Ship design goes multidisciplinary

The MARSTRUCT five-year series of conferences is aimed at advancing the field of marine structures. Nicolas Besnard, Principia, and Fabian Pécot, Sirehna (both of Nantes, France) and Philippe Rigo, ANAST-ULG (Liege, Belgium) report on developments ahead of the March conference in Lisbon.

In the frame of the European funded project *MARSTRUCT*, a joint study was performed to define an innovative methodology for ship design, highlighting the possibilities offered by well-tried optimisation techniques. The methodology was validated on a realistic study case: specifications were defined for a fast ferry, and a first design was defined. The methodology was then applied to improve the design.

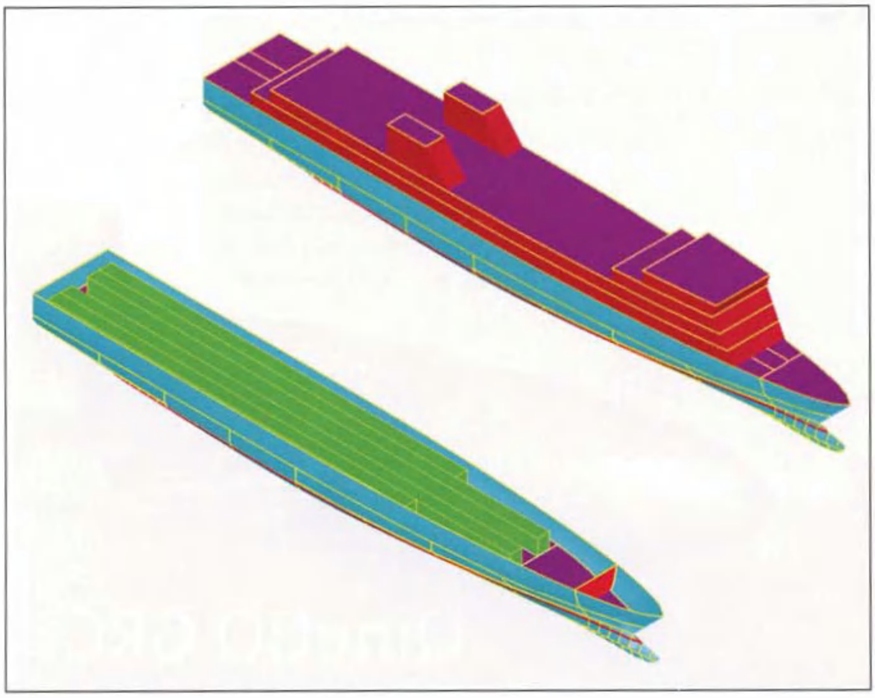
MARSTRUCT is a European Network of Excellence on marine structures, and is part of the Sixth Framework Programme (FP6). The objective of the project is to create a European network of researchers, working in cooperation on shared research topics. A large range of topics are addressed: simulation and testing of different structure behaviours (ultimate strength, collision and grounding, corrosion, etc.), hydrodynamic loads, etc.

The present study took place in the frame *of a work package devoted to identifying* and improving methodologies and tools for design.

The methodology consists in a two-level and multidisciplinary optimisation. *The first level (global level) consists in* modifying the ship's overall dimensions to reach a global objective. The second level (local level) allows defining the successive designs locally, optimising inner properties of each *global iteration*.

The methodology is based on an iterative process built around three tools operated in interaction. AVPRO, naval architecture software, is used to generate the ship model at each step of the global optimisation and to assess the model (evaluation of hydrostatic properties, ship weight, hull stability, hull resistance, etc.). LBR5, a tool for ship structural calculation and optimisation is used to define and optimise the midship section of each global iteration design according to Rule constraints, with an objective of least weight. modeFRONTIER, the optimisation environment, coordinates the tools and performs the global *optimisation*.

Figure 1: Views of the initial design of the fast ferry.



AVPRO

AVPRO is a naval architecture tool developed by Principia. Based on a *parametric* model, AVPRO allows the defining of a 3D model of the ship with a minimum amount of data, in order to comply with the short duration of early design. The model includes the ship *surfaces (hull(s), decks, bulkheads and* superstructures), areas, capacities and equipments.

