From Redesign to Optimal Hull Lines by means of Parametric Modeling

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Abstract

The efficient development of optimal solutions to design problems of high complexity has become imperative to increase competitiveness and success in shipbuilding. Information technology integration is a key factor in speeding-up the design process and in improving the product evolving from it. This holds in particular when one-of-a-kind systems need to be engineered and delivered in a short time.
The paper intends to contribute to the field of ship design by presenting a parametric approach to the modeling and hydrodynamic optimization of ship hull forms. Focus is given to the redesign and parameterization of complex shapes featuring hulls with bulbous bows. A sophisticated modeling technique – integrated in the novel system FRIENDSHIP-Modeler – is discussed with regard to efficient and effective form generation and variation.
Based on a RoPax ferry typical of fast short-sea shipping, all stages from redesign to hydrodynamic optimization will be described. The paper therefore presents an overview on the practicalities of shape import, identifying suitable parameters for shape variation and applying parametric principles to optimization. For the task of optimization and IT integration the state-of-the-art system called modeFRONTIER was utilized while the numerical flow simulation was performed with the well-established SHIPFLOW code. Additional wave pattern analysis via SWASH – the new wave analysis tool developed at the Technical University Berlin – was undertaken to strengthen the applicability of the flow simulation in the context of formal optimization.
All tools combined establish an advanced hydrodynamic design process implemented as a multi-layer optimization problem of non-linear programming. The elaborate example given will serve to illustrate objectives, methods and results.

1. Introduction

Can we still squeeze out a few percent ? Shall I increase the bulb's volume and is it advantageous to shift the forward shoulder ? Would we not like to know more about the design space we find ourselves in ?

In naval architecture we often face the predicament of coming up with a good hull shape within the tight corset of many constraints from many different fields – safety and comfort, cargo capacity and handling to mention just a few. Once a feasible solution is identified the design team often lacks the resources in time and budget to undertake an extensive search for further improvement. It would therefore be quite nice to let the computer do the busy-work, gain the freedom to lean back and wait and, in the end, simply decide which favorable result we are inclined to accept. Unfortunately, such a tool is not (yet) available. But even a long journey commences with the first step and a promising course adopted to accomplish the task of investigating many designs in a reasonably short time is automated optimization by means of parametric modeling as discussed for instance by *Birk and Harries (2000)*.

Simply put, automated optimization is the formal process of finding a good (the best) solution from a set of feasible alternatives. It requires a complete mathematical problem formulation in terms of objective functions (what is to be improved), free variables (what shall be consciously changed) and constraints (what restricts the feasibility). Within this paper we will follow this line of thought and focus on hydrodynamic design. We assume the somewhat idealized vista point of optimizing an initial hull by minimizing its wave resistance component in calm water. The example ship chosen is that of a fast ferry called FantaRoRo that was devised as an elaborate test case within the European R&D project FANTASTIC, see *Maisonneuve et al. (2003)* for an overview on FANTASTIC. The FantaRoRo test case was set up by the consortium to study the potential of the tools developed or improved throughout the project. Several alternative optimization schemes were applied by various partners. The purpose of this paper is to present the details of the approach developed at the Technical University Berlin.

A comprehensive optimization task from redesign to optimal hull lines will be discussed. Figure 1 shows the lines plan of the example ferry. The main particulars of the design are summarized in table I. Key constraints for the optimization are given in table II. As can be seen from table II we allowed ourselves a tangible freedom in shape modification so as to better see merits (and shortcomings).

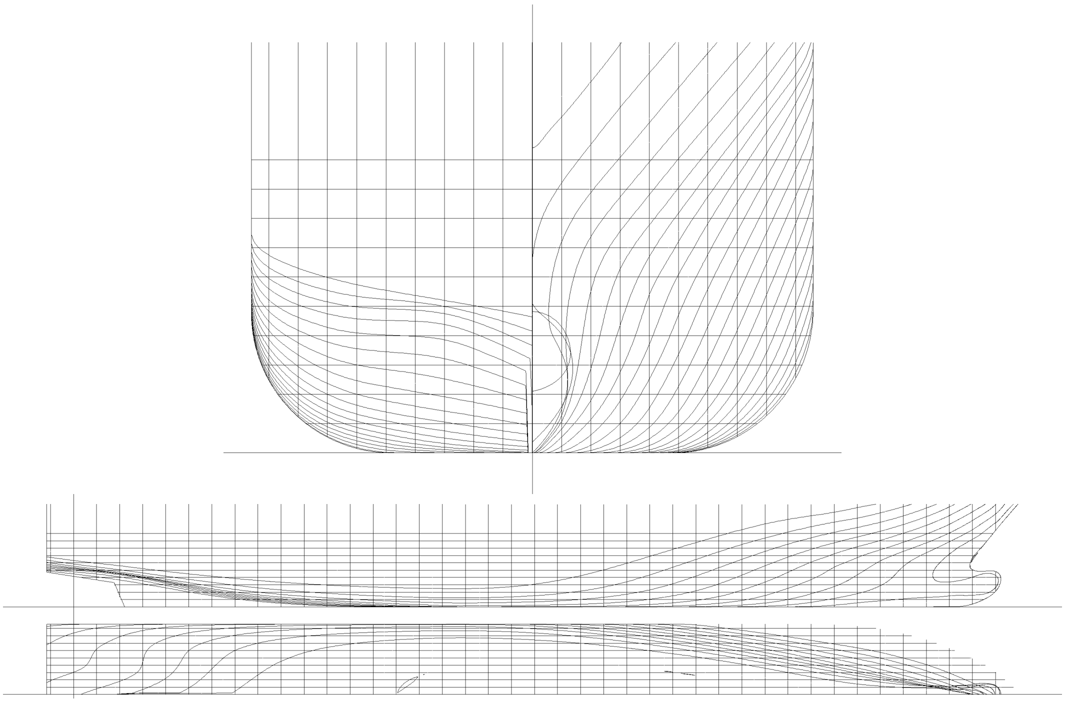


Fig. 1: FantaRoRo initial shape

Tab. I: Main particulars of FantaRoRo

L_{PP}	122.74 m	Length between perpendiculars
B	19.2 m	Maximum breadth molded
T	5 m	Design draft
$\forall$	6584 m^3	Displacement volume
C_B	0.549	Block coefficient
x_{CB}	57.8 m	Longitudinal center of buoyancy from AP
A_{WP}	1836 m^2	Waterplane area
V_S	21 kn	Design speed
F_n	0.311	Froude number

Tab. II: Key optimization constraints

		No changes aft of the maximum section
L_{maxAP}	128 m	Maximum length forward of AP
$\Delta\forall$	±10 % $\forall$	Maximum change of volume
Δx_{CBaft}	0.6 m	Maximum aftward shift of x_{CB}
Δx_{CBfor}	0.7 m	Maximum forward of x_{CB}

2. Design Scenarios in Geometric Modeling

Independent of the modeling approach, two design scenarios can be generally distinguished:

- Redesign of an existing shape and
- Design from scratch.

In shipbuilding the redesign of an existing shape and its subsequent modification to meet new criteria is widespread. A shipyard normally utilizes its data base of previous projects to set up an initial hull which then serves as the starting point for another vessel. A model basin also faces the task of remodeling a given shape regularly. It typically receives a hull form for tests and further perfection in either a proprietary or a common exchange format. Unless the model basin happens to run the same Computer Aided Design (CAD) software, however, a geometry import and certain post-processing is needed.

Design from scratch is undertaken more often in the field of yacht design in which the entire hull shape is established virtually from an empty piece of paper (or screen). Due to the simpler geometry of a yacht's bare hull and appreciably higher influence of aesthetics, many designers prefer this line of work. Nevertheless, when undertaking an optimization even in yacht design one may encounter the remodeling of a parent hull, see e.g. *Hochkirch et al. (2002)*.

