 knots
Building material – Fiber Reinforced Plastic
Propulsion – 2 x 600HP diesel engines with waterjets

WORKFLOW

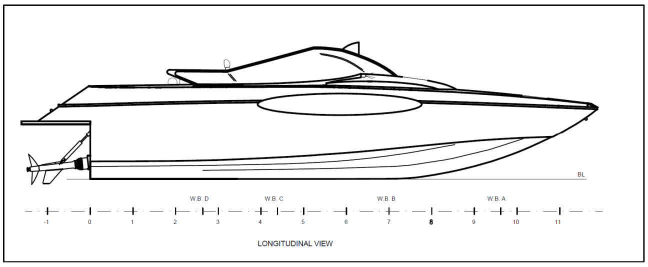
- General arrangement and Exterior redesign,
- Hydrodynamics and Propulsion,
- Structural design

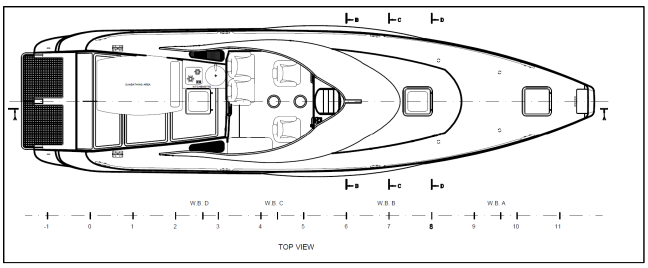
GENERAL ARRANGEMENT

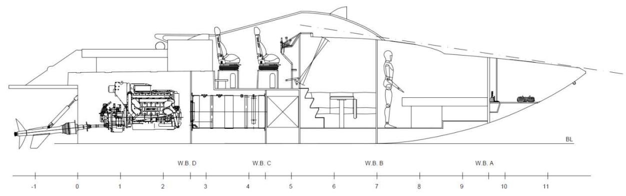
DESIGN PHILOSOPHY

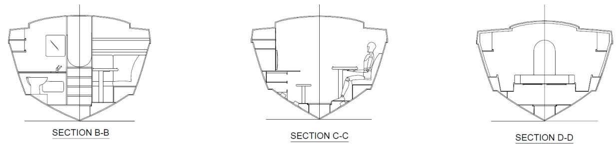
- Yacht is **performance orientated** designed for **2+2 passangers,** aiming at younger clients for weekend cruises, or to be used as a tender next to a larger yacht for day trips.
- The "aggressiveness" of the hull an the design compromises comfort.

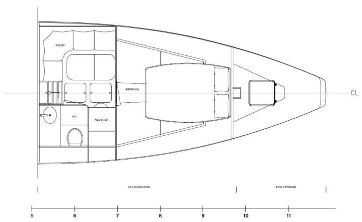
- High speed motor yacht 3D model is generated using Rhinoceros NURBS modeling software



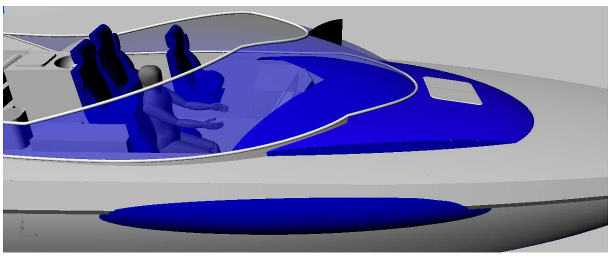








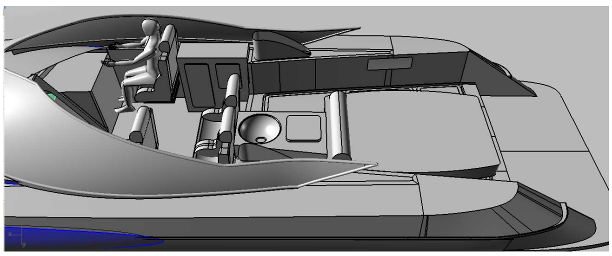
L_{OA}	13,500	m	Lenght Overall
L_{WL}	10,289	m	Lenght of waterline measured with the craft at rest in calm water
V	55,000	kn	Maximum service speed
T	0,740	m	Draught of the craft, in m, measured vertically on the transverse section at the middle of length L, from the moulded base line of the hull to the full load
Δ	10,700	t	Displacement
B	3,350	m	The greatest moulded breadth, in m, measured on the waterline at draught T
a_{CG}	18,000	°	Deadrise angle, in degrees, at LCG, to be taken between 10° and 30°,
C_B	0,486	-	Total block coefficient (as per FPV.B.Ch 1.Sec 2 [2.1.1])



