A HIGH-SPEED CRAFT WITH COMPOSITE HULL

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ABSTRACT

An existing ship construction, Transport Ship 2000, developed and owned by FMV, have been modified for civil passenger usage in coastal traffic. New ship specification, general arrangement and insulation plans have been established. Four different ship versions have been studied. The influence of lighter insulated hulls on the ships performance, have been analysed. Composite hulls show a competitive purchase price and low LCC, for this application. Version 3A is the most promising compared to the reference ship (Version 0) with predicted 52 % lower structural weight for the hull, 43 % lower weight for the insulated hull, 30 % lower empty insulated hull production cost, 26 % lower ship production cost, 21 % lower LCC for 20 years service and similar ship performance for the intended usage.

1. INTRODUCTION

Composite materials have been the preferred hull material choice for small boats, during the recent 40 years. An indicated trend is that the usage will spread to smaller ships and structures in larger ships. Advances in materials- and manufacturing technology during the recent 10-15 years strengthens this trend. Of primary importance is here the general introduction of the vacuum infusion process in the ship building industry. This enables important improvements regarding material quality, system weight, manhour reductions, production cost, etc.

2. EXISTING HIGH-SPEED CRAFT

The Swedish LÄSS project (light weight construction applications at sea, www.lass.nu) has studied the influence of light-weight design, using both composite and aluminium materials, on several concept ships. One such concept ship is a 24 m aluminium high speed craft with a fully loaded speed of 27.5 knots, see Figure 1. It was designed to be built in a series of some 20 ships. Only two were in fact built due to military budget cuts. The relatively small size together with the high speed, makes it a suitable object for light-weight design. The existing modern military transport ship (Transport Ship 2000), made from aluminium, has been derived into several civil versions to enable comparisons regarding production cost and Life Cycle Cost (LCC).

Figure 1: Military Transport Ship 2000.

3. PROJECT GOAL

The project goal was to convert the aluminium ship to civil DNV-standard as reference ship, then design a corresponding composite ship with 30 % lower structural weight for the insulated hull, similar ship performance and 25 % lower production cost and LCC for 20 years service.

4. PROCEDURE

Development was concentrated on the empty hull including insulation. Systematic design of several ship versions towards the same specification and ship standard was performed to quantify the function and value of lightweight construction for high-speed ships of this size. The existing military aluminium ship, developed and owned by the Swedish Defence Material Administration, have been modified for civil passenger usage. New specification, general arrangement and insulation plans for the different ship versions were established.

5. SHIP SPECIFICATION

A new ship specification was established [1]. Some main requirements are:

- 36 passengers and 3 crews.
- 10 ton load displacement.
- 3 or 2 water jet propulsions.
- Developed for production of 20 ships.
- Utilisation cycle: 20 years service. 3000 yearly running hours. 26 knots normal loaded operational speed with 80 % running time. 20 knots loaded operational speed with 10 % running time. 10 knots loaded operational speed with 10 % running time.

6. SHIP VERSIONS

The new general arrangement drawing is in Figure 2. The separate 4 m^3 fuel tank in Version 0 have 600 kg in structural weight. The composite ships have hull integrated fuel tanks which approximately saves these 600 kg. The same type of water jet machinery is used in all versions to enable comparisons without influences from differing machinery performance. One machinery unit consists of a Scania DSI 14 68M diesel engine with a maximum power of 460 kW, which drives a water jet propulsion unit. These machineries are a dominant part of the ship with a unit weight for engine plus water jet propulsion, of 3080 kg and a unit price of 250 kEuro. Version 0, 1, 3 have three water jet propulsions. Version 3A has two water jet propulsions and 33 %

smaller fuel tanks. The smaller fuel tank translates into a reduction of the loaded displacement by 1100 kg, due to reduced fuel weight. More fire insulation is used in the composite ship versions compared to the aluminium ship due to DNV HSLC-code regulations. The composite ships are manufactured using vacuum infusion in separate tools.

The following ship versions were studied [2]:
Version 0: aluminium.
Version 1: Sandwich with glass/vinylester.
Version 3: Sandwich with carbon/vinylester.
Version 3A: Version 3 with two water jet propulsions and 33 % smaller fuel tank.