In the following we will concentrate on redesign rather than on design from scratch. Once the initial shape is established the successive steps of hydrodynamic design are equal in any case, see figure 4.

2.1. Parametric Modeling

In parametric modeling the design problem is formulated partly or even fully in terms of parameters. Parameters are the descriptors of the product to be developed. In geometric modeling the parameters are more precisely called form parameters. Instead of simply replacing numbers by variables and then again assigning values to them, parameters feature relationships. The value of a parameter might thus be computed from a formula including higher ranked parameters, it might also depend on certain conditions or it might be computed from a set of equations etc. In this way a product is represented at a much higher level then by point data alone as it is still done very often.

For example: A cube is completely defined by the three Cartesian components of all eight corner points. Conventionally you would enter the point data to each corner, i.e., you would specify 24 real numbers in total. In a parametric model you could reduce the definition to one single parameter if you wanted, say a characteristic length. The breadth and height of the cube could be computed as a fixed percentage of the characteristic length. If you needed more freedom you could use three parameters, namely the cube's length, breadth and height independently. As can be readily deduced, a parametric description comprises all instances of a product and a specific product can be generated with less effort. However, to some extend the parametric model also imposes a limitation due to its build-in relationships. For further discussions see *Abt et al. (2001)*.

Today's CAD software can be generally subdivided into three categories:

- Conventional tools without parametric support,
- Tools with certain parametric capability and
- Fully-parametric design tools.

In the context of optimization a conventional non-parametric approach has serious disadvantages. While the number of free variables – e.g. point data – that govern the problem rapidly becomes prohibitively high, the influence of each individual variable also decreases. Moreover, the fine tuning of variables to achieve a desirable result gets very demanding.

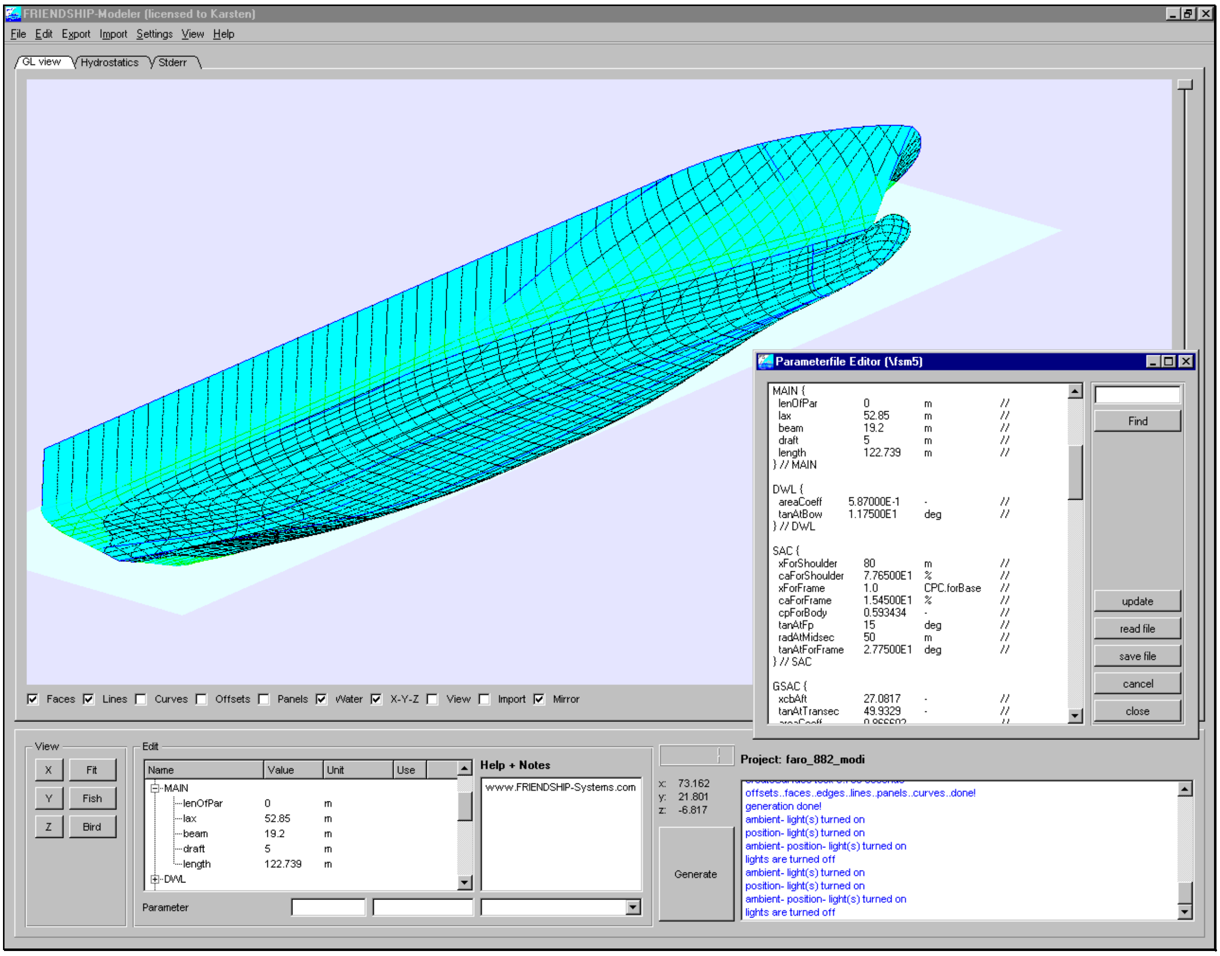
Consequently, a fully-parametric design tool has been developed for the hydrodynamic design of ships and yachts which is now available on the market: The FRIENDSHIP-Modeler. The

FRIENDSHIP-Modeler originates in research performed at the Technical University Berlin, see *Harries (1998)*. A substantially extended and enhanced version is available from FRIENDSHIP-Systems, see website in reference list.

2.2. FRIENDSHIP-Modeler

The FRIENDSHIP-Modeler's key feature is a fully-parametric shape description. Each hull – be it a sailing yacht with keel and rudder or a ship with bulbous bow – is generated in a three stage process. The entire model is based on B-splines curves and surfaces which are optimized for fairness.

In the first step a flexible set of longitudinal curves (basic curves) is produced from form parameter input. An excerpt of the human readable form parameter file for the example FantaRoRo can be seen in figure 2. In the second step a skeleton of transverse curves is created according to the parametric information contained in the basic curves. In the third step a set of fair surfaces is built that interpolate this skeleton of transverse curves. Figure 2 also shows the graphical user interface (GUI) of the FRIENDSHIP-Modeler, featuring an improved FantaRoRo (TUB 882*modi) in perspective view.