Thanks to precise surface and volume calculation on the 3D model, a precise *weight evaluation is performed on the* model, including structure, capacities, areas and equipments. Hydrostatic calculations can also be performed, and include static equilibrium, intact and *damaged stability, flooding calculations*. The results can be exported through XML files. The XML format is a convenient format to connect several tools to each others.

LBR5

LBR5 is a structural analysis and optimisation tool developed by ANAST-University of Liege, specifically oriented towards the conceptual and early design stages. LBR5 allows performing a 3D structural analysis of a portion of the structure (usually located in the mid-ship region), and a scantling optimisation of the structural elements (plate thickness, size and spacing of the longitudinal and transversal members), based on different objective functions, as higher inertia, less weight and/or lower cost.

The elastic analysis of the entire structure is based on the analytical formulations of the behaviour of stiffened panels. This analytical approach allows short computation times, and is suitable for the integration within an optimisation process.

The optimisation module is based on the mathematical optimisation algorithm CONLIN. The user can impose constraints to the model: technical constraints (upper and lower bounds of the design variables), geometrical constraints (such as stiffener aspect ratios), and structural constraints (allowable stresses and deflexions, safety coefficient regarding buckling, etc.). LBR5 also includes a cost module which allows the direct calculation of the construction cost, taking into account the unit costs of raw materials and labour costs.

modeFRONTIER

AVPRO and LBR5 are embedded in the optimisation environment modeFRONTIER which coordinates the tools and performs the global optimisation on the ship model.

modeFRONTIER is a general purpose optimal design tool developed by ESTECO, which is able to deal with multidisciplinary problems. It is a state-of-the-art PIDO tool (Process Integration and Design Optimisation) that offers a large number of functionalities in terms of process integration, design optimisation and post-processing analyses.

Study case

In order to demonstrate the possibilities offered by the two-level and multidisciplinary optimisation, a fast ferry was chosen as the study case.

A ROPAX design was initiated with AVPRO, with the following specifications:

- a garage capacity of 400m (trucks)
- one full length garage deck
- cruise speed: 30knots
- propulsion ensured by two gas turbine generators and two pods.

The resulting ship is 150m long, 7500dwt ship, illustrated in figure 1.

The hull resistance is an obvious objective to minimise for a fast ferry. This is a very sensitive parameter, as reducing the resistance directly leads to a reduction of fuel consumption, allowing reduction of the fuel tank capacity. It can also allow selecting smaller propulsion installations, less expensive and of reduced weight. So the global objective of the optimisation is to minimize the hull resistance at the cruise speed of 30knots.

The main requirement for the ferry is a minimum garage length of 400m. This requirement will be set as a restriction for the optimisation. Other restrictions will ensure the feasibility of the ship design. First, the balance of the ship will be assessed to check that the volume of the generated hull is sufficient to accommodate the weight of the structure, equipments, garage and other areas. Secondly, some basic hydrostatic stability requirements will be checked on the intact stability curve, so that the generated hull geometry complies with International Maritime Organisation (IMO) requirements.

The weight is a highly significant parameter on fast ships.

The structural weight on its own can represent about half of the total weight of a ship. To address the structural weight efficiently, a local optimisation is defined to generate for each design iteration a weight-optimised structure, complying with Rule strength requirements. For each design iteration the structure is generated, analysed and optimised on the basis of the midship section; the thickness of the decks, longitudinal bulkheads and hull shell, as well as longitudinal stiffeners are addressed by the optimisation, with a least weight objective. The Bureau Veritas Steel Ships rules are considered, concerning the hull girder loads, the minimum strength and maximum allowed stress levels.

The resulting optimisation problem is a two-level and multidisciplinary optimisation problem. The first level (global level) consists in modifying the ship model overall dimensions to reach a global objective of minimal hull resistance, keeping a specified minimum garage length, and considering some feasibility restrictions. The following design variables are selected for the global level optimisation: waterline length, waterline beam and draught. The second level optimisation (local level) allows defining the successive structural designs, optimising structural weight properties of each iteration of the global level, and complying with standard strength Rules. The local design variables are the scantlings of the midship section (plate thickness and stiffener dimensions and spacing).

