

## MODELING MEETS SIMULATION – PROCESS INTEGRATION TO IMPROVE DESIGN

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### Abstract

*Marine systems are one-off or small-series designs which are produced in a global market with tightening competitiveness and rising expectation of high quality. The natural gap between the knowledge about a product and this knowledge's relevance for decision making at an early point in the design process needs to be reduced.*

*The ability to simulate important aspects of a product's life-cycle is steadily growing and so are the methods of modeling. Integrating modeling and simulation excels the design process. It also brings about new insights since alternatives, trends, robustness etc. can be studied more comprehensively. Optimization is an important and unifying contribution to integration. Considerable progress has been made. As the amount of information becomes overwhelming new design methodologies need to be developed. There is a vast field of research and work ahead.*

*This paper presents a selection of past developments along with a brief discussion of much needed future work.*

### Keywords

CAD; CAGD; CAE; CFD; Integration; Optimization; Parametric modeling; Ship design; simultaneous engineering.

### 1 Introduction

Most marine systems are one-off designs. They require large investment and operate in harsh environments. This – understandably – leads to a certain conservatism. However, the marine industry is global and providers face severe competition. This then implies that innovative solutions are needed, the state-of-the-art having to be constantly pushed forward.

The design of marine systems is dominated by a considerable number of objectives and constraints which are related to the many competing aspects pertinent to the product's life time. Fig. 1 presents the generic phases of a product's life-cycle and their repercussions on design and planning. Apart from overall economic measures of merit (which do not necessarily match for all parties involved) it is not always clear at an early stage which design aspects

### Übersicht

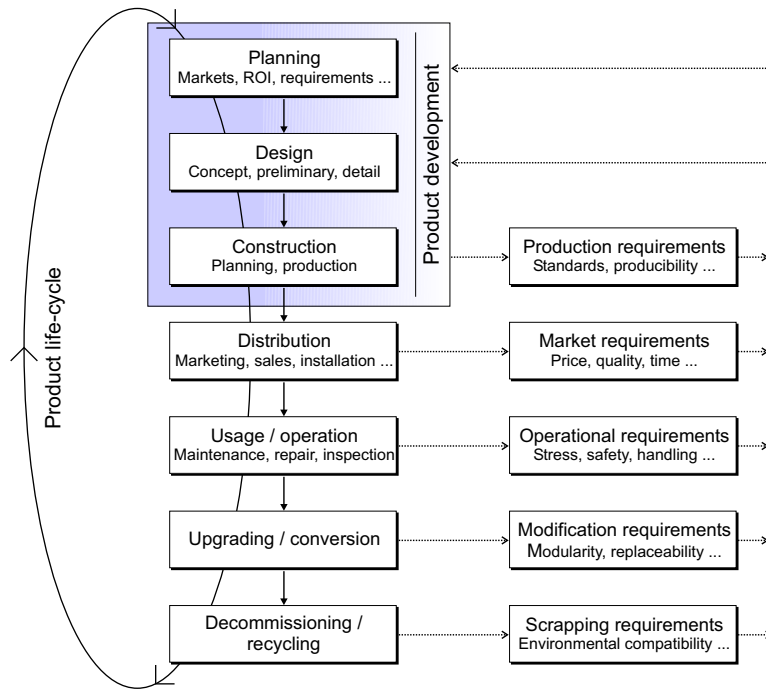
*Maritime Systeme werden als Unikate oder in kleiner Serie für einen globalen Markt mit stetig wachsendem Wettbewerb und steigender Qualitätserwartung entwickelt. Während der frühen Phasen des Entwurfs besteht eine Lücke zwischen dem Wissen über das zu fertigende Produkt und dessen Entscheidungsrelevanz. Diese Lücke gilt es zu verkleinern, um die Wettbewerbsfähigkeit zu erhöhen.*

*Wichtige Aspekte des Produktlebenszyklus lassen sich zunehmend rechnergestützt modellieren und simulieren. Die enge Verknüpfung zwischen Modellierung und Simulation verbessert dabei den Entwurfsprozess. Alternativen, Trends, Robustheit etc. lassen sich umfangreicher untersuchen. Formale Verfahren des Optimierens stellen einen wichtigen und vereinenden Beitrag zur Integration dar. Substantielle Fortschritte wurden hier erzielt. Mit Zunahme der Informationsvielfalt geht aber auch ein Bedarf an neuen Entwurfsmethoden einher, der nur durch intensive Forschung und Entwicklung gedeckt werden kann.*

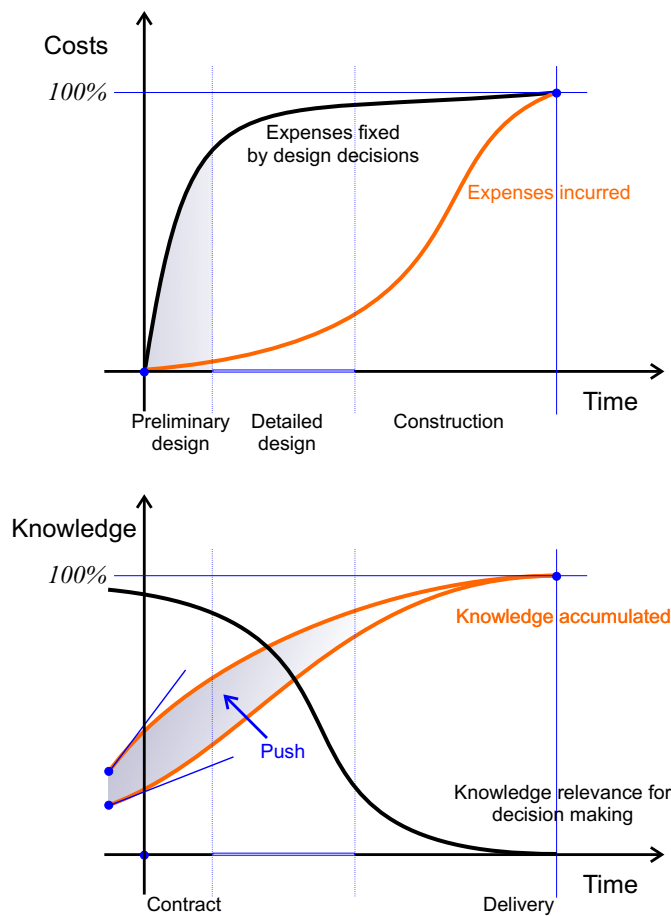
*Dieser Beitrag fasst einige wichtige Entwicklungen zusammen und diskutiert zukünftige Aufgaben.*