Elevated part of the deck in front of the windshield:
- Ensures more space inside
- Provides estheticaly a 'dampening element' between the deck angle and the windshield angle longitudinally

Bumper
- A semi-elliptic integrated inflatable tube as in RIB boats
- Follows the curvature of the elevetad part of the deck (blue)

Windshield :
- Double-curvature multi-layered tinted glass enclosed with a stainless steel pipe
- Low profile to minimize air drag
- Backwards it ends abruptly in a retro style manner ensuring a dynamic look

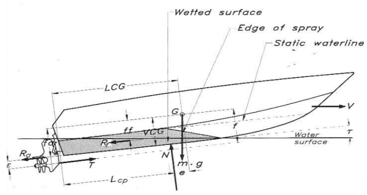


Cockpit and sunbathing area

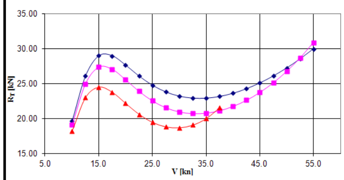
HYDRODYNAMICS AND PROPULSION

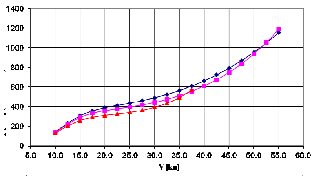
SAVITSKY METHOD

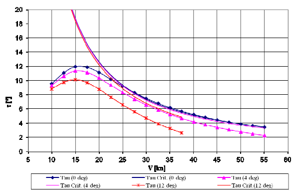
- Preliminary resistance evaluation and behavior for a high speed planing craft
- Max. Speed = 55 kn ⟶ Fn = 6.2



Results are derived for three different trim tab positions:
0 deg 4 deg 12 deg







2 x Seatek 820HP diesel engines (OPC ≈ 0.7) chosen. Porposing problem detected!

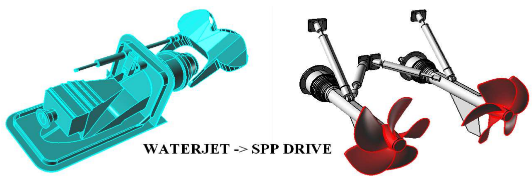
PORPOISING SOLUTIONS

• Using dynamically computer controlled trim tabs to correct the vessel's trim based on the acceleration data acquired from the gyroscopic sensor.

• Moving the center of gravity backwards to reduce the bow-down moment which arrives from coupling the weight G and the bottom pressure resultant N.

• Prolonging the sprayrails backwards, if possible, to enclose the flow between them making the pressure area narrower and moving the center of pressure forwards, thus reducing the bow-down moment described in the previous point.

All three solutions are applicable with Arnesson **Surface Piercing Propeller** drive!



MATERIALS AND TECHNOLOGY

FIBER REINFORCED PLASTIC

- Various fiber reinforcements combined with a resin matrix to produce a tailor-made material, locally customizable.

RESIN

Vinyl ester resin – suitable for infusion

LAMINATE SKINS

- **0/90° Glass 1225 kg/m²**
  ± 45° Glass 1225 kg/m²
- **MAT 450 kg/m²**
- **MAT 225 kg/m²**

STIFFENERS

- **+/- 45 Glass - Carbon hybrid 820 kg/m²**
- **UNITAPE Carbon 820 kg/m²**

SANDWICH CORE

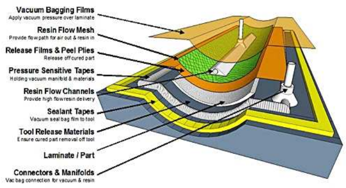
- **BALSA CORE 150 kg/m³**

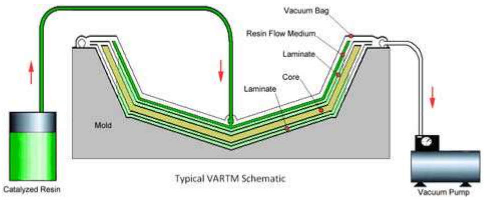
STIFFENER CORE

- **Polyurethane foam**

VACUUM INFUSION

- Liquid, catalyzed, low-viscosity resin is forced into a reinforced mold by means of low pressure