The optimisation process is initiated with a population of designs generated by modeFRONTIER randomly distributed in the whole design space. Then, the different steps of the optimisation are the following. First AVPRO is launched by modeFRONTIER, reads the model file and generates the geometry of the 3D model. Then, the midship section and hull girder loads are exported to LBR5. LBR5 analyses and optimises the structure of the model according to predefined Rule requirements (local optimisation), and returns the results to AVPRO. AVPRO can now compute the total weight of the ship, perform hydrostatic calculations (balance check, stability). The available garage length is also measured on the 3D model, and the hull resistance is assessed using an analytical Holtrop

Table 1. Results of the optimisation of the fast ferry

	Initial design	Optimised design
Length L (m)	150	152
Ratio L/B	7.5	8.1
Beam B (m)	20	18.8
Ratio B/T	4	4.4
Draught T (m)	5	4.3
Parking length (m)	440	421
Propulsion power at 30 knots (kW)	21 400	16 700

method. All these results are exported by AVPRO to modeFRONTIER, which at last performs the global optimisation based on these results, using a genetic algorithm.

Results of the two-level optimisation

The results obtained for the initial design and the final optimised design are given in table 1. The optimisation leads to a gain of 22% on the required propulsive power, keeping the vehicle capacity above the minimum requirement, and complying with the stability requirements. The table also points out that the design variables are modified with a slight decrease of beam (6%), and a larger decrease of draught (14%), whereas the length remains almost unchanged (1% increase).

Length and beam directly affect the garage capacity: basically the beam is adjusted to accommodate the 3.10m wide vehicle lanes, and the length is adjusted to obtain the correct garage length. The initial design proved to be quite close to the optimal garage arrangement, so only small length and width variations were observed.

The draught has a great impact on the displacement, and consequently on the hull resistance. So the optimisation process led to decreasing the draught as much as possible, keeping the hull volume sufficient to carry the ship weight, and respecting the stability criteria. The optimisation led to an important reduction of the displacement (21%). Actually, the initial design presented weight margins that were too large and were reduced by the optimisation process. Furthermore, the structural weight optimisations, led at each iteration of the global optimisation, resulted in a significant reduction of the structural weight.

Conclusion

The validity and feasibility of such an approach coupling different tools (general purpose optimal design tool, a structure dedicated optimisation tool and a naval architecture tool) have been demonstrated. The interoperability of these tools was made possible thanks to the ability of the general purpose optimal design tool to manage multi-purpose problems with different tools, and efficient input and output facilities. In particular the study highlighted the importance of universal input and output capabilities for tools connected together through an optimisation environment, and in this respect the XML format proved to be very efficient. *NA*