☑ Faces ☑ Lines ☐ Curves ☐ Offsets ☐ Panels ☑ Water ☑ X-Y-Z ☐ View ☐ Import ☑ Mirror

```
MAIN {
  lenOfPar       0            m            //
  lax            52.85        m            //
  beam           19.2         m            //
  draft          5            m            //
  length         122.739      m            //
} // MAIN

DWL {
  areaCoeff    5.87000E-1     -            //
  tanAtBow     1.17500E1      deg          //
} // DWL

SAC {
  xForShoulder   80           m            //
  caForShoulder  7.76500E1    %            //
  xForFrame      1.0          CPC.forBase  //
  caForFrame     1.54500E1    %            //
  cpForBody      0.593434     -            //
  tanAtFp        15           deg          //
  radAtMidsec    50           m            //
  tanAtForFrame  2.77500E1    deg          //
} // SAC

GSAC {
  xcbAft         27.0817      -            //
  tanAtTransec   49.9329      -            //
```

Name	Value	Unit	Use
⊟-MAIN			
lenOfPar	0	m	
lax	52.85	m	
beam	19.2	m	
draft	5	m	
length	122.739	m	
⊞-DWL			

Parameter

www.FRIENDSHIP-Systems.com

x: 73.162
y: 21.801
z: -6.817

Project: faro_882_modi

```
offsets..faces..edges..lines..panels..curves..done!
generation done!
ambient- light(s) turned on
position- light(s) turned on
ambient- position- light(s) turned on
lights are turned off
ambient- light(s) turned on
position- light(s) turned on
ambient- position- light(s) turned on
lights are turned off
```

Fig. 2: GUI of FRIENDSHIP-Modeler with excerpt of form parameter file and perspective view of TUB 882*modi

2.3. Parametric Redesign of Existing Shapes

The FRIENDSHIP-Modeler supports both the redesign of existing shapes and the design from scratch. The original hull shape for the FantaRoRo test case was developed within NAPA, see website in reference list. Figure 3 presents a comparison between the original geometry and the redesigned geometry. Considering NAPA's different modeling concept, fair agreement can be observed, in particular in the underwater portion of the hull. No considerable attempt was made to further reduce the deviations in the forebody since the entire hull was free to change from the maximum section forward in the optimization.

Hull shapes can currently be imported into the FRIENDSHIP-Modeler either via IGES files or via offset data. In the former case the user fills up a parameter file interactively and iteratively compares the hull form produced with the geometry imported until satisfaction. In the latter case – which was pursued here – the offset data is analyzed with regard to key form parameters. A template is selected which suits the topology of the ship at hand (e.g. ship features a bulbous bow). The determined form parameter values are then inserted in the form parameter file in accordance with the chosen template. Afterward, additional form parameters might be added as desired.

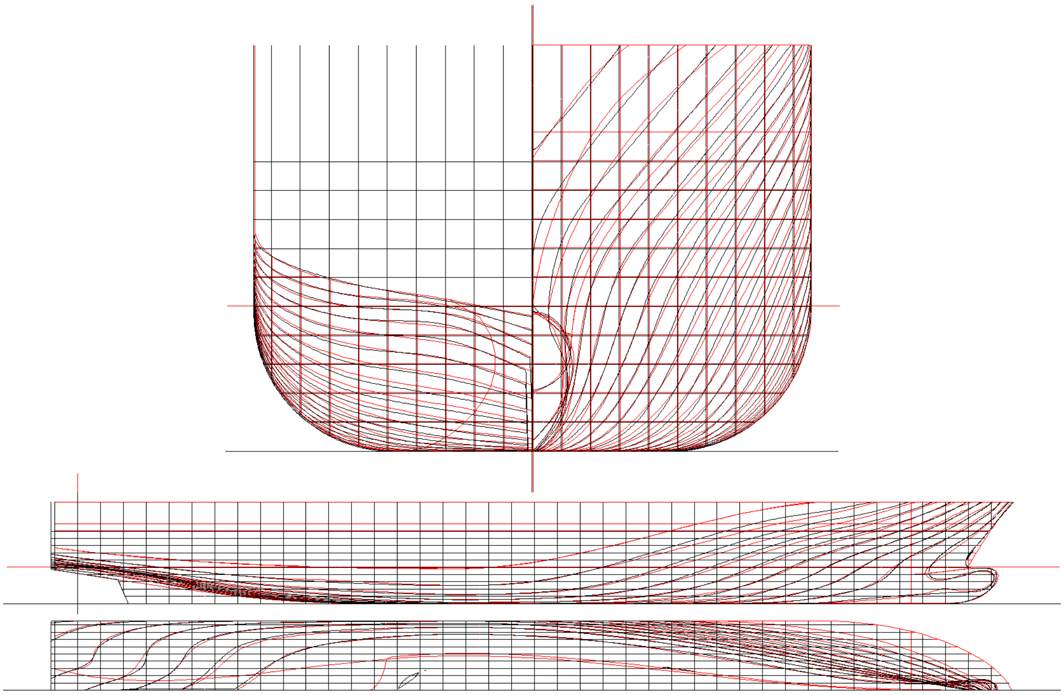


Fig. 3: FantaRoRo original shape (black) and redesigned geometry (gray)

3. Hydrodynamic Optimization

Figure 4 depicts the typical process flow of a formal hydrodynamic optimization. A very tight integration of four modules is essential for the optimization's success:

- Shape generation,
- Hydrodynamic analysis,
- Performance assessment and
- Optimization strategies.

Throughout this study the shape generation was done via the FRIENDSHIP-Modeler. The hydrodynamic analysis was carried out with the potential flow module of the well-known SHIPFLOW code, see website in reference list. (Complementing computations were undertaken with SHIPFLOW's boundary layer module.) The prime objective function of the optimization having been the wave resistance, a sophisticated wave cut analysis was utilized for performance assessment in addition to pressure integration over the panels. SWASH, a tool developed at the Technical University Berlin, was applied for longitudinal wave cut analyses, see *Heimann (2000)*. It yields the wave pattern resistance R_{WP} while – by convention – a pressure integration provides the wave resistance R_W. SWASH treats wave cuts of finite length with a special truncation correction and allows a detailed examination of gains and losses via the spectral distribution of a wave energy equivalent along the components of the steady ship wave system.

Finally, for integration of the various tools and as a workbench providing many different optimization strategies the multi-objective design environment modeFRONTIER was utilized, see website in reference list.

From figure 4 it can be seen nicely that hydrodynamic optimization is an iterative and interactive design process that should not be confused with a black box that yields the best ship for simple questions asked. Even though many design variants might be automatically assessed at each time an optimization run is started, the entire design procedure requires the users to evaluate and reconsider their problem set-up as the investigation progresses.

The process commences with a pre-processing phase. Once a parametric model is established – a form parameter file is produced for the FRIENDSHIP-Modeler – the geometry can be generated and modified very elegantly. A detailed analysis of the initial design will then be undertaken which implies panel variation studies, convergence tests and accuracy checks for instance.