- Better fiber to resin ratio,
- Stronger laminate,
- Low void content,
- Reduces operator exposure to harmful emissions,
- Reduced resin usage due to pre-compacted fabric,
- Faster ply lay-up,

SCANTLING BY RULES

RULES

Scantling has been defined in accordance with **RINA FPV 2007** (Fast Patrol Vessel) Code, and **RINA HSC 2002** (High Speed Craft) Code, on which the previous is depending on.

HULL SCANTLING – CONSTRUCTION PHILOSOPHY

- **Hull bottom –** Single-skin, glass fiber, stiffened plating
  Heavier and more flexible - accounts for lower overall center of gravity hull, it is able to withstand high loads from accelerations and slamming forces.

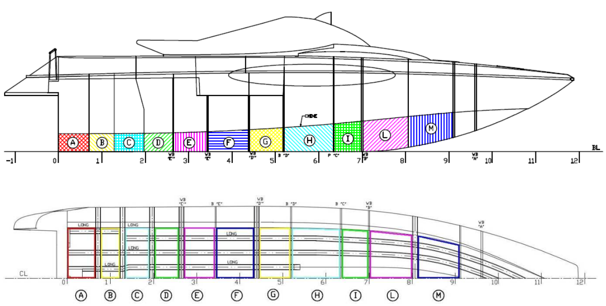
- **Hull sides** – Balsa sandwich with skins in glass fiber
  Stiffer and lower-weight structure in respect to the single skin bottom.

- **Stiffeners** – Top hat, hybrid glass/carbon and carbon reinforcement with PU foam core
  Unitape reinforcement in the stiffener heads ensures excelent directional properties as far as possible from the neutral line.

Scantling calculation was automated with MS Excel, and the lamination scheme and schedule was optimized in an interative maner!

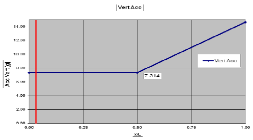
BOTTOM PLATING

Bottom, single skin, plating is checked verified plate by plate against:
- Minimum allowed thickens;
- Maximum allowed bending stress due to the design pressure (slaming/impact);
- Maximum allowed deflection.



Area of navigation is defined to be unrestricted.
Saftey factor applied according to the Rules equals to 4,5.

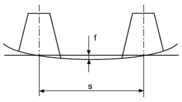
BOTTOM PLATING REPORT



Equivalent laminate properties:

PLY	MATERIAL	ti (mm)	Ei (MPa)
1	0/90 GLASS 1225	1.16	23000
2	0/90 GLASS 1225	1.16	23000
3	0/90 GLASS 1225	0.97	26900
4	0/90 GLASS 1225	0.97	26900
5	0/90 GLASS 1225	0.97	26900
6	+/-45 GLASS 1225	0.97	18000
7	+/-45 GLASS 1225	0.97	18000
8	+/-45 GLASS 1225	0.97	18000
9	0/90 GLASS 1225	0.97	26900
10	0/90 GLASS 1225	0.97	26900
11	0/90 GLASS 1225	0.97	26900

Material	number	t_i [mm]	t_{tot} [mm]
MAT 450	2	1.13	2.26
0/90 GLASS 1225	5	0.97	4.85
±45 GLASS 1225	3	0.97	2.91
0/90 GLASS 1225	3	0.97	2.91
total thickness (mm)			13.31
minimum thickness (mm)			6.76