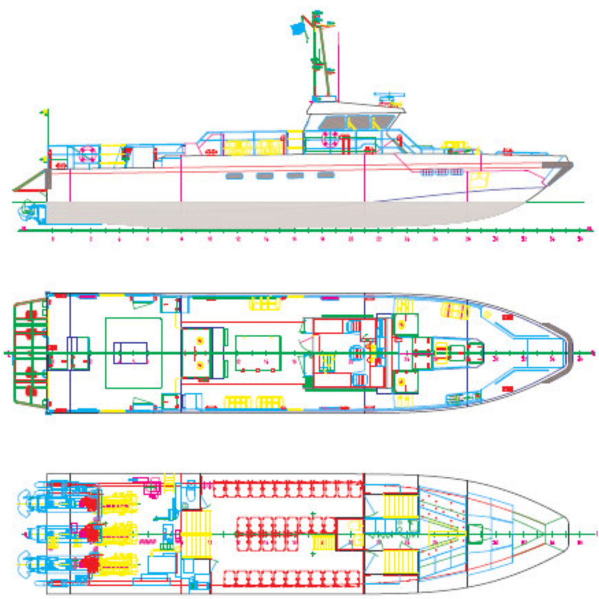

Figure 2: General Arrangement of civil passenger ship with 3 water jet propulsions.

7. INSULATION

New insulation plans (fire-, thermal- and noise insulation) for the different ship versions were established. Specific thermal- and moisture insulation are not included in the composite versions, since they were considered not to be needed due to the inherent properties of sandwich composite materials. Approved fire insulation materials according to DNV HSLC-code regulations, were used. Fire insulation was increased above regulations to ease certification and reduce the needed specific noise insulation for the ship versions. This means that A60 fire insulation was used in the engine compartment instead of the required A30. Fire restricting material was also used in all internal compartments including below the waterline, in the composite ship versions. The military Transport ship 2000, have a lower total insulation weight at 2590 kg, which is mainly due to its lower fire insulation standard. Table 1 and Figure 3 shows the obtained insulation weights listed by each insulations primary function. The insulation package is identical for all composite ship versions, which eases development and analysis.

Table 1: Hull insulation materials.

Insulation	*Material*	*Version 0 [kg]*	*Version 1 [kg]*	*Version 3 [kg]*	*Version 3A [kg]*
Other	Cover, support	755	653	653	653
Noise	Damping compound, damping elements, mineral wool	1766	901	901	901
Fire	Firemaster 607, Fireliner FPG Mk2	462	1374	1374	1374
Thermal, Moisture	Glass wool	291	-	-	-
Total	-	3251	2928	2928	2928

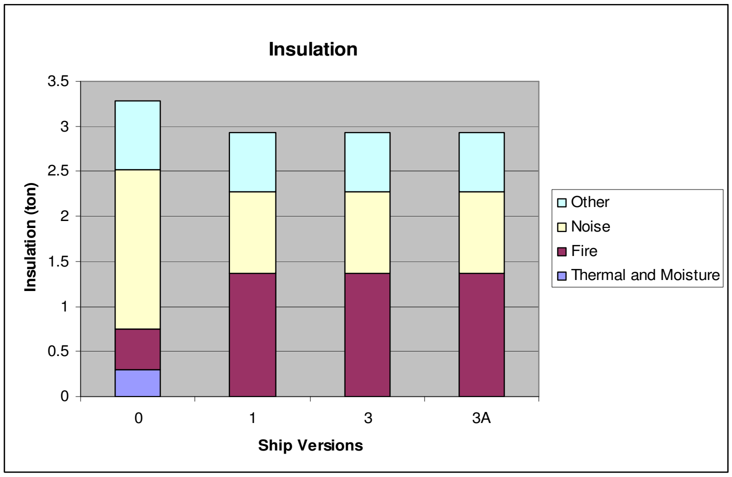

Figure 3: Hull insulation materials.

8. DIMENSIONING

All the ship hulls were dimensioned according to the DNV HSLC-code [3]. Version 3A uses the same dimensioning as the one obtained for Version 3. A further slight reduction in hull weight can hence be gained for Version 3A by taking away supporting structures for one engine, which is hence neglected here. Chosen composite hull materials were DNV certified glass fiber, carbon fiber and vinylester/Divinycell. A similar structural layout was used as for the reference ship. Sandwich laminates were used as much as possible in the design. Simplified production was introduced in the design to reduce the production cost including use of a minimised number of fiber weaves, weave thicknesses and PVC-densities. The empty insulated hull is defined in the same way as in the specification for the original military ship. This means that the engines and most additional equipment are not included in the empty insulated hull.