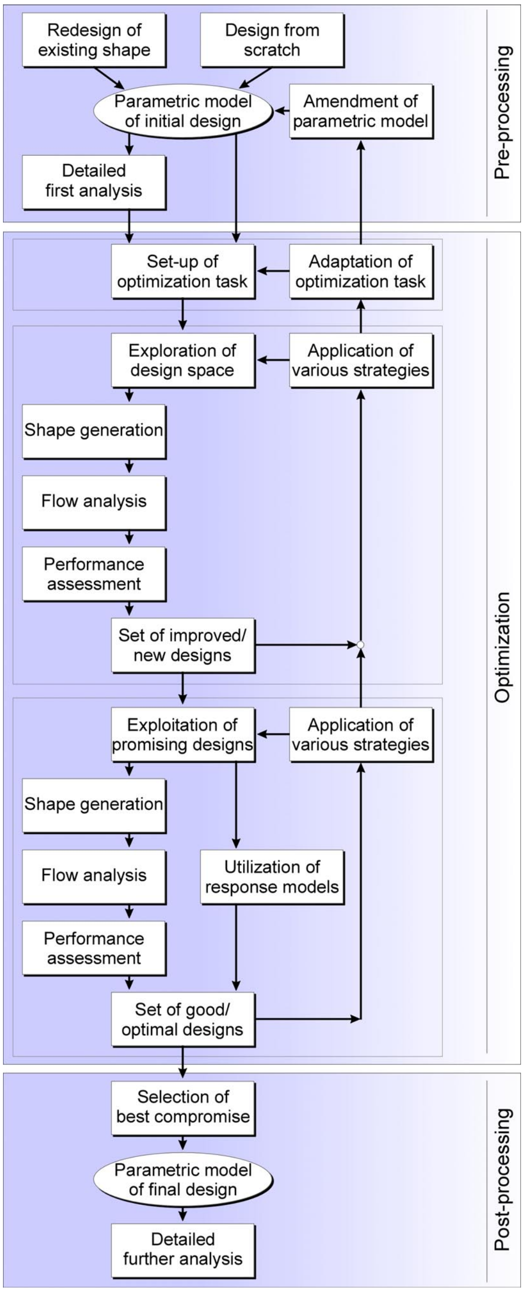


Fig. 4: Process flow in hydrodynamic design

Then follows the actual optimization phase which can be further subdivided into three steps. In the first step the optimization task is formulated. The free variables – i.e., the form parameters that shall be varied – are chosen along with their appropriate bounds. One or several objective functions are identified and the constraints are incorporated. In the next step the design space is explored so as to gain a first insight. One might chose a design-of-experiment (DoE), for example a random distribution of variants. For each set of free variables three key modules are executed one after another: shape generation in accordance with the current set of form parameters, flow analysis on the basis of the present hull geometry and performance assessment based of the flow field just computed. A set of designs is thus produced which (hopefully) contains some improved hull forms. This step is carried out several times, possibly applying different optimization strategies. It might also happen that the optimization set-up needs to be adapted to better suit the problem at hand. For example, the bounds of selected free variables are shifted, increased or decreased. (Depending on the gains in the objective functions achieved and the general behavior of the shape modification, even a further step backward can be advisable in order to amend the parametric model.) Following the exploration step, a third step is taken. Utilizing the set of designs investigated so far, a further exploitation of promising variants is attempted. This is done by either a deterministic or a stochastic optimization strategy. An example of the former is the SIMPLEX algorithm according to Nelder and Mead, see *Press et al. (1994)*, an example for the latter being the MOGA (multi-objective genetic algorithm), see *Spicer, Poloni et al. (1998)*. The exploitation is usually performed several times until satisfying solutions have been found. (One interesting alternative to going through the time consuming and resource intensive flow analysis and performance assessment is to bypath the full simulation by a response model.) At the end of the exploitation step several improved designs are available from which the best is to be identified.

In the case of a multi-objective optimization the selection of the final design is a non-trivial task in itself. It is undertaken in the third phase of post-processing. The process may then end with a further analysis of the final design.

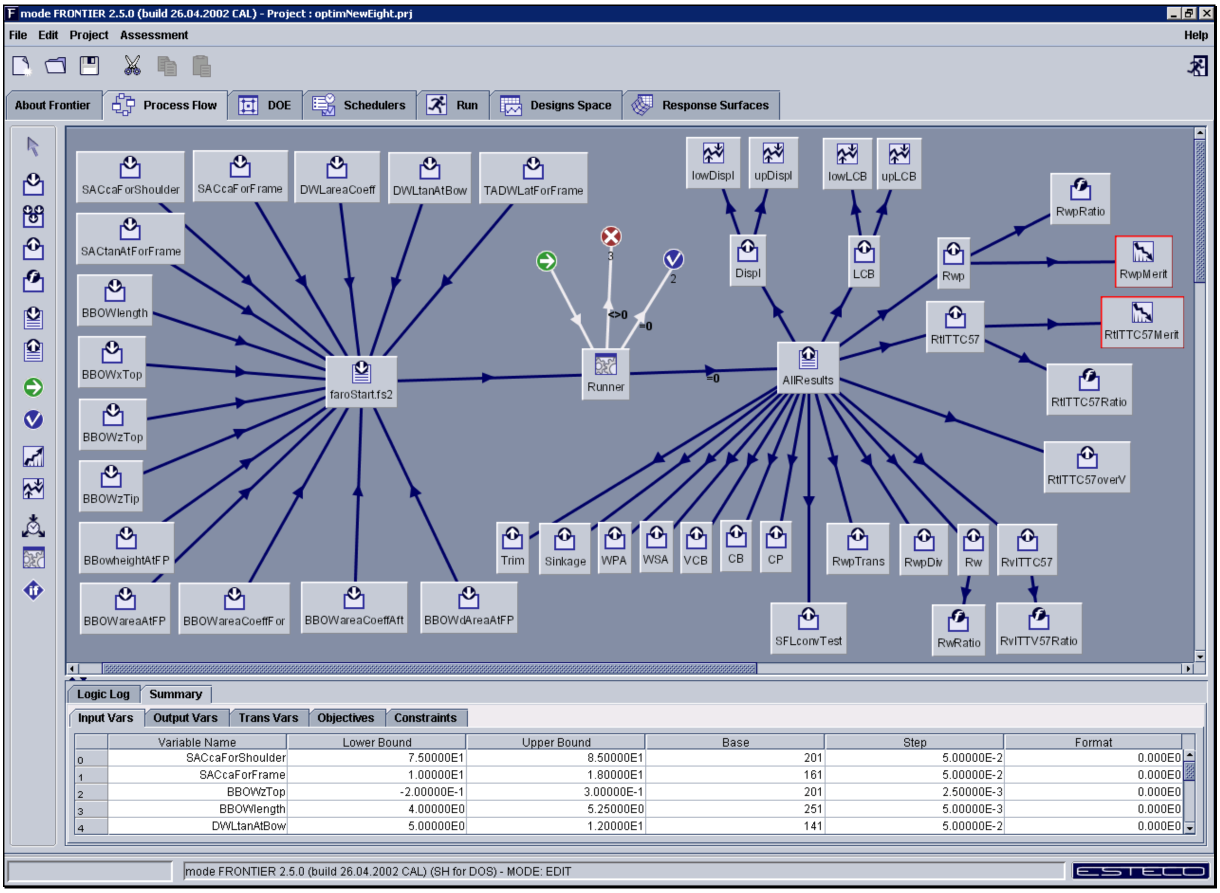
4. Towards Optimal Hull Lines – Elaborate Example

4.1. Optimization Process

The optimization set-up as realized with modeFRONTIER is shown in figure 5. A set of 15 form parameters was used here for modifying the hull geometry. The free variables correspond to two basic curves – the design waterline DWL and the sectional area curve SAC (for the forebody) – and the bulbous bow BBOW. In table III the form parameters are listed along with the (final) bounds and the values they assume for several designs that were considered favorable with respect to various objectives. The values of the initial hull form are given, too.

From figure 5 you may also note that inequality constraints were imposed on displacement and longitudinal center of buoyancy, see table II. (Actually, the displacement of the bare hull was implicitly kept constant within the FRIENDSHIP-Modeler during the optimization but slight changes in the overall displacement occurred due to variations in the bulb volume.) Several important quantities like trim and sinkage, waterplane area, wetted surface area etc. were monitored.

As already stated above, the wave pattern resistance R_{WP} and the wave resistance from pressure integration R_W were employed as the major objective functions. The total resistance R_T was also taken into consideration. Following Froude's hypothesis, the viscous component of the total resistance was simply added to the wave resistance component. The frictional resistance was computed from the ITTC 57 line, a reasonable form factor was estimated and assumed constant since no changes were permitted in the afterbody.