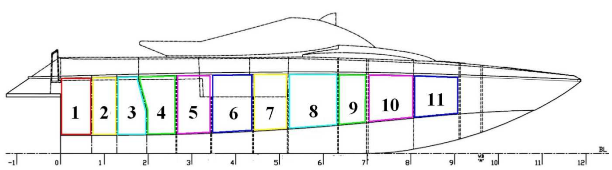


PANEL	A	B	C	E	D	F	G	H	I	L	M
x [m]	0.346	0.978	1.628	2.335	3.064	3.894	4.817	5.768	6.665	7.515	8.617
αd [°]	19.150	19.334	19.430	19.820	20.600	21.940	23.890	26.880	30.000	30.000	30.000
s [m]	0.419	0.419	0.235	0.235	0.235	0.240	0.245	0.235	0.246	0.235	0.230
l [m]	0.652	0.452	0.565	0.610	0.668	0.938	0.668	1.131	0.636	1.042	1.042
MAT 450	2	2	2	2	2	2	2	2	2	2	2
0/90 E 1225	5	4	4	4	4	4	4	4	4	4	4
±45 E1225	3	3	-	-	-	-	-	-	-	-	-
0/90 E 1225	3	3	3	3	3	4	4	4	4	4	3
thk tot	13.31	12.15	9.05	9.05	9.05	10.02	10.2	10.2	10.2	10.2	9.05
thk min	6.76	6.76	6.76	6.76	6.76	6.76	6.67	6.67	6.67	6.67	6.67
Etot	23737	23824	25786	25786	25786	25925	25925	25925	25925	25925	25786
V	5.56	4.97	3.4	3.4	3.4	3.88	3.88	3.88	3.88	3.88	3.4
EI	2.8E+06	2.1E+06	7.0E+05	7.0E+05	7.0E+05	1.0E+06	1.0E+06	1.0E+06	1.0E+06	1.0E+06	7.0E+05
I	112.45	80.62	26.09	26.09	26.09	38.94	38.94	38.94	38.94	38.94	26.09
K	17	17	17	17	17	17	17	17	17	17	17
σ_{BR}	422.5	433.3	480	480	480	480	480	480	480	480	480
Kv	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.210	1.296	1.461	1.675
av	7.314	7.314	7.314	7.314	7.314	7.314	7.314	8.200	9.476	10.684	12.251
S	0.273	0.189	0.133	0.143	0.157	0.225	0.164	0.266	0.156	0.245	0.24
u	2.699	1.871	1.312	1.416	1.551	2.224	1.617	2.626	1.546	2.419	2.368
K_1	0.534	0.595	0.658	0.727	0.798	0.878	0.968	1	1	1	0.906
K_2	0.500	0.5	0.512	0.502	0.5	0.5	0.5	0.5	0.5	0.5	0.5
K_3	0.978	0.974	0.973	0.965	0.95	0.924	0.887	0.829	0.769	0.769	0.76
p [kN/m^2]	141.2	156.9	177.3	190.6	205.1	219.7	232.3	224.4	208.2	208.2	188.7
μ_1	0.93	0.68	1	1	1	1	1	1	1	1	1
a	0.40	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
rc	1.00	1	1	1	1	1	1	1	1	1	1
ks	0.37	0.27	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
SF	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
σd	102.0	38.6	42.5	45.7	49.1	42.0	46.3	41.2	41.8	38.2	43.3
σde	106.7	106.7	106.7	106.7	106.7	106.7	106.7	106.7	106.7	106.7	106.7
μ2	0.90	0.55	1	1	1	1	1	1	1	1	1
f	3.64	3.4	2.01	2.16	2.32	1.81	2.08	1.7	1.9	1.58	1.96
fmax	4.19	4.19	2.35	2.35	2.25	2.4	2.45	2.35	2.46	2.35	2.3

SIDE PLATING

Hull side, sandwich, plating is verified and has satisfied against:

- Minimum allowed thickens of the skins (interior and exterior);
- Maximum allowed bending stress due to the design pressure (sea pressure) of each ply in the skins.
- Maximum allowed shear stress of the sandwich core.
- Maximum allowed deflection of the skins.



Equivalent laminate properties:

PLY	MATERIAL	THK [mm]	MODULUS [N/mm2]	$(EI)_i$ [Nmm2/mm]	$(I)_i$ [mm4/mm]
1	MAT 450	1.13	8050	807089	100.260
2	MAT 450	1.13	8050	625176	77.662
3	0/90 GLASS 1225	0.97	26900	1367421	50.833
4	0/90 GLASS 1225	0.97	26900	1025796	38.134
5	BALSA CORE 150Kg/m^3	12.7	4070	711610	174.843
6	MAT 225	0.65	8050	274932	34.153
7	0/90 GLASS 1225	0.97	26900	1695561	63.032
8	0/90 GLASS 1225	0.97	26900	2127922	79.105