should be regarded as objectives and which as constraints. While this holds true for the design of all complex products, in ship design there is an additional difficulty associated with customized products and unit production: The bulk of the costs is typically fixed very early while the knowledge about the product is still quite limited. The freedom to make design decisions is high at the beginning but approaches zero as the product evolves. Fig. 2 illustrates this dilemma. It also points to its partial solution: The amount of knowledge and information from which to start a design has to be elevated while the velocity of knowledge generation needs to be increased. By reducing the gap between knowledge and its relevance the risk of serious misjudgment is reduced.

Naturally, the initial amount of knowledge and the velocity of knowledge generation are related to each other but they also differ: The amount of knowledge available is a function of the past and the mechanisms to store, retrieve and interpret previous data. The velocity of knowledge generation, meanwhile, is a function of the future and the techniques to model and simulate (what might be).



**Figure 1: Product life-cycle**



**Figure 2: Costs and knowledge vs. time**

This paper attempts to contribute to the field of knowledge generation. This is due to the fact that with deviation from established products the know-how gained from traditional solutions is less likely to substantially improve competitiveness. The ability to come up with innovative designs depends on the levels of sophistication in modeling, simulation and their tight integration.

Our background being the geometric modeling of ship hull forms and the numerical simulation of their fluiddynamic behavior, the focus of our discussion will be the hydrodynamic design of marine systems. It is hoped that one might be able to abstract from our point of view to other fields of interest.

## 2 Modeling

Modeling –

- *the design of forms,*
- *the creation of a mathematical representation of reality,*
- *the generation of a preliminary sculpture (usually on a smaller scale),*
- *the construction in imitation,*
- *the creation of a pattern.*

Geometric modeling constitutes an important part of marine design projects since, usually, many shapes need to be generated and varied. An advanced modeling approach significantly improves both the process and the product evolving from it, particularly if complex shapes like ship hull forms are considered.

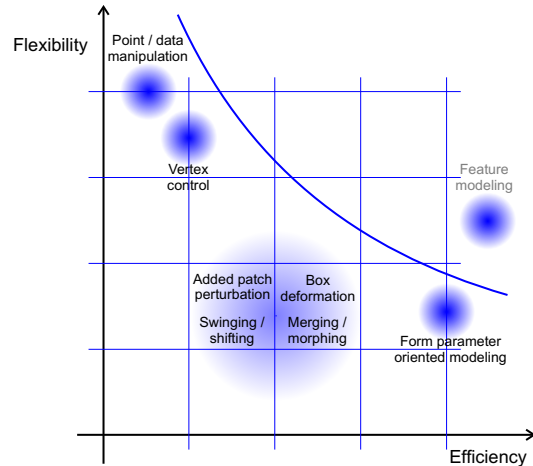
Many different Computer Aided Geometric Design (CAGD) techniques have been developed over the last decades. We focus on boundary representations (B-Rep) since constructive solid geometry (CSG) is less applicable to free form design. The available techniques can be subdivided into conventional and parametric approaches, see Fig. 3, and characterized in terms of

**Flexibility** The ability to cope with any possible shape.

**Efficiency** The swiftness with which information (here geometry) is generated.

**Effectiveness** The quality of the outcome (correctness, completeness, comprehensiveness).

Flexibility and efficiency are somewhat contradictory. Fig. 4 presents an estimate of the various B-Rep techniques with respect to flexibility and efficiency.



**Figure 4: Qualitative assessment of flexibility vs. efficiency in geometric modeling**

### 2.1 Conventional modeling

Conventional modeling techniques build on a low-level definition of geometry. Often points are used to define curves and surfaces. The actual work is predominantly interactive.

One mode of operation is from point via curve to surface data in which the final surface description resembles a patch work to cover the set or mesh of curves. Here, the curves and even more so their underlying data like points, angles etc. are the shape defining entities. Lofting and Coon's patches are prominent examples.