	Variable Name	Lower Bound	Upper Bound	Base	Step	Format
0	SACcaForShoulder	7.50000E1	8.50000E1	201	5.00000E-2	0.000E0
1	SACcaForFrame	1.00000E1	1.80000E1	161	5.00000E-2	0.000E0
2	BBOWzTop	-2.00000E-1	3.00000E-1	201	2.50000E-3	0.000E0
3	BBOWlength	4.00000E0	5.25000E0	251	5.00000E-3	0.000E0
4	DWLtanAtBow	5.00000E0	1.20000E1	141	5.00000E-2	0.000E0

mode FRONTIER 2.5.0 (build 26.04.2002 CAL) (SH for DOS) - MODE: EDIT

Fig. 5: Optimization set-up in modeFrontier

Tab. III: Form parameters in example optimization

Free variable / form parameter	**Lower bound**	**Upper bound**	**TUB parent (initial hull)**	**TUB 876**	**TUB 848***	**TUB 879***	**TUB 882***	**TUB 882*modi**
SACcaForShoulder	75.0 %	85.0 %	77.9059 %	79.25 %	76.75 %	78.20 %	77.65 %	77.65 %
SACcaForFrame	10.0 %	18.0 %	13.1966 %	15 %	15.85 %	16.25 %	15.45 %	15.45 %
SACtanAtForFrame	20.0	60.0	35	37.5	26.0	28.75	27.75	27.75
DWLtanAtBow	5.0	12.0	9.5	10.5	11.2	11.3	11.75	11.75
DWLareaCoeff	0.57	0.65	0.625	0.57375	0.57	0.6125	0.587	0.587
TADWLatForFrame	60.0	100.0	63.1275	63.1275	61.0	60.0	60.25	60.25
BBOWareaCoeffFor	0.825	0.925	0.85	0.9125	0.925	0.925	0.925	0.925
BBOWareaCoeffAft	0.35	0.45	0.4	0.4175	0.45	0.414	0.45	0.4
BBOWareaAtFP	7.0	10.0	8.57	10.0	10.0	10.0	10.0	10.0
BBOWdAreaAtFP	30.0	50.0	35	42.5	43.5	49.6	46.1	40.0
BBOWlength	4.0	5.25	4.24	5.175	5.25	5.25	5.25	5.25
BBOWheightAtFP	87.5 %	95.0 %	90.0 %	90.0 %	87.5 %	87.5 %	87.5 %	87.5 %
BBOWzTop	-0.2	0.3	- 0.08	0.3	0.3	0.3	0.2975	0.3
BBOWxTop	60.0 %	75.0 %	68.0 %	68.0 %	75.0 %	72.6 %	73.3 %	73.3 %
BBOWzTip	-1.5	-0.5	-1.15	-1.15	-0.735	-0.66	-0.685	-0.685

Note: TUB 876 stems from a different optimization run as the variants marked with an asterisk *
TUB 882*modi resembles TUB 882* apart from a slight modification introduced a posteriori right aft of FP

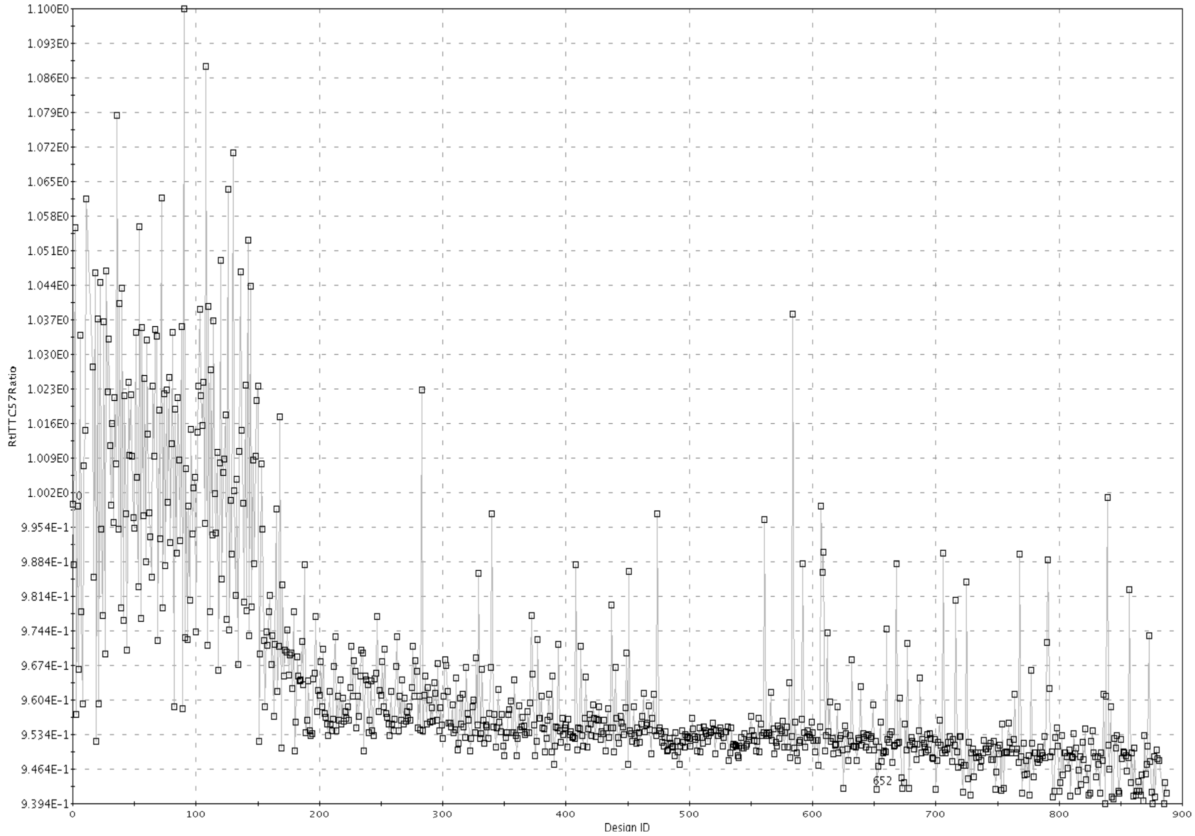


Fig. 6: Optimization history

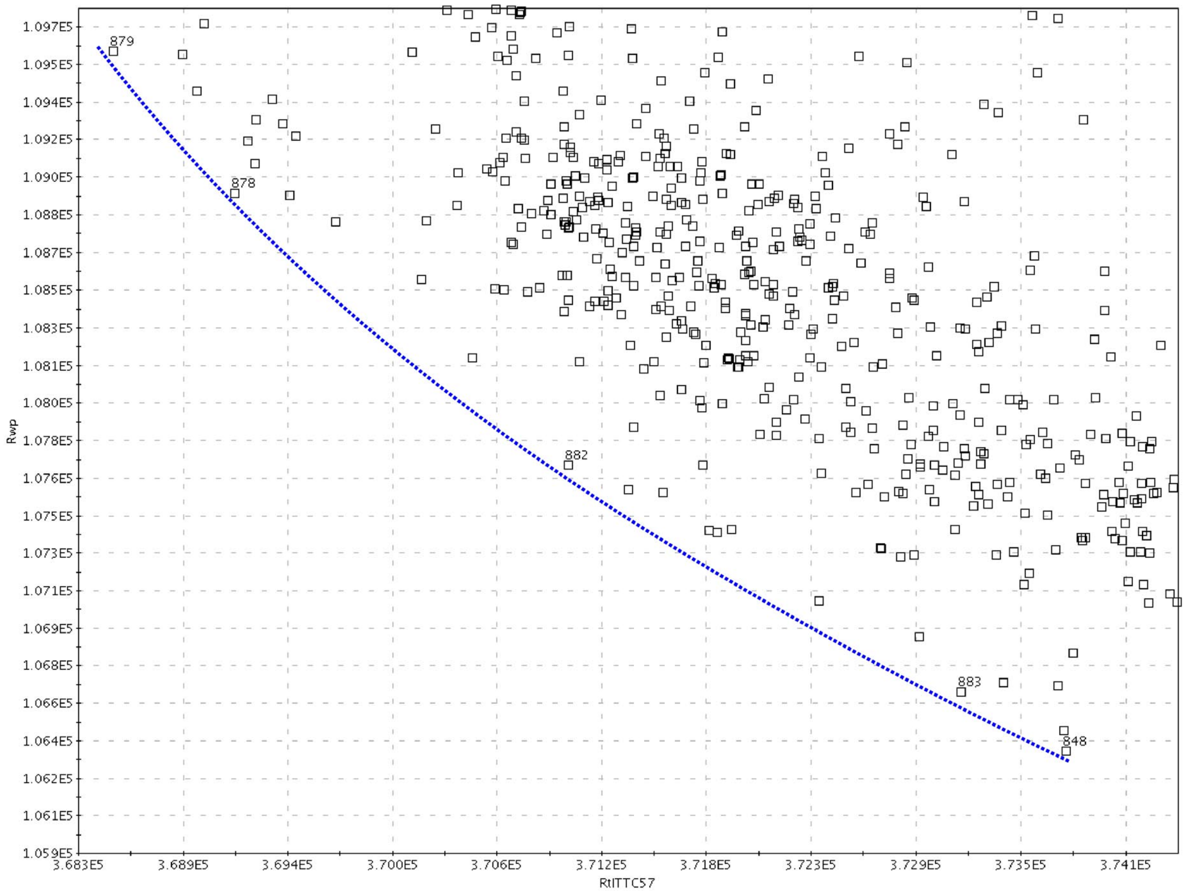


Fig. 7: Scatter diagram with R_{WP} and R_T as ordinate and abscissa, respectively