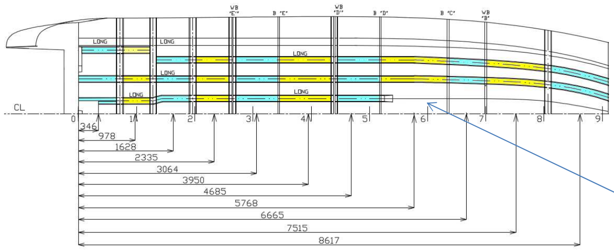
Material	number	t_i [mm]	t_{tot} [mm]
MAT 450 (ext)	2	1.13	2.26
0/90 GLASS 1225 (ext)	2	0.97	1.94
BALSA CORE 150Kg/m^3	1	12.7	12.7
MAT 225 (int)	1	0.65	0.65
0/90 GLASS 1225 (int)	2	0.97	1.94
total thickness - exterior skin		**[mm]**	4.20
total thickness - interior skin		**[mm]**	2.59
minimum skin thickness		**[mm]**	2.25

Ply	Material	σ_d		σ_{de}
1	MAT 450	2.69 MPa	<	16.33 MPa
3	0/90 GLASS 1225	9.99 MPa	<	80.00 MPa
6	MAT 225	2.03 MPa	<	16.33 MPa
8	0/90 GLASS 1225	8.50 MPa	<	80.00 MPa

LONGITUDINAL STIFFENERS

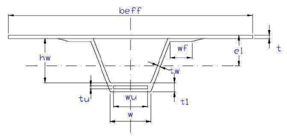
Longitudinal, bottom, stiffeners are verified and has satisfied against:

- Allowable bending stress
- Allowable shear stress



Stiffener is interrupted and the accomodation modul fitting continuest to play the structural element ensuring the same rigitdity (EI) .

Equivalent laminate stiffener properties with associetad plating properties



	Material	N°	ti [mm]	t tot [mm]
wf	+/- 45 Glass Carbon 820	4	0.90	3.6

	Material	N°	ti [mm]	t tot [mm]
tw	+/- 45 Glass Carbon 820	4	0.90	3.6

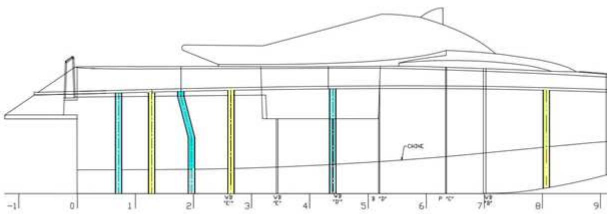
	Material	N°	ti [mm]	t tot [mm]
t1	+/- 45 Glass Carbon 820	2	0.90	1.8
	MAT 225	1	0.65	2.45
	UNITAPE 820 Carbon	3	1	5.45
	+/- 45 Glass Carbon 820	2	0.90	7.25

	Material	N°	t_i [mm]	t_{tot} [mm]
t	MAT 450	2	1.13	2.26
	0/90 GLASS 1225	8	0.97	10.02
	±45 GLASS 1225	3	0.97	12.93

TRANSVERSAL STIFFENERS

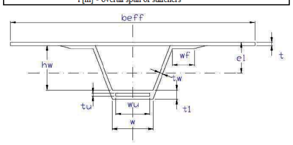
Transversal stiffeners are verified and has satisfied against (**same as longitudinals**):

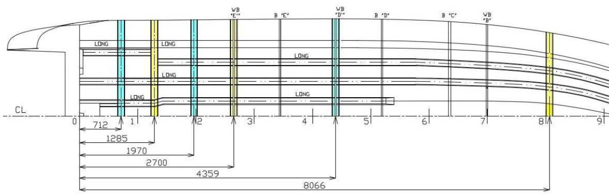
- Allowable bending stress
- Allowable shear stress



STIFF	trans 712	trans 1285	trans 1970	trans 2700	trans 4359	trans 8066
x[m]	0.712	1.285	1.97	2.7	4.359	8.066
αd [°]	19.150	19.330	19.580	20.160	22.870	30.000
s [m]	0.642	0.619	0.708	0.729	0.863	1.042
l [m]	1.360	1.362	1.364	1.370	1.401	1.040

x[m] - distance from AP to the center of the panel
αd [°] - deadrise angle
s [m] - spacing of stiffeners, measured along the plating
l [m] - overall span of stiffeners