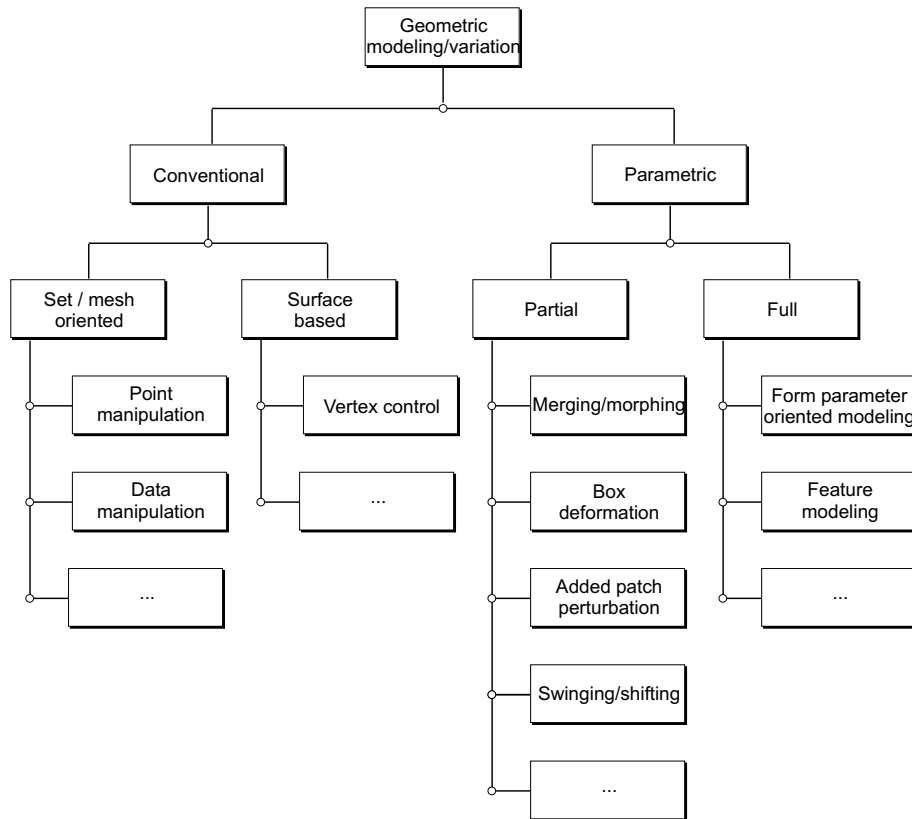
Another approach is to model the surface directly. Usually this is done by associating a surface with a polyhedron of vertices like in the Bézier and the B-spline world. The vertices are interactively manipulated to sculpture the shape, see Fig. 5. Prominent curves like for instance sections, waterlines etc. are then derived from the surface definition in order to show shape characteristics which can be customarily interpreted.

Conventional modeling techniques are very flexible since there are no inherent restrictions with regard to geometry or topology.<sup>1</sup> However, the amount of data becomes high which makes fine tuning a demanding and variation a time-consuming task.

### 2.2 Parametric modeling

In parametric modeling the design problem is formulated partially or even fully in terms of high-level entities which are tailored to the design task at hand. These entities are generally called parameters and in geometric modeling they are more specifically called form parameters. Parameters are the descriptors of the product to be developed. Parameters feature relationships. Their values might be com-

<sup>1</sup>Irregular topologies may be handled via degenerated quadrilateral patches, trimmed patches or triangles.



**Figure 3: B-Rep design and variation techniques**

puted from a formula, they might depend on certain conditions or they may be determined from a set of equations etc. In this way a product is represented in a problem-dependent context at a much higher level.

The most prominent advantage of parametric techniques is that variations – i.e., small to intermediate modifications – can be produced very efficiently. Extreme changes naturally cause problems since a suitable parametrization is per se a specialization rather than a generalization. (You will just not be able to produce a sailing yacht from a super tanker template.)

Partially parametric approaches build on a non-parametric definition of the shape and a description of the modifications in terms of parameters. Fully parametric approaches aim at a comprehensive and consistent parametric definition of the entire geometry.

The *FRIENDSHIP-Modeler* is a form parameter oriented modeler that attempts a hull type dependent definition in which the specifics of each shape are captured. Parameters are descriptors like lengths, volumes, areas, angles etc. and each geometry is computed by fulfilling the form parameters and optimizing for fairness. Fig. 6 to Fig. 9 show example hulls generated with different parametric models of the *FRIENDSHIP-Modeler*. It becomes obvious that no universal parametrization

exists. Fig. 10 illustrates a single parameter variation in which the length of the bulb is successively increased from 0m via 2m to 4m for a rather blunt bow.

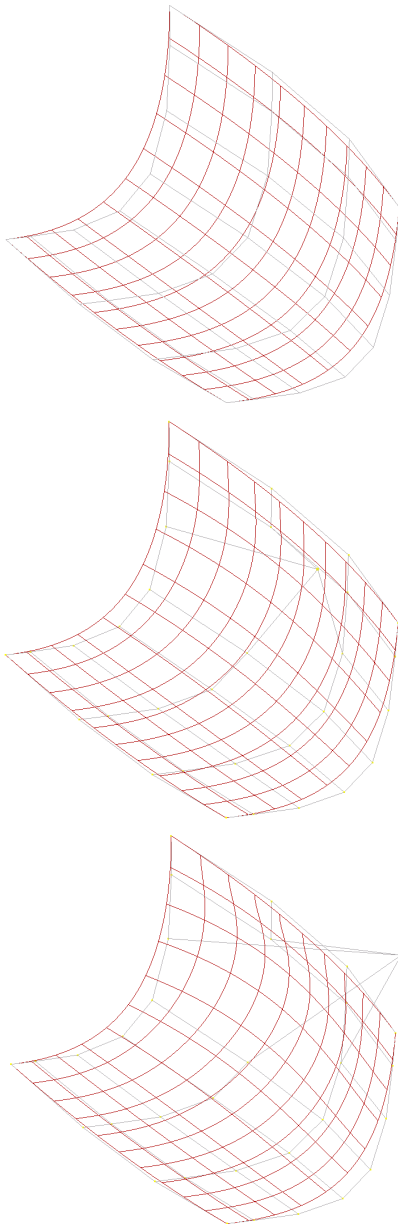
Partially parametric approaches are

**Merging / morphing** Two or more shapes are combined to produce a new shape as a mix of the given shapes. For instance, a suitable weighting factor is assigned to each topologically identical parent shape and a new shape is produced by linear superposition.

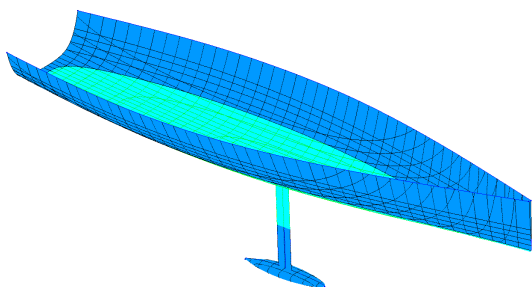
Fig. 11 and Fig. 12 present an example in which the polyhedron of a B-spline surface was first modified manually and then merged, the shape being the bulb of a fast ferry. For simplicity the weights of both parents were set to 0.5 each.