The hull structural weight is in Table 2. The empty insulated hull displacement is in Table 3 and Figure 4, with fuel tank and some minor equipment added. Weight reduction for empty hull with insulation package is 28-43 % for the studied ship versions compared to the reference ship Version 0.

Table 2: Hull structural weight.

Material	*Type*	*Version 0 [ton]*	*Version 1 [ton]*	*Version 3 [ton]*	*Version 3A [ton]*
aluminium	SIS 4140, 4212	10.6	-	-	-
Fiber	E-glass	-	3.1	-	-
Fiber	T700 carbon	-	-	1.8	1.8
Resin	Vinylester	-	2.6	2.0	2.0
Core	PVC Divinycell H60, H80, H100, H130	-	1.7	1.3	1.3
Total	-	10.6	7.4	5.1	5.1

Table 3: Hull displacement.

Ship Data	*Version 0 [ton]*	*Version 1 [ton]*	*Version 3 [ton]*	*Version 3A [ton]*
[1]Hull displacement excl. insulation	11.7	7.9	5.6	5.6
Insulation weight	3.3	2.9	2.9	2.9
Hull displacement incl. insulation	15.0	10.8	8.5	8.5

[1]Including fuel tank (Version 0) and minor hull mounted equipment.

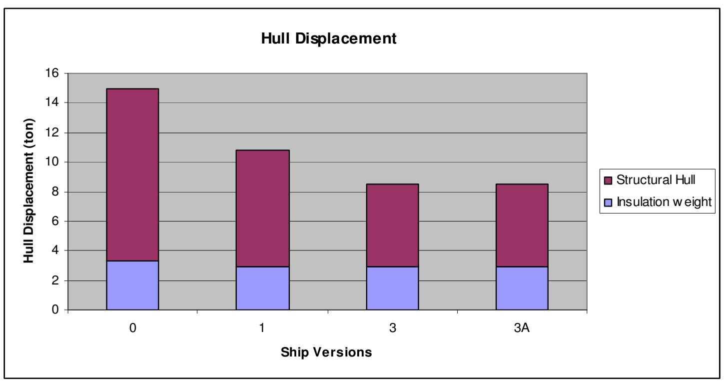

Figure 4: Insulated hull displacement.

9. SHIP DATA

Measured data during delivery trials on the two manufactured military ships have been used together with calculations to predict the ships performance. These data includes speed and fuel consumption in fully loaded and unloaded conditions. The military ships increased the top speed from 27.5 knots to 33 knots when the displacement was altered from 48 tons to 38 tons, by switching from full load to zero load. These values are well in line with the obtained top speed values in Table 4 for Version 0, 1, 3. The drag reduction and top speed for Version 3A when one water jet is removed, have been estimated in collaboration with Rolls-Royce. All ship versions can fulfil the utilisation cycle. Version 3A is however the only version which shows a significant reduction in fuel consumption by the use of a light insulated hull together with one engine less.

Table 4: Ship data.

Ship Data	*Version 0*	*Version 1*	*Version 3*	*Version 3A*
Total loaded displacement [ton]	47.6	43.4	41.1	36.9
Top speed [knots]	28	29.5	31	27.5
Maximum installed power [kW]	1380	1380	1380	920
Power fully loaded at 26 knots [kW]	1100	1030	990	845
Fuel consumption fully loaded at 26 knots [liter/hour]	264	257	247	212
Fuel consumption fully loaded at 20 knots [liter/hour]	165	148	137	114
Fuel consumption fully loaded at 10 knots [liter/hour]	38	33	30	28

10. COST

The production costs have been calculated without tax, 4 % interest rate and 5 % inherent profit. Production of a 20 ship series, at a shipyard in Sweden, is studied in the cost calculations [4]. The material types used in the hull with insulation, cost between 2-43 Euro/kg. Initial costs for development (marketing, ship specification, quotation, contract, design, dimensioning, construction, drawings, quality system, etc) and manufacturing equipment (tools, cutting, welding, measurements, 50 % assumed remaining manufacturing equipment value, etc.) as well as finalisation costs (certification, delivery approval, etc.) have been estimated. The material waste during empty insulated hull manufacture is assumed to be 3-6 %, depending on the used materials and manufacturing methods. Some hull material is delivered pre-cut to shape to the shipyard, i.e. aluminium sheets for Version 0 and fiber weaves and core material for the composite ship versions.