	Material	N°	ti [mm]	t tot [mm]
wf	+/- 45 Glass Carbon 820	5	0.9	4.5

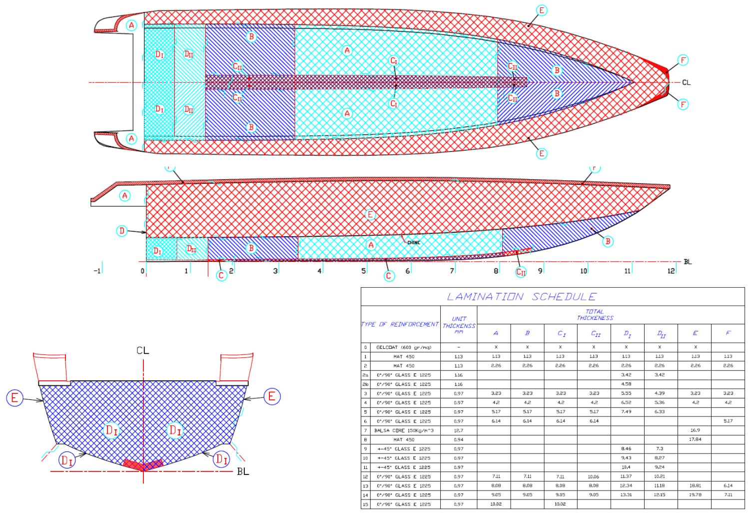
	Material	N°	ti [mm]	t tot [mm]
tw	+/- 45 Glass Carbon 820	5	0.9	4.5

	Material	N°	ti [mm]	t tot [mm]
t1	+/- 45 Glass Carbon 820	2	0.9	1.8
	MAT 225	1	1	2.8
	UNITAPE 820 Carbon	4	0.65	5.4
	+/- 45 Glass Carbon 820	3	0.9	8.1

	Material	N°	t_i [mm]	t_{tot} [mm]
t	MAT 450	2	1.13	2.26
	0/90 GLASS 1225	7	0.97	9.05

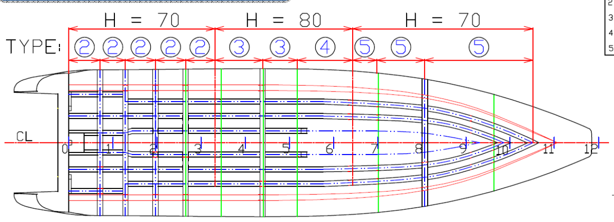
STRUCTURAL DRAWINGS

LAMINATION SCHEME AND SCHEDULE

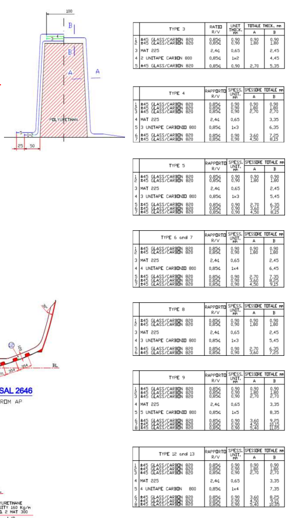


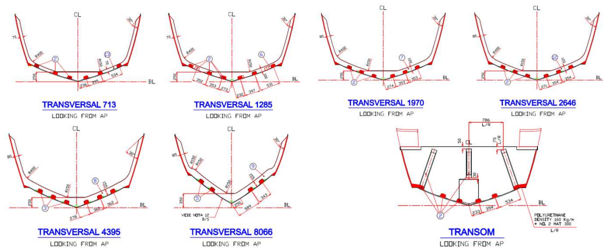
HULL STRUCTURE

	REINFORCEMENT TYPE	RATIO R/V	UNIT THICK. mm	TOTALE THICKNESS A	TOTALE THICKNESS B
1	±45 GLASS/CARBON 820	0,85:1	0,90	0,90	0,90
2	±45 GLASS/CARBON 820	0,85:1	0,90	1,80	1,80
3	MAT 225	2,4:1	0,65		2,45
4	1 UNITAPE CARBON 800	0,85:1	1x1		3,45
5	±45 GLASS/CARBON 820	0,85:1	0,90	2,70	4,35