**Box deformation** A parent shape is placed into a box. Instead of varying the parent shape itself the box is distorted, dragging and squeezing the original shape. The method is also known as volume distortion, see Farin (2003).

For instance, a B-spline surface is embedded into a trivariate Bézier volume with parameters  $u$ ,  $v$  and  $w$ . The embedded B-splines' vertices are associated with their positions in the  $u$ - $v$ - $w$ -space of the box. By successively modifying the vertices of the Bézier volume

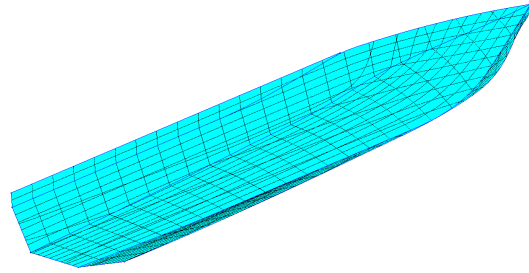


**Figure 5: Sculpturing of a Bézier surface via vertex manipulation**

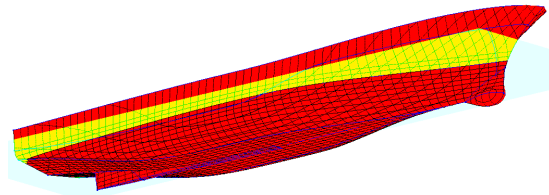


**Figure 6: Example yacht hull**

the vertices of the embedded B-spline surface change position too, thus deforming the original shape. Note that the vertices of the surface are changed in a concerted manner and not in-



**Figure 7: Example hard chine hull**



**Figure 8: Example frigate hull with sonar dome**

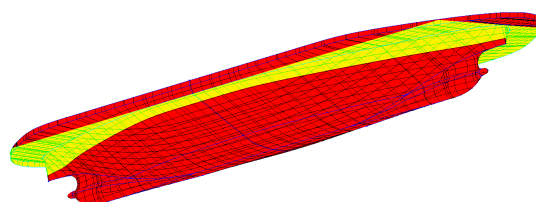
dividually.

**Added patch perturbation** A patch is placed on top of a given shape. The patch is used to perturb the original geometry which itself is left untouched. Changes are brought about by modifying the inner part of the patch so that positional or higher order continuity with the parent shape is maintained.

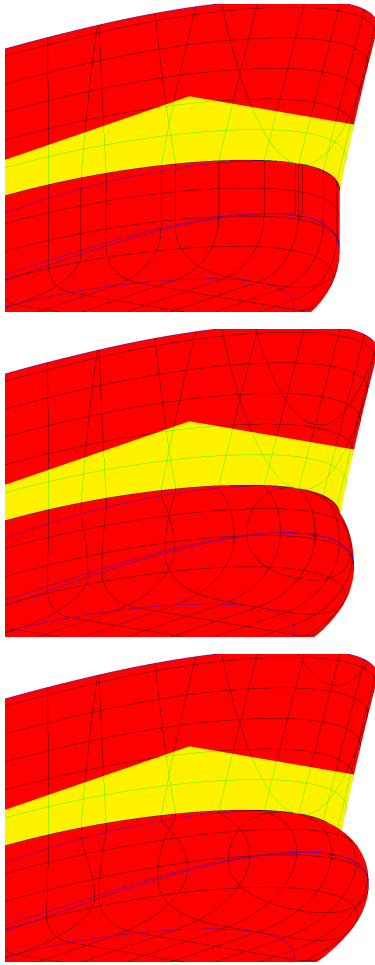
**Swinging / shifting** The swinging technique is also known as the Lackenby method, see Lackenby (1950). It is special to naval architecture: The sectional area curve of a parent hull is systematically changed and the new hull is determined by moving entire sections longitudinally to match the new sectional area curve.

The shifting method also utilizes positional modifiers to evoke shape variations. It is more general than the Lackenby method since point data is shifted in three dimensional space using arbitrary transformation functions.

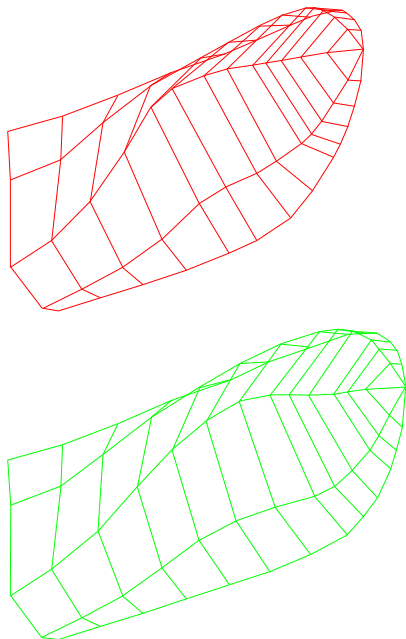
The complexity of the various parametric approaches differ and so does their applicability in certain design situations. A fully parametric approach allows to investigate a substantial range of design variants. One might even go beyond the common experience if desired and, possibly, identify new and favorable characteristics. The partially



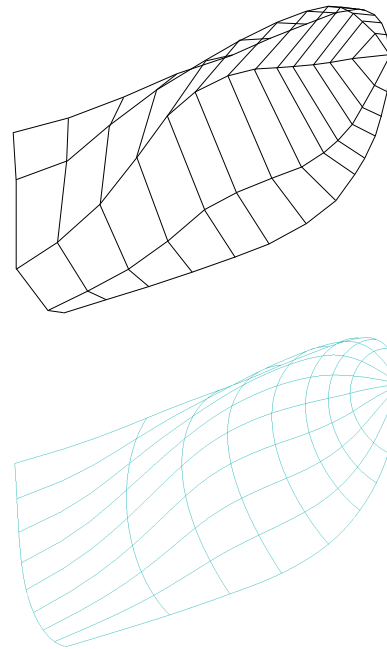
**Figure 9: Example double ended ferry**



**Figure 10: Single parameter variation of bulb length for dredger hull**



**Figure 11: Two parent polyhedrons for merging (see Fig. 12)**



**Figure 12: Merged polyhedron (compare to Fig. 11) and resulting geometry**

parametric approaches meanwhile allow to quickly investigate those alternatives that can be readily envisioned by the design team. Fully parametric and conventional design methods constitute generation techniques while partially parametric approaches have their focal point in variation.