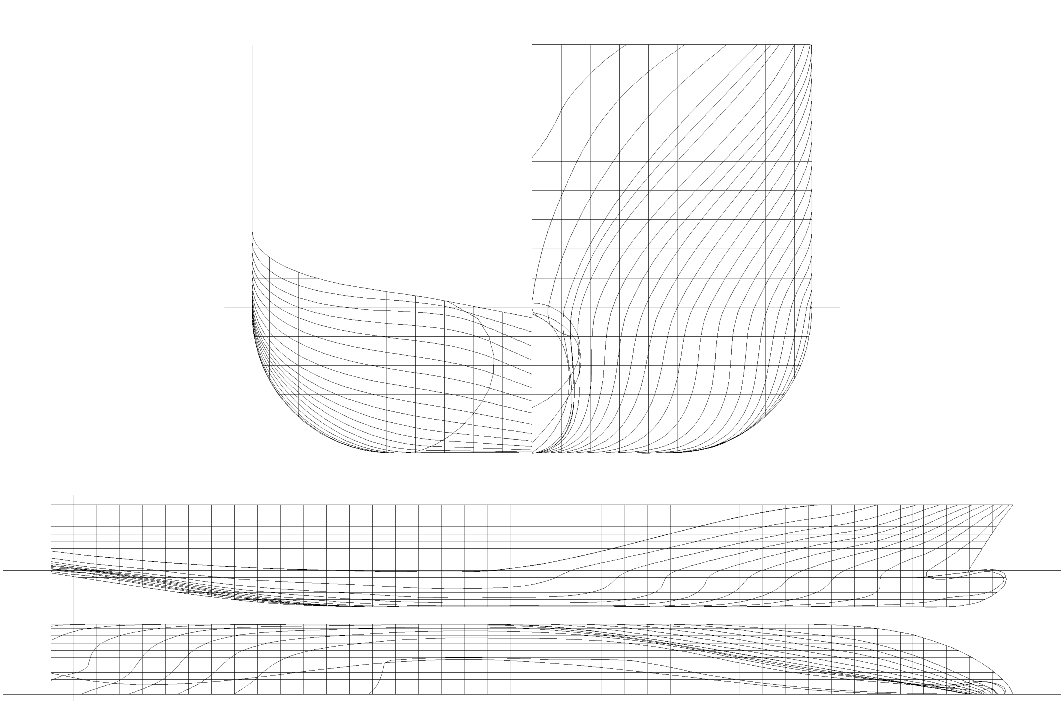


Fig. 8: Lines plan of TUB 876

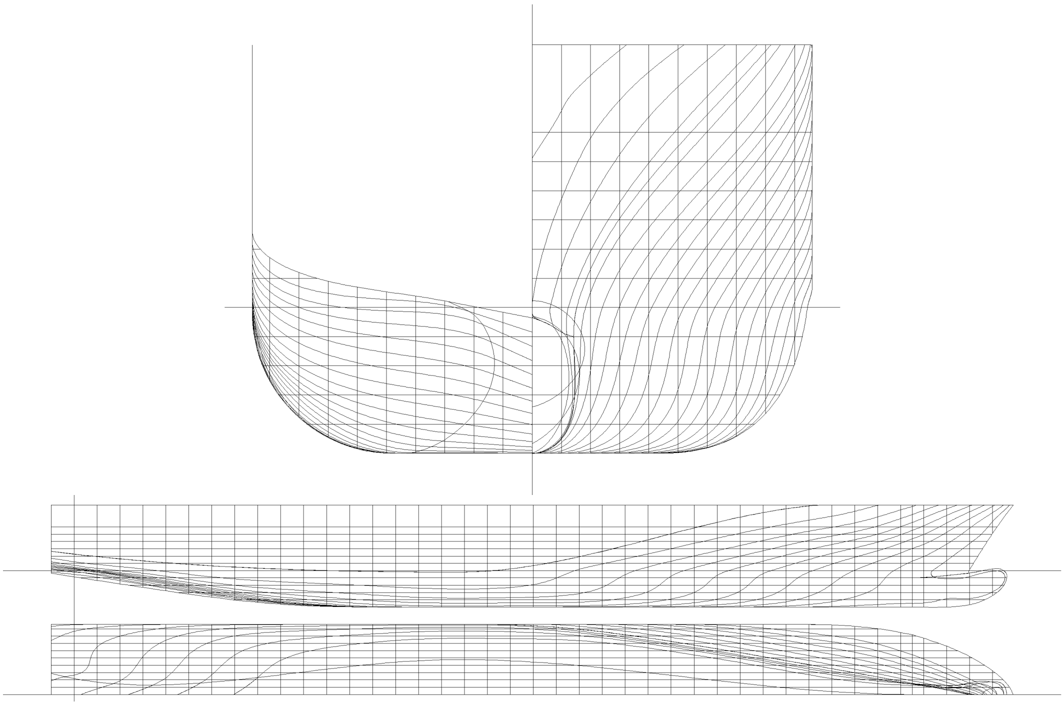


Fig. 9: Lines plan of TUB 882*modi

For the optimization runs a medium size panelization with 1185 panels covering one half of the hull surface and 5125 panels for the free surface per symmetric half was employed. The free surface panelization was extended $x/L_{PP} = 2.4$ downstream of the stern in order to allow for the longitudinal wave cut analysis. The non-linear flow analysis was restarted from previously converged non-linear solutions so as to reduce computational effort. Trim and sinkage were free.

An exemplary optimization history is provided in figure 6, the ordinate being the ratio of R_T to $R_{T\text{initial}}$ and the abscissa being the design id. A design-of-experiment with 150 candidates is followed by a MOGA optimization. Figure 7 depicts a scatter diagram of R_{WP} vs. R_T. The designs are marked by square boxes while a Pareto front – the set of all solutions for which a single objective cannot be further improved without deteriorating any other objective – is drawn as a dotted curve. All hull forms lie above and to the right of the Pareto front. Those designs that are closest display low wave pattern resistance along with low total resistance. Apparently, it is impossible to decrease R_{WP} below certain limits without impairing R_T. For those variants that make up the Pareto front the design id is given. In tables III and IV data for good designs are summarized.

Throughout the process several optimization runs were executed. Instead of discussing them all only the final run shall be explained in detail: From the data basis built up in previous optimizations a MOGA was started with the 80 best candidates for the initial population. The wave pattern resistance and the total resistance were utilized as the two competing objectives. A total of 30 generations was generated and traced. Finally, in order to further benefit from the results achieved already a SIMPLEX search was activated from the very best designs. For the SIMPLEX just one objective was accounted for, namely the sum of R_{WP} and R_W. The SIMPLEX was finally terminated at a stage were improvements became marginal.