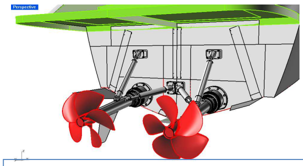
	REINFORCEMENT TYPE												
	1	2	3	4	5	6	7	8	9	10	11	12	13
h	70	70	80	80	70	100	120	155	155	70	85	120	70
b	120	120	120	120	120	120	120	120	120	120	120	120	120
W	100	100	100	100	100	100	100	100	100	100	100	100	100
Wf	50	50	50	50	50	50	50	50	50	50	50	50	50
t	3,5	2,5	2,5	4,5	3,5	4,5	4,5	5,5	4,5	2,5	2,5	5,5	5,5
t_1	3,5	4,5	5,5	8	7,5	9,0	9,0	11	8,0	5,5	5,5	10	10



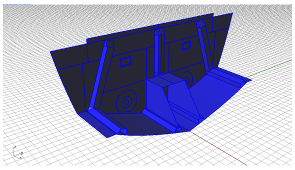


FINITE ELEMENT ANALYSIS - TRANSOM

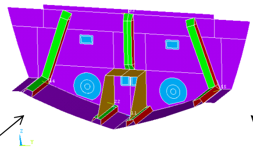
MODEL AND SECTION DEFINITION



Arnesson SPP drive and transom CAD surface model



The transom structure model to be exported for a FEM simulation was carefully divided in regions (on area per regions), each region defined by a different lamination



Transom model verified after import and divided in sections

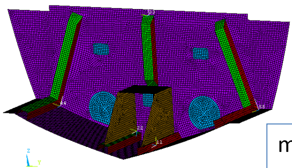
SECTION		MATERIAL ID LAYOUT			
Name	ID	Layer 1	Layer 2	Layer 3	Layer 4
Transom	2	-	7	12	7
Stiffener side	3	-	4	-	-
Connections	4	1	7	12	7
Stiffener head	6	-	4	5	4
Bracket	7	-	7	-	-

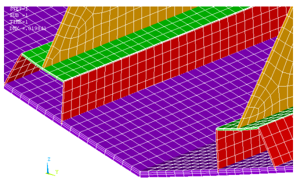
Transom model verified after import and divided in sections

MATERIAL	STEEL	G/C HYBRID	UNITAPE CARBON	0/90 GLASS	+/-45 GLASS
MAT ID	1	4	5	7	12
EX	2.10E+11	2.65E+10	1.02E+11	1.33E+10	1.73E+10
EY	isotropic	2.65E+10	3.00E+09	1.40E+10	1.69E+10
EZ	isotropic	2.65E+10	3.00E+09	4.20E+09	4.20E+09
NUXY	0.32	0.2	5.88E-03	0.21038	0.19572
NUYZ	isotropic	0.2	0.2	6.00E-02	4.96E-02
NUXZ	isotropic	0.2	5.88E-03	6.32E-02	4.86E-02
GXY	-	2.10E+09	2.10E+09	4.03E+09	4.49E+09
GYZ	-	2.10E+09	2.10E+09	1.75E+09	1.75E+09
GXZ	-	2.10E+09	2.10E+09	1.75E+09	1.75E+09
DENS	7850	1000	1000	1555	1650
PRXY	0.32	0.2	0.2	0.2	0.2
PRYZ	isotropic	0.2	0.2	0.2	0.2
PRXZ	isotropic	0.2	0.2	0.2	0.2

Material ID and properties used for section definition in FEM calculation

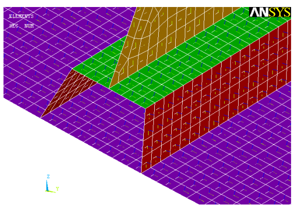
MESH

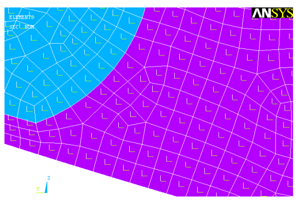




Section shape turned on for different layer perception

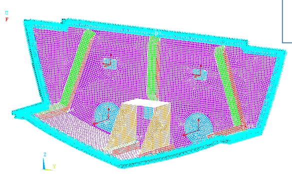
mesh element type: SHELL181
number of elements: 19282
Base element type: Quad
Base size: 0.02 meters





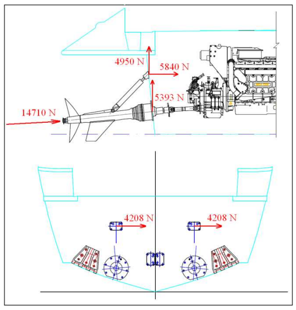
Element local coordinate system

BOUNDARY CONDITIONS



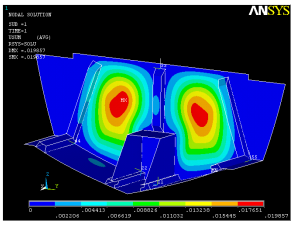
Displacement of nodes has been prohibited in all directions (UX, UY, UZ). Rotation is allowed.