Parametric methods mark a substantial progress in efficiency, see Fig. 4. The long-term goal, however, is to establish feature modeling in which designs will be specified in terms of performance rather than geometry. Consider a bulb for instance: A performance definition would be to ask for an entity that reduces wave resistance. Feature modeling is still subject to development and parametric modeling forms a key mechanism in its realization.

The challenge and the art of parametric modeling lies in establishing a balanced description that corsets undesirable shapes without impairing the necessary freedom of variation, see Birk and Harries (2003) for more details. A good parametrization is characterized by a small set of parameters. This then enables the designers to concentrate on the meta-level of a functional description and to combine modeling and simulation effectively.

## Simulation

Simulation –

- *the attempt to predict aspects of the behavior of a system by creating an approximate (mathematical) model of it while omitting certain (less important) characteristics,*

- *the act of imitating the behavior of some situation or some process by means of something suitably analogous,*
- *the (imitative) representation of the functioning of one system or process by means of the functioning of another (sometimes on a smaller scale),*
- *the technique of reproducing actual events and processes under test or idealized conditions.*

In the context of design one usually concentrates on computer simulations since any transfer from the digital to the real world implicates a certain delay. Physical models simply need time to build, are quite expensive and very time-consuming to change.<sup>2</sup> When leaving the beaten track past solutions become less meaningful and first-principle methods need to be employed to forecast system behavior. In general, all aspects of the product's lifecycle are of interest and potentially subject to simulation, see Fig. 1. Prominent examples are hydrodynamic performance of the ship, structural behavior of the hull, operational assessment like loading-unloading, evacuation and routing – all of which and many more influence economic success. According to our interest and experience we shall confine our discussion to simulations by means of Computational Fluid Dynamics (CFD).

The full-scale viscous simulation of the flow about a ship with operating propeller under realistic environmental conditions remains a long-term goal. Happily it is no prerequisite for integrating CFD into the design process. Naval architects traditionally subdivide the complex problem of a self-propelled ship that maneuvers in a sea state into several subproblems:

- (Calm water) resistance,
- Propulsion,
- Seakeeping,
- Maneuvering,
- Special problems.

Even though all these subproblems are quite impressive themselves many methods are available today that yield meaningful results for a comparison of design variants. Moreover, it forms an immanent part of any simulation that the complexity of the real world is broken down to manageable pieces that still hold enough truth for engineering. For example, potential flow codes that solve the non-linear wave resistance problem generally give a reliable

<sup>2</sup>It is in no way insinuated here that model tests have become unnecessary but they become more and more important at advanced stages.

ranking already, see for instance Valdenazzi et al. (2003).

Furthermore, Moore's law of steady and substantial growth in computational resources holds a certain promise. An increase in computer speed and storage capacity can be utilized as follows in any combination:

**Higher number of variants** More designs can be analyzed in a given period.

**Faster response time** The same number of variants can be studied in less time.

**Better accuracy** Denser grids can be used for higher resolution of flow phenomena.

**Improved modeling** More sophisticated flow models can be utilized to better capture the real world.

In the sections to come we will concentrate on potential flow simulations since they are reasonably accurate for wave resistance computations and sea-keeping analyses and fast enough to allow simulations in the range of several hundred to a few thousand variants.

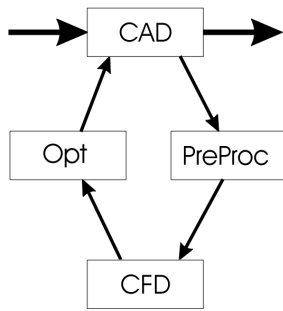
### 3 Integration

#### 3.1 Optimization

The desire to optimize is human: Resources have always been limited and a human trait is to search for the best under the given circumstances. The formal process of optimization is the mathematical representation of what people try to do all the time in almost any situation: Identify a good or even the best feasible compromise. The quality of this search for the optimum is substantially enhanced if a clear statement is made about the objectives (what is to be improved), the free variables (what can be consciously changed or influenced) and the constraints (what restricts the feasible domain). This task is very demanding and should not be underestimated since sometimes objectives, free variables and constraints are either not quite clear or no suitable mathematical models are forthcoming for their determination.

Let us suppose that good tools to model and simulate the specific design problem are present. Then it becomes a matter of integration to combine these tools and to set up an automated process to investigate a considerable number of variants. The more variants one succeeds to study the better is the knowledge about the product and the basis for decision making.

The current level of integration varies as depicted in Fig. 13 and Fig. 14. The common work flow involves various software packages:



**Figure 13: Common work flow**

- Modeling (CAD)
- Preprocessing and simulation (CFD)
- Assessment
- Optimization

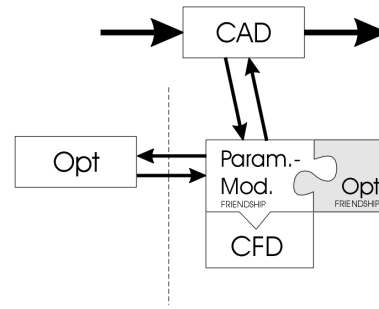
The assessment may be part of the CAD, the CFD or a separate package while the optimization engine typically is a generic tool.

Many different optimization strategies have been proposed which are either deterministic or probabilistic, see Birk and Harries (2003) for an overview. There is a consensus that each strategy has its advantages and drawbacks so that the choice depends on the problem. A common characteristic is that the effort scales superproportionally with the number of free variables  $N$ , typically in the order of  $N^2$ . Since most simulations range from a few minutes to several hours or even days it is imperative to reduce  $N$  as much as possible. And this is where parametric modeling comes into play: Describe a complex system with very few input variables and consequently cut down substantially on  $N$ , see section 2.