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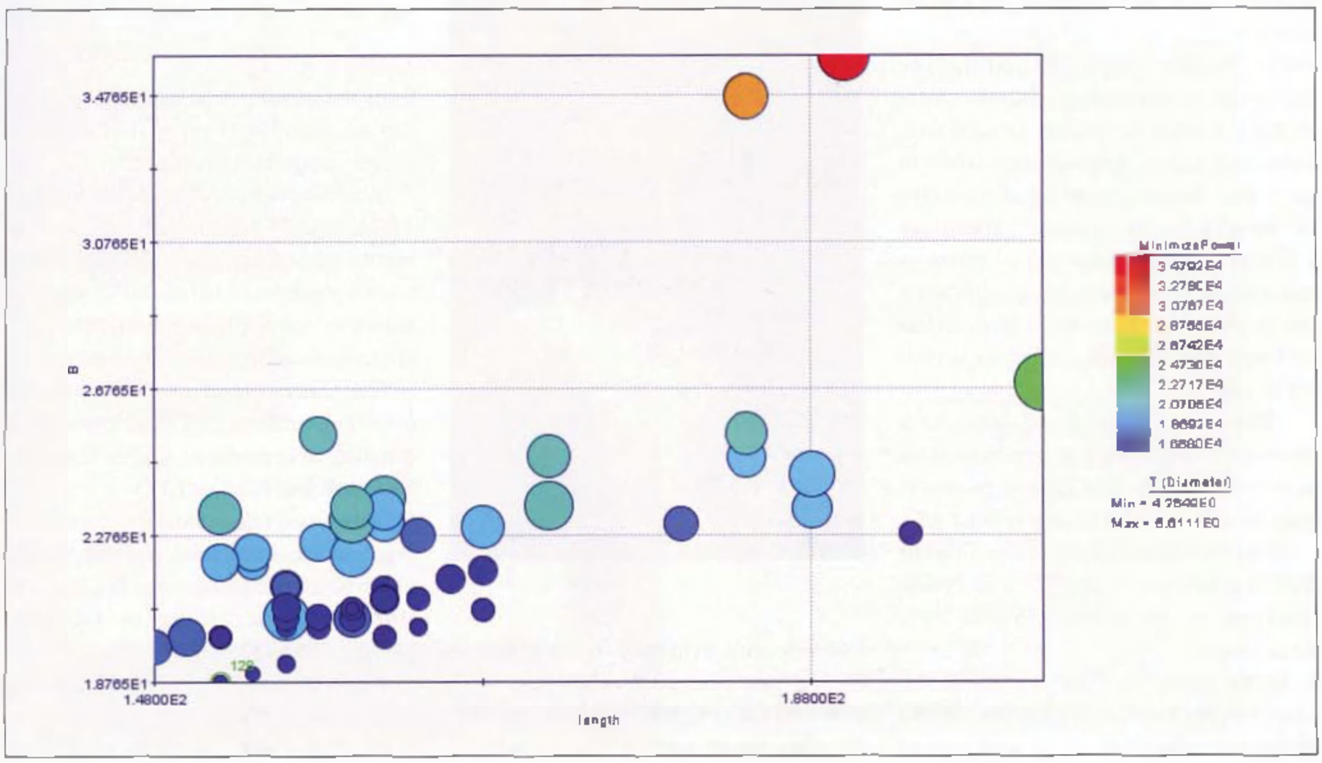
Web links

MARSTRUCT: http://www.mar.ist.utl.pt/marstruct
PRINCIPIA: http://www.principia.fr/eng
SIREHNA: http://www.sirehna.com
ANAST-ULG: http://www.anast.ulg.ac.be

Figure 2. Feasible designs in a length vs. breadth diagram. Diameter of circles represents draught and colour represents power.



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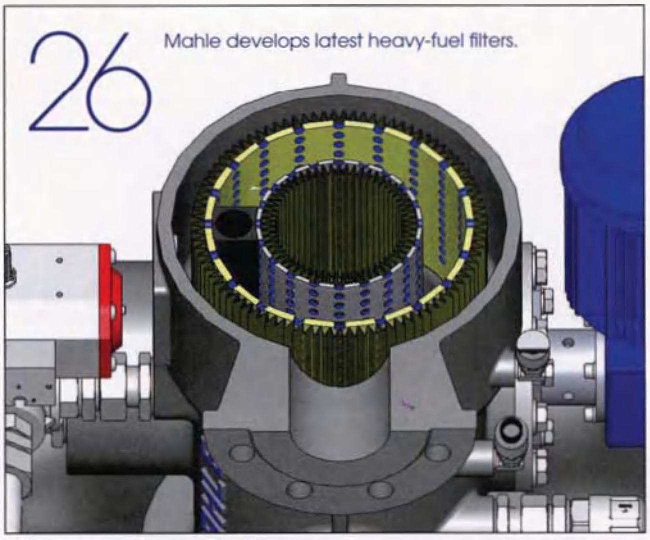

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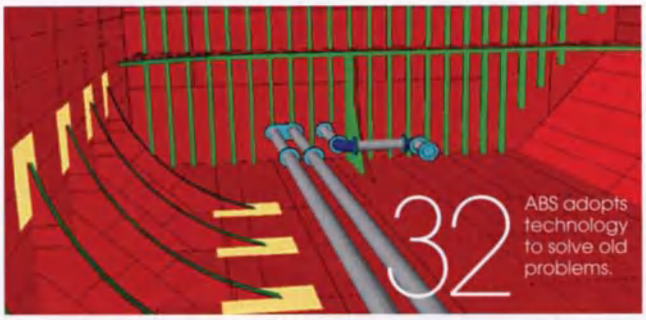

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