All composite versions show improvements towards the reference ship (Version 0) for the empty insulated hull, see Table 5 and Figure 5. Production cost is predicted to be lowered by 30-39 % for the insulated hull. The material share for the insulated hull is much lower for the aluminium ship which indicates that the manufacturing process, vacuum infusion, for the composite ships is more rational. The manhour cost for mounting of the insulation package is substantial. The hull manufacture waste is generally smaller for the composite ships than for Version 0.

All composite versions show improvements towards the reference ship (Version 0) for the total ship production cost and LCC, see Table 6, Figure 6 and Figure 7. The LCC-analysis is here approximate with some minor cost influences neglected. The production cost for the complete ship is lowered by 11-26 % Especially Version 3A benefits from the reduction in the number of expensive engines from 3 to 2. Maintenance and remaining ship values are estimated from experience. Composite hulls have generally less problems with fatigue and corrosion, which are the main reasons for the assumed differences. Composite hulls are here assumed to have the same value in Euro after 20 years of service as when they were new. The LCC is lowered by 5-21 % for the composite versions. LCC is completely dominated by the fuel cost for this application, which explains why Version 3A is the best. Composite hulls are hence indicated to be a good choice for this type of ship with light-weight benefits translated into lowered production costs and LCC. Carbon fiber hulls are indicated as the optimum selection.

Table 5: Production cost for empty insulated hull.

Cost Type	*Version 0*	*Version 1*	*Version 3*	*Version 3A*
Total manhour cost [kEuro]	427	211	209	209
Hull mounted equipment [kEuro]	29	17	17	17
Material (brutto) [kEuro]	57	85	131	131
[1]Material share [%]	11	28	37	37
Hull manufacture material waste [kEuro, ton]	3, 0.8	2.5, 0.3	4, 0.2	4, 0.2
Total [kEuro]	512	313	357	357

[1]Excluding hull mounted equipment.

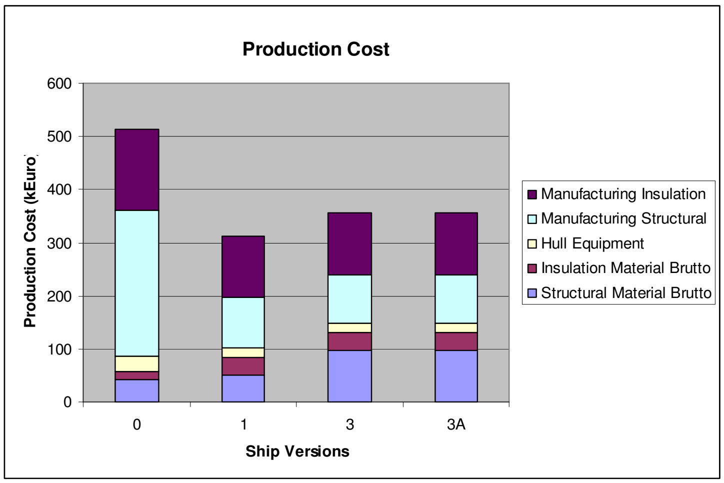

Figure 5: Production cost for empty insulated hull.

Table 6: Ship cost data for studied versions.

Ship Data	*Version 0*	*Version 1*	*Version 3*	*Version 3A*
Total ship production cost [MEuro]	1.70	1.46	1.51	1.26
Maintenance [kEuro/year]	15	11	11	11
Remaining ship value after 20 years service [% of original purchase price in current value]	70	100	100	100
LCC-cost during 20 years operation [%]	100	95	92	79

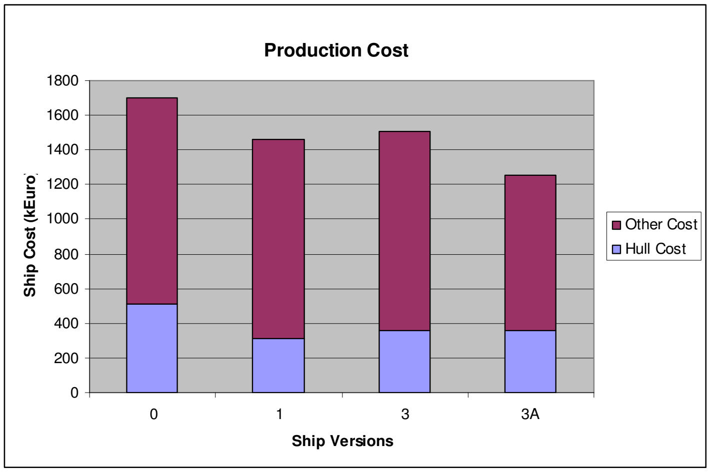

Figure 6: Total ship production cost.