LOAD CASE



Loads from the SPP drive acting on the transom. Provided by Arnesson.

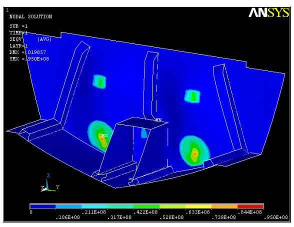
DEFLECTIONS



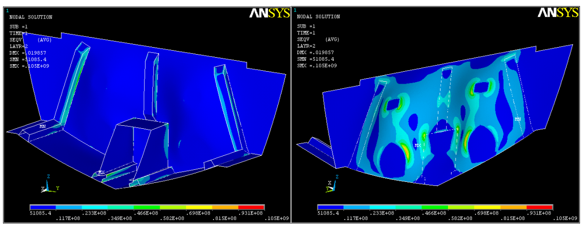
Displacement vector sum. Max. = 17mm

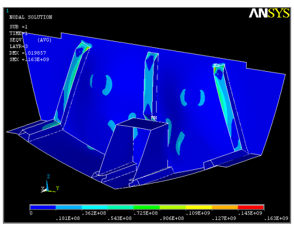
VON MISES STRESS DISTRIBUTION

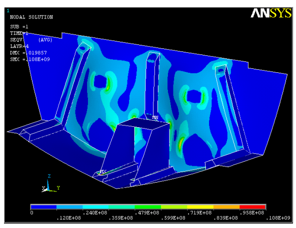
LAYER 1: Connection plates – Steel



LAYER 2: Transom, Bracket, Connections – 0/90 Glass knitted rowing; Stiffener sides, Stiffener heads – Glass/Carbon Hybrid rowing







LAYER 3: Transom, Connections – ±45 Glass rowing;
Stiffener head – Unitape carbon

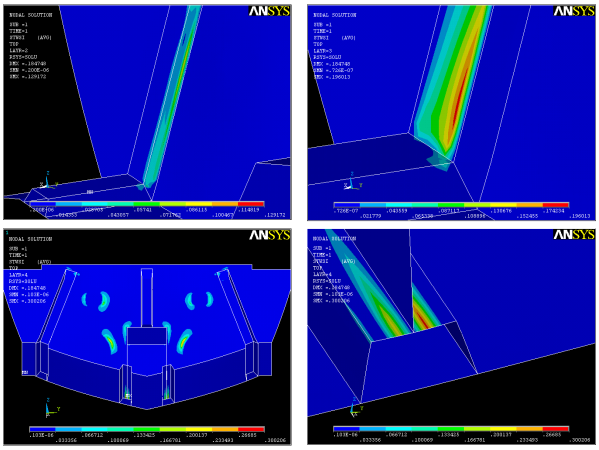
LAYER 4: Transom, Connections – 0/90 Glass rowing; Stiffener heads – Glass/Carbon Hybrid rowing

TSAI-WU FAILURE CRITERIA

Common and generally conservative predictor of ply failure. A failure index is essentially the inverse of a safety factor. A value of 1.0 indicates the onset of first ply failure.

Layer 2

Layer 3



Layer 4

Layer 4
maximum effect detail
max = 0.26

CONCLUSION

A high speed, 55 knot, motor yacht concept has been developed.
Several areas have been studied:

- General arrangement and exterior design,
- Hydrodynamics and propulsion,
- Structural design.

Structural design has been determined according to RINA rules and by means of FEM simulation. Strucural drawings have been provided.

Future work on the project should address other yacht design areas and altogether should be furthermore refined following the design spiral to create a competitive project.

Structural Design of an High Speed Motor Yacht in GRP by Rules and direct FEM analysis

THANK YOU FOR YOUR ATTENTION!