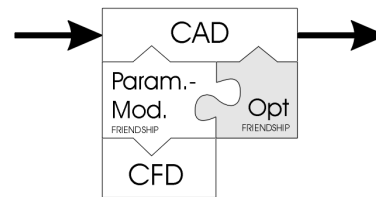
Nevertheless, the majority of designs are still modeled conventionally. Consequently, one either optimizes using conventional techniques with the disadvantage of many free variables, see Fig. 13, or one converts the conventional model into a parametric description, see Fig. 14, and utilizes the associated benefits. The conversion from a conventional into a parametric model implies additional work or a certain redesign. The next level of integration therefore implies then that the redesign is done with very little manual work and almost automatically as indicated in Fig. 15.

### 3.2 Process flow

Fig. 16 presents the typical process flow of optimization once a tight integration is realized. The details are taken from our consultancy work in hydrodynamic design but can be generalized to many other applications. The process is iterative and interactive and should not be confused with a black



**Figure 14: Advanced work flow**



**Figure 15: Future process integration**

box that yields good answers to ill-posed questions. 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 typically commences with a pre-processing phase. Once a parametric model is established the geometry can be generated and modified very elegantly. A detailed analysis of the initial design will then be undertaken which implies grid variation studies, convergence tests and accuracy checks for instance. Then follows the actual optimization phase which can be further subdivided into three steps.

In the first step the optimization task itself 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 and to investigate the design space. One might choose a design-of-experiment (DoE), for example a Sobol 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 on 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. Depending on the gains in the objective functions 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 further exploitation of promising variants is carried out on the basis of an appropriate optimization algorithm. For example the tangent search strategy as introduced by Hilleary (1966) may be applied. The exploitation is usually performed several times until satisfying solutions have been found. At the end of the exploitation step several improved designs are available.

In the case of a multi-objective optimization the selection of the final design itself is not necessarily a trivial task. It is undertaken in the third phase of post-processing by studying the Pareto frontier which is the set of all designs that cannot be further improved with regard to one objective without impairing any other. The process may then end with a further analysis of the favored variants.

## 4 Selected examples

Based on the given background we would like to briefly present some examples for illustration. Details are found in the cited papers.<sup>3</sup>

### 4.1 Optimization of a fast ferry

A comprehensive optimization example without the typical restrictions of proprietary rights is the FantaRoRo test case which was realized within the EU project FANTASTIC, see Valdenazzi et al. (2003). The forebody of a contemporary ferry was to be improved with respect to total resistance at  $F_r = 0.311$ ,  $L_{PP}$  being 122.74 m. The total resistance was computed via non-linear wave resistance codes and ITTC type approximations of the viscous components.

The optimization comprised the steps outlined in Fig. 16. Following a DoE a multi-objective genetic algorithm was employed to identify a hull shape that would tangibly reduce resistance, see Abt et al. (2003). In the end a reduction in total resistance of about 6% could be achieved, the improvement in wave resistance being about 15%. Fig. 17 shows the wave contours of the initial and the final hull taken from Harries and Heimann (2003). Many hundred designs were investigated in the automated process which would have been prohibitive in an interactive design mode.

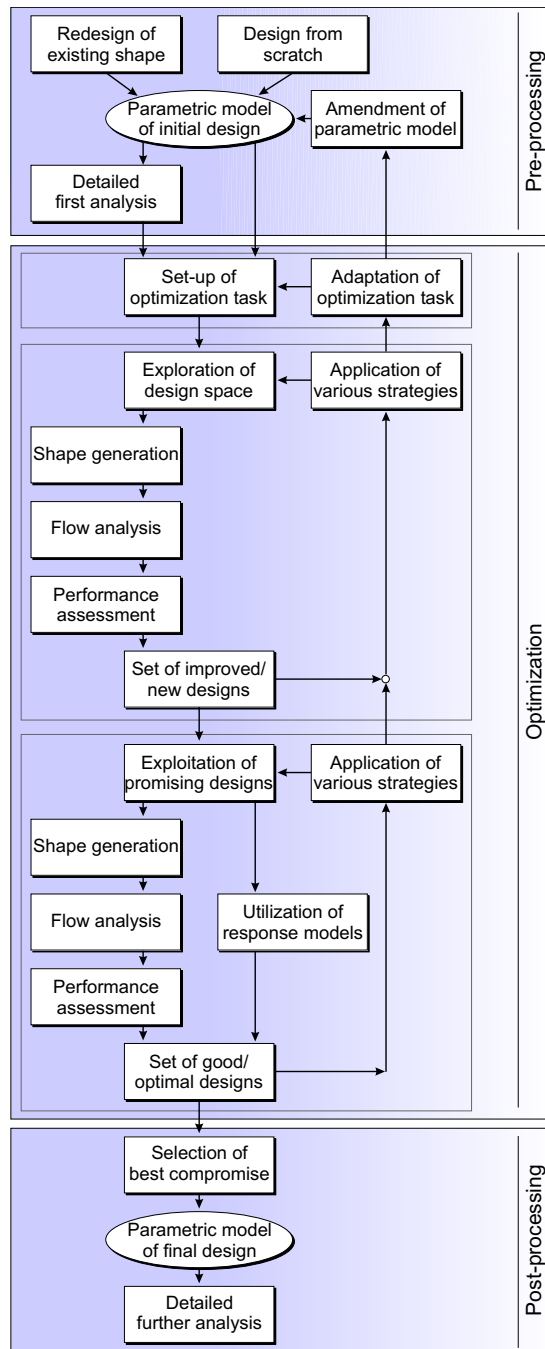


Figure 16: Process flow

### 4.2 Constraint management

Before engaging in any directed search a preliminary exploration of the design space is advisable. Fig. 18 shows the projection of a (quasi-)random Sobol sequence as the basis for a statistical analysis, the coordinate axes being two normalized free variables of the multi-dimensional search domain, see Abt et al. (2004) for more. The distribution of feasible and infeasible solutions as well as lucrative regions for subsequent exploitation can be studied.