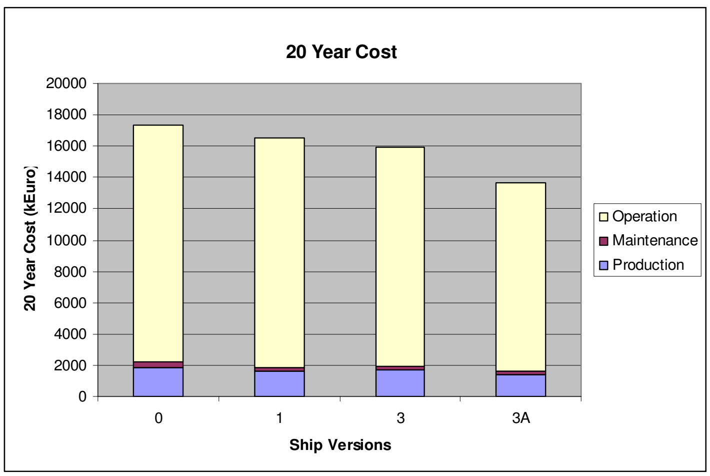

Figure 7: LCC for ship versions.

11. COAST GUARD CRAFT

The Swedish defence material administration has performed related studies on possible future use of similar ship designs for the Swedish coast guard, derived from Transport ship 2000 along the lines of Version 3A in this paper, see Figure 8 [5]. This ship is a 24 m composite material high speed craft, 48 tons loaded displacement with a fully loaded speed of 30 knots using water jet propulsion. They wanted a ship that was robustness reinforced above the demands in the DNV HSLC-code. A separate specification has hence been added for reinforcement towards increased service robustness, due to the tough service conditions for coast guard craft. Proven reinforcement principles from the previous carbon/Divinycell/vinylester military “Stridsbåt 90E” have been applied using the DNV HSLC-code. Implemented extra reinforcements, includes the keel (to support anchoring on beaches, sea bed contacts at speed and dry docking) and hull (to support docking to port and ships at sea and movement through ice). The coast guard craft is hence separately reinforced with 1320 kg, which is around 26 % increased structural hull weight. This can be regarded as an upper case in robustness reinforcement.

Figure 8: Projected new coast guard craft with composite material hull.

Linear scaling indicate that the empty insulated hull cost for the passenger ship (Version 3A) increases with 14 %, if it is reinforced in a similar way with 26 % increased structural hull weight as the coast guard craft. See 3A Reinforced in Figure 9. Comparisons with the other ship versions indicate that this cost increase could still be acceptable, if a really robust ship was needed and the ship performance was not significantly affected.

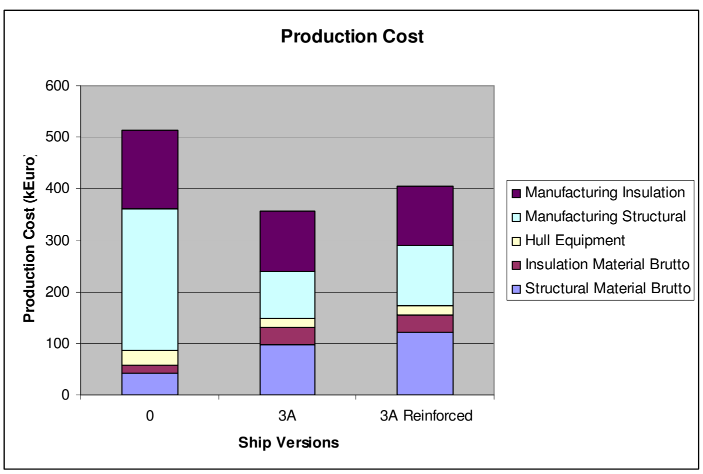

Figure 9: Production cost for empty insulated hull.

12. CONCLUSIONS

Composite high-speed craft have been studied in several versions. The influence of lighter insulated hulls on the ship performance, have been analysed. Composite hulls show a competitive purchase price and low LCC, for this application. Version 3A is the most promising compared to the reference ship (Version 0) with predicted 52 % lower structural weight for the hull, 43 % lower weight for the insulated hull, 30 % lower empty insulated hull production cost, 26 % lower ship production cost, 21 % lower LCC for 20 years service and similar ship performance for the intended usage.

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