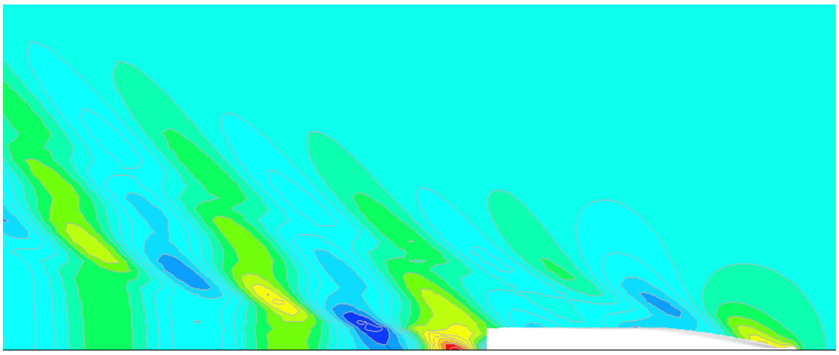
4.2. Further Analysis

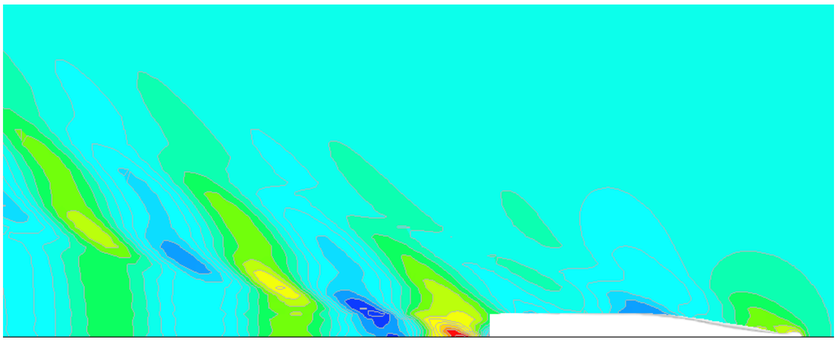
For a more thorough comparison of the most promising designs further flow analysis and assessment was undertaken with a finer panel mesh of 1767 panels on the hull surface (247 of them for the bulb upstream of FP) and 7976 panels on the free surface per symmetric half. Along the hull more than 40 free surface panels per fundamental wavelength ($\lambda_0/L_{PP} = 0.609$) were utilized in longitudinal direction. The width of the free surface panels next to the hull was 0.02 L_{PP}. A slight panel stretching was applied sidewise and downstream of the stern.

The results are presented in table IV. When compared to the initial hull form one may observe that TUB 848* reduces the wave generation the most while TUB 879* promises the highest improvement in pressure distribution. TUB 882* along with its slightly modified version TUB 882*modi might be characterized as the trade-off bringing together the advantages of both former designs. TUB 876 (see figure 8 for a lines plan) is an intermediate result from one of the first optimization runs. It features pronounced (S-shaped) buttocks resulting from a narrow design waterline. It therefore resembles an interesting deviation from conventional hull shapes.

Tab. IV: Comparison of promising variants

Results	**TUB Parent (initial hull)**	**TUB 876**	**TUB 848***	**TUB 879***	**TUB 882***	**TUB 882*modi**
$R_{T\ ITTC57}$ [N]	403601	386148	380127	376900	378362	378541
Gain [%]	–	4.32	5.82	6.62	6.25	6.21
R_W [N]	165726	146184	139786	137528	138568	138944
Gain [%]	–	11.79	15.65	17.01	16.39	16.16
R_{WP} [N]	136031	118114	113869	117098	115238	115757
Gain [%]	–	13.17	16.29	13.92	15.29	14.90
R_{WP} due to transverse waves [N]	98817	78374	79354	82741	80887	81459
Gain [%]	–	20.69	19.70	16.27	18.14	17.57
R_{WP} due to diverging waves [N]	37213	39741	34515	34357	34351	34298
Gain [%]	–	-6.79	7.25	7.67	7.69	7.83
Wetted surface area [m^2]	2479	2501	2505	2495	2499	2497


initial hull form


TUB 876

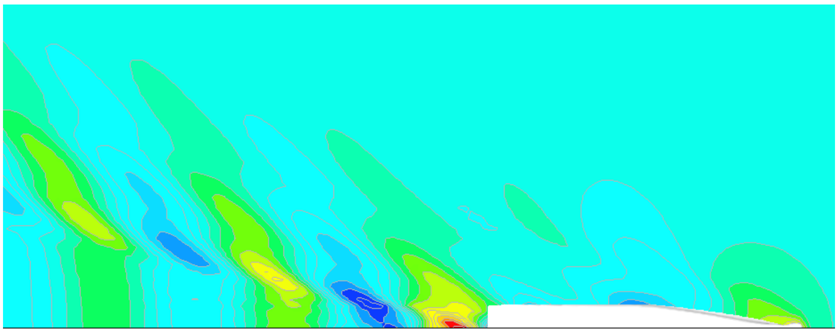

TUB 882*modi

Fig. 10: Wave contours of initial hull form, TUB 876 and TUB 882 modi

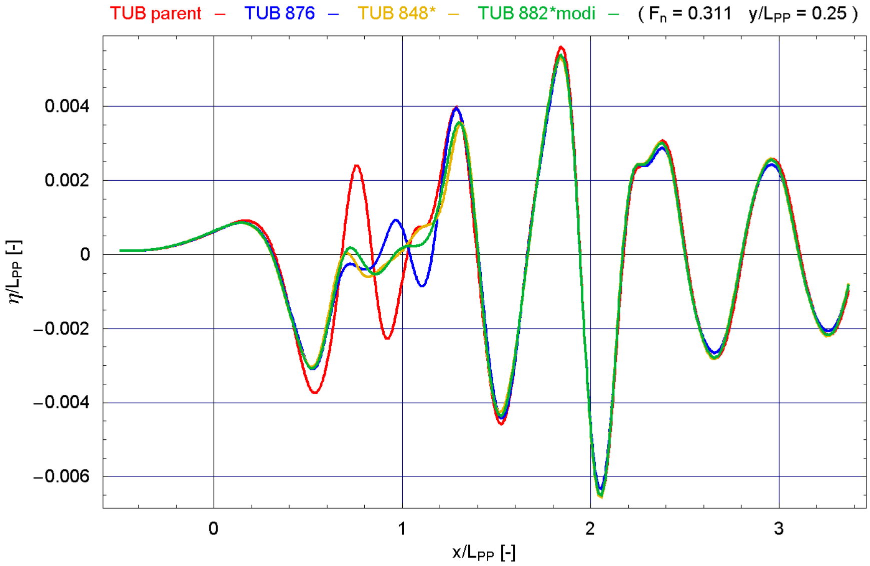


Fig. 11: Longitudinal Wave cuts at y/L_{PP} = 0.25

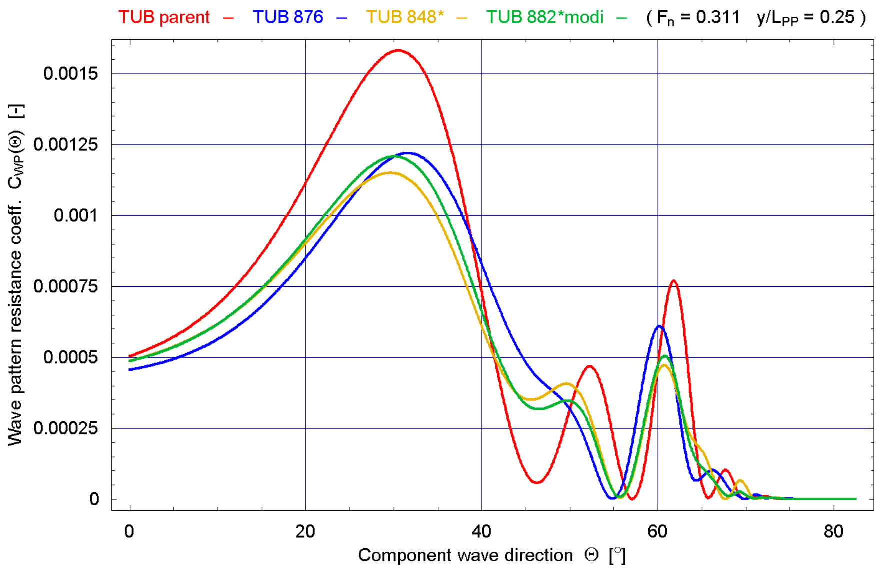


Fig. 12: Distribution of the wave pattern resistance coefficient as a function of wave direction