Fig. 19 illustrates the increase in the number of feasible designs as a result of relaxing an inequality constraint by 5%.

<sup>3</sup>See [www.FRIENDSHIP-Systems.com](http://www.FRIENDSHIP-Systems.com) for downloads.

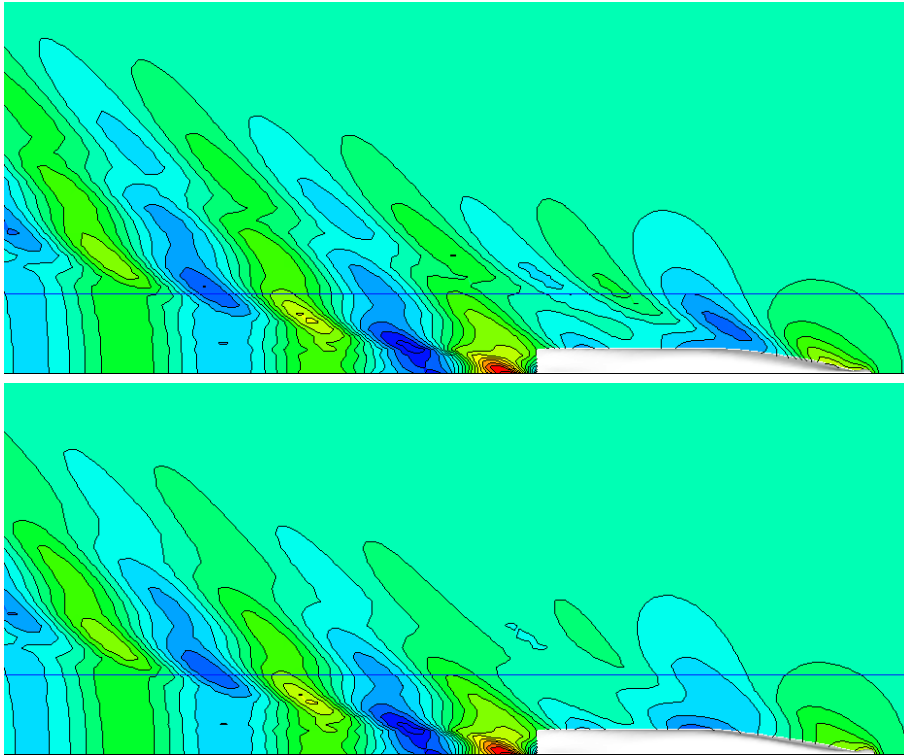


Figure 17: Wave contours of initial (top) and final design (bottom)

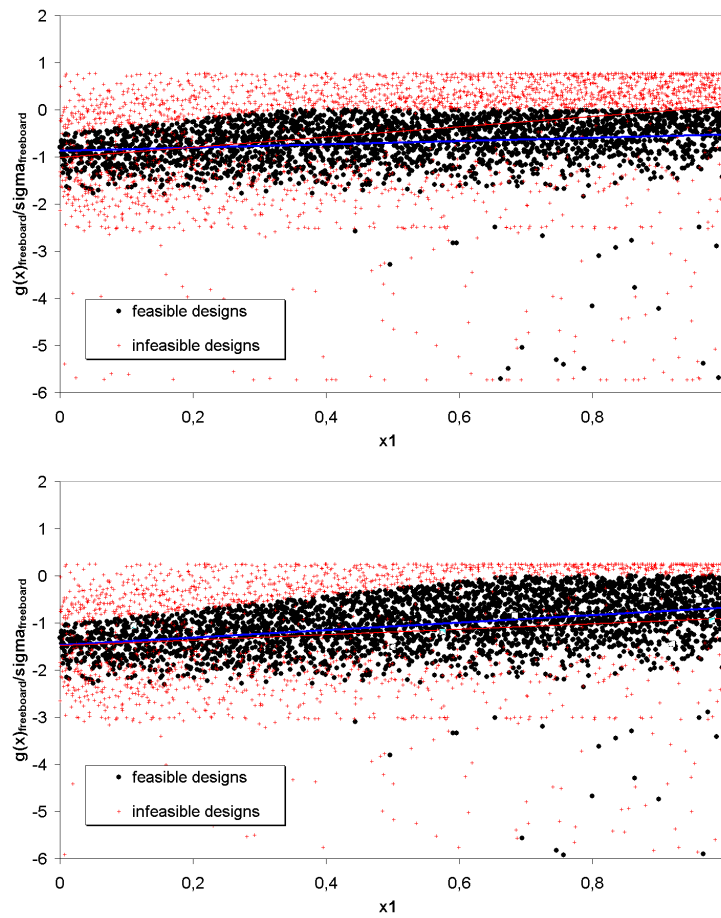


Figure 19: Distribution of feasible and infeasible designs for different limiting values of an inequality constraint