The initial hull, TUB 876 and TUB 882*modi (see figure 9 for the lines plan) shall be looked at a little closer: The reduction in resistance accomplished by TUB 876 and TUB 882*modi when compared to the initial hull originates in more favorable wave interferences. Figure 10 displays contour plots of wave height for the three hulls. It is evident that the wave system has been substantially influenced. Longitudinal wave cuts are depicted in figure 11 for which a wave pattern analysis is presented in figure 12. Figure 12 reveals that the major portion of wave resistance improvement is attained by a reduction of the transverse wave components comprising wave directions up to appr. 35°. With the exception of TUB 876 further though smaller gains stem from the diverging waves as associated with the wave directions above 35°, compare to table IV. TUB 876 is best with regard to transverse waves but does perform less beneficial for diverging waves while TUB 882*modi represents an excellent trade-off capable of significantly minimizing wave energy losses.

Figures 13 and 14 feature the pressure distribution and limiting streamlines of the initial hull, TUB 876 and TUB 882*modi. The forebodies and bulbous bows are distinctively different and their effect on pressure distribution and flow direction is pronounced. From figure 14 one may also get an appreciation of the wave profiles along the hulls.

5. Conclusion

A comprehensive optimization of a fast ferry was presented on the basis of a synthesis model which comprised advanced parametric modeling, state-of-the-art flow analysis and detailed performance assessment. The optimization process features a multi-phase, multi-step, interactive and iterative character whose roots lie in the complexity of hydrodynamic design. The process relies on a complete IT integration as the prerequisite for automated optimization. The automated optimization itself enables the designer to investigate many variants without the overhead of tedious and non-creative work. In a multi-objective problem the best result depends on the designer's preferences (introducing also some subjectivity).

The process is initialized by redesigning a hull form in a fully parametric design tool. The selection of suitable free variables and the determination of their bounds is an important issue and needs adjustment during the optimization. For the exploration and the exploitation of the design space deterministic and stochastic strategies are applicable, each having their advantages and disadvantages. In order to get a first insight into the problem, one may start with a random distribution. A particularly good candidate can be improved quickly with a deterministic search. A more time-consuming but very comprehensive search is provided via genetic algorithms. One should not limit oneself to just one strategy but should try to combine all available tools to the best advantage.

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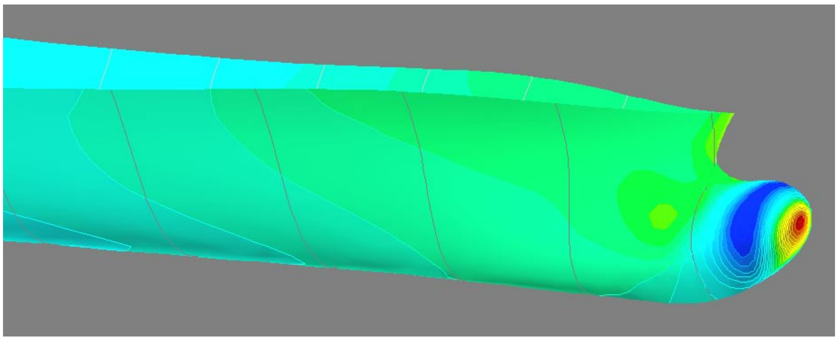
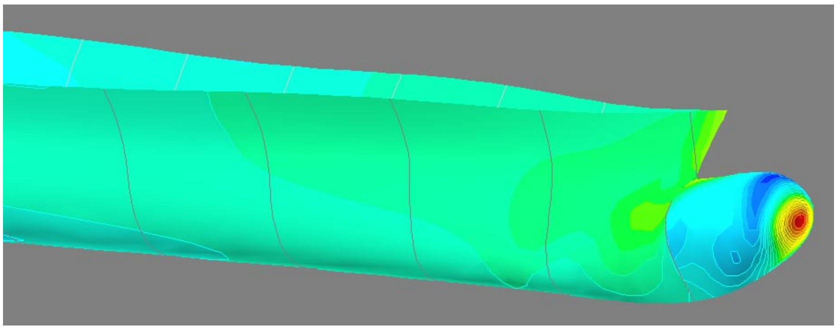
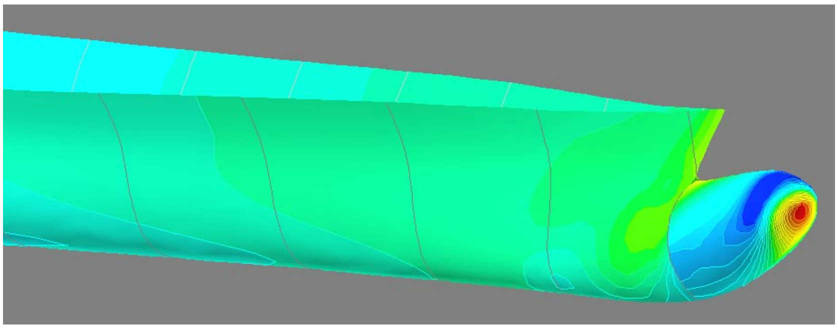


initial hull form

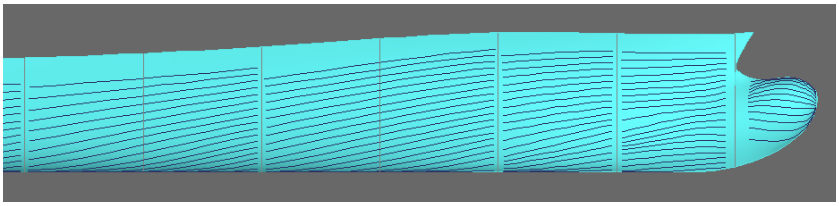


TUB 876

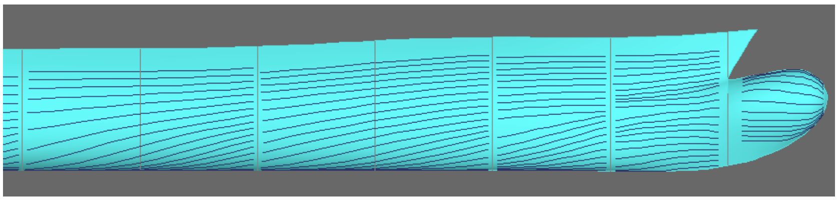


TUB 882*modi

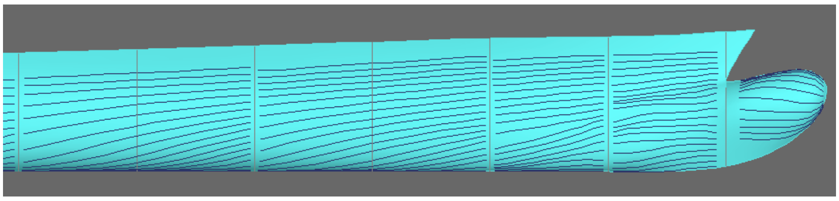
Fig. 13: Pressure distribution on initial hull form, TUB 876 and TUB 882 modi



initial hull form



TUB 876



TUB 882*modi

Fig. 14: Limiting streamlines for initial hull form, TUB 876 and TUB 882 modi