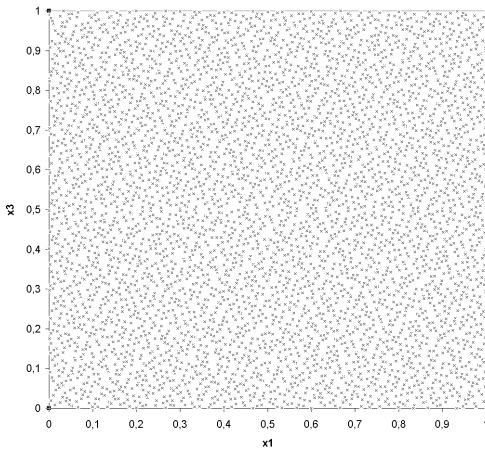


Figure 18: Sobol sequence

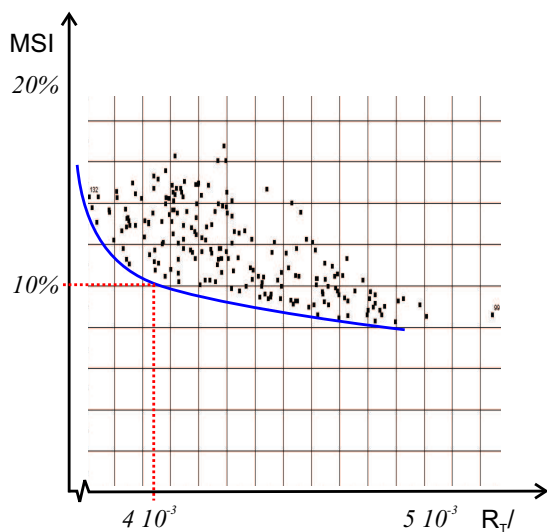


Figure 20: Pareto frontier of motion sickness incidence and normalized resistance

#### 4.3 Pareto optimal design

As soon as several objectives are pursued a trade-off needs to be found. Fig. 20 illustrates such a situation for a fast ferry, see Harries et al. (2001). A reasonable compromise was sought between the motion sickness incidence (MSI) of passengers and the resistance of the vessel. The MSI and the resistance were determined with potential flow codes.

The Pareto frontier is given by the curve bounding all designs in the lower left corner. The Pareto frontier assists in finding the designs which – according to the preferences of the design team – yield good performance in both (all) objectives. It can be nicely observed that for a certain MSI value, say 10%, the non-dimensional objective  $\frac{R_T}{\Delta}$  cannot be reduced below certain limits, here  $4 \cdot 10^{-3}$ .

## 5 Outlook

Naturally, geometric modeling, hydrodynamic simulation and formal optimization as discussed above

represent just one field in the design of marine systems as a whole. Still they serve well to illustrate the benefits of integration and help to identify areas in which more work is needed:

**Holistic design** Holistic design comprises all aspects of a product over the many stages and across the many disciplines.

Multi-objective and multi-disciplinary optimization as well as robust design are important contributors.<sup>4</sup> Genetic algorithms, global optimization strategies, constraint management, sensitivity analysis are important fields of research.

**Design methodology** Design methodology is concerned with the idealized way of work and, resulting from this, the best practise in order to achieve a desired result in a practical environment.

Decision support, data mining and knowledge discovery along with fuzzy logic, neural networks, expert systems, advanced scientific visualization and virtual reality are investigated. Man-machine interaction and user interfaces are further topics.

**Integration** Integration encompasses the necessary information and communication technologies to combine the many different tools and to handle the overwhelming amount of data.

Product data management, data exchange, information filtering and quality assessment are currently considered.

All these techniques are steadily improved. Nevertheless, the main advantage should be expected from a suitable technology combination. Much more research is needed to not only make all techniques available but also to make them applicable.

## 6 Conclusion

Design processes and resulting products can be improved by studying and managing as many variants as possible at an early stage when there is still considerable freedom for key decisions. By means of a tighter integration of modeling and simulation the knowledge on the envisioned product can be generated swiftly and comprehensively.

Major aspects of a product's life-cycle should best be considered simultaneously in order to deliver an excellent product. One prerequisite is that good

<sup>4</sup>Multi-objective optimization takes into account several objectives on the basis of the same free variables and constraints while multi-disciplinary optimization considers various objectives that relate to the same design but are functions of disparate sets of variables and constraints.

tools for modeling and simulation are available. Another prerequisite is that there is an advanced level of integration. The former is increasingly met while the latter has yet to be fulfilled in a broader context. More work in both academia and industry is needed here.

One small but important piece in the maritime design mosaic is the hydrodynamic performance of the system. Design integration was discussed for geometric modeling and fluiddynamic simulation of ship hull forms as a representative example of what has been achieved so far. Relevant modeling techniques were discussed. Formal optimization was shown to assist in generation, analysis and assessment of design alternatives which broadens the basis for decision making.

## References

- Abt, C., Harries, S., Heimann, J. and Winter, H.** (2003): *From Redesign to Optimal Hull Lines by means of Parametric Modeling*, 2nd International Conference on Computer Applications and Information Technology in the Maritime Industries, Hamburg
- Abt, C., Harries, S. and Hochkirch, K.** (2004): *Constraint management for marine design applications*, 9th International Symposium on Practical Design of Ships and Other Floating Structures, PRADS 2004, Travemünde
- Birk, L. and Harries, S.** (Editors) (2003): *OPTIMISTIC – Optimization in Marine Design*, Mensch & Buch Verlag, Berlin, ISBN 3-89820-514-2
- Farin, G.** (2003): *Curves and surfaces for CAGD*, fifth edition, Morgan Kaufmann, Jersey City, New York
- Harries, S. and Heimann, J.** (2003): *Optimization of the wave-making characteristics of Fast Ferries*, 7th International Conference on Fast Sea Transportation, Ischia (Golf of Naples)
- Harries, S., Valdenazzi, F., Abt, C. and Viviani, U.** (2001): *Investigation on optimization strategies on the hydrodynamic design of fast ferries*, 6th International Conference on Fast Sea Transportation, Southampton
- Hilleary, R. R.** (1966): *The tangent search method of constrained minimization*, Technical Report./Res. Paper No. 59, United States Postgraduate School Monterey
- Lackenby, H.** (1950): *On the systematic geometrical variation of ship forms*, RINA-Transactions, vol. 92
- Valdenazzi, F., Harries, S., Janson, C.-E., Lee-Andersen, M., Maisonneuve, J., Marzi, J. and**

**Raven, H.** (2003): *Optimisation of the Forebody and its Experimental Verification*, International Conference on Ship and Shipping Research, International Conference on Ship and Shipping Research, NAV 2003