DESIGN OPTIMIZATION

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SUMMARY

This paper explains how a significant optimization step in the yacht design can be achieved. Within the yachting industry it is typical that a designer (read stylist) starts with the design and having a Naval Architect stepping in at a later stage. By approaching yacht design as a co-creation between the designer supported by a Naval Architect, the outcome will in many aspects be significantly better; more purposeful designed for the Owner’s full intend. Looking back in time there is a clear trend that designs are getting more and more volume in a limited LOA. This trend is voting for getting a Naval Architect involved from day one.

1. INTRODUCTION

Over the last 5-8 years we clearly see a strong trend of Client requirements on efficiency, fuel consumption and comfort becoming more demanding. As a result the optimization process in yacht design has increased and improved significantly. The development of optimization tools like Computer Fluid Dynamics, viscous flow analysis, Wake field optimization studies, FEM Vibration analysis etc. have contributed largely to this.

While all of these tools are rather sophisticated nowadays and can provide remarkable results because of the required detailed input, they are usually being applied in the detailed design and engineering phase of the design process. While these optimization tools can significantly contribute to the efficiency gain and/or comfort increase, the biggest gain in optimizing the yacht can be found in the first stage of the design process, the concept design process.

2. HISTORICAL PERSPECTIVE

Figure 1 shows "Skipper" Herreshoff in his workshop on the third floor of the Castle. The nickname “Skipper Herreshoff” was given to him by the locals. During a period of 25 years Herreshoff designed a huge amount of classically beautiful yachts such as Ticonderoga, a sleek 72 foot clipper-bowed ketch that broke all kinds of records for her speed and agility, and larger Cup racing designs including J and M boats. A famous publisher of those days describes L. Francis Herreshoff's design style as follows, "His designs are marked by clean, sweeping lines and simplicity of hull and rig that show they have been drawn by a true artist." (Sensible Cruising Designs, McGraw Hill, Inc.) This statement is certainly clear to anyone who has seen Ticonderoga ("Big Ti" as many call her). Ticonderoga is a masterpiece of artwork, never mind speed. It is symmetry at anchor and symmetry in motion. No reverse-transom modern stern, no plastic hull and no aluminum mast.

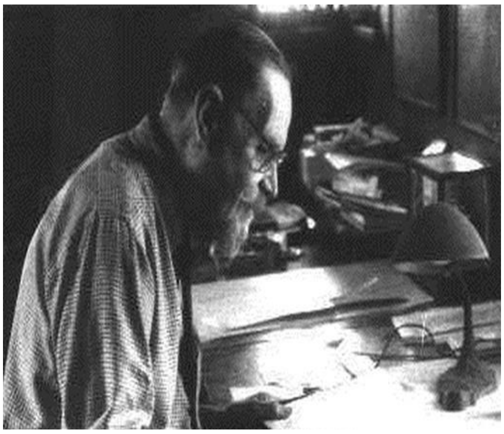

Figure 1 [*Skipper Herreshoff*]

This short biography nicely shows that back in the early days of yacht design, form and function were automatically integrated in the design because the designer and naval architecture profession simply were gathered in one and the same person. Any owner in need of a new yacht would hire a naval architect and commission him to design a new boat. The naval architect would then start with putting the main hull particulars along with calculating the weight of the boat. These main parameters would accommodate the weight and provide seagoing comfort, safety and efficiency. Based on the main particulars, the linesplan of the hull together with the general arrangement plan would be drawn. With the design of the main particulars and general arrangement, the naval architect basically determined the styling of the yacht as well. However, at that time, the form was more following the function.

Since the 1970's, designers like Jon Bannenberg Sr. introduced styling in the yacht design business as a dedicated profession. From that moment the naval architect and the stylist would work side by side on yacht design projects, each bringing their own skills and expertise. The stylist would work on the looks of the yacht above the waterline, while the focus of the naval architect would be more below the waterline. The functional design more and more followed the styling.

Today, the design process usually starts with a stylist; the naval architect being typically not yet involved in the conceptual design phase. It is the designer who determines the main particulars for the general arrangement. Obviously with this, the designer also determines the seakeeping behaviour, safety and performance of the design.

3. THE PROCESS

Since the early days it is the essence of yacht design to combine form and function into one and the same design. The final result should above all match the Owner's requests. Lots of decisions in the yacht design process have something to gain and something to lose. As we all know examples of such decisions are the main dimensions, building material, location of the engine room, propulsion concept, shape of the hull, internal volume versus the length etc. All these design considerations have impact on the behaviour, functionality and cost price of the yacht. While these considerations often are beneficial for one design consideration at the same time they might have a negative effect on other aspects of the yacht. This means in the conceptual design phase the proper balance between these design considerations is to be found. It is the main task of the designer and naval architect to match them corresponding to the intended use and preferences of the Owner.

In the concept design phase the main dimensions, characteristics and general arrangement plan are determined and often more or less fixed. Due to this fixation, the behaviour and functionality of the yacht are fixed for a great deal as well. Turning this around, this means that the yacht can be best optimized to match the intended use, the operational profile and preferences of the Owner in the conceptual design phase. In other words; the first weeks of the design process are crucial for the behaviour and functionality of the yacht over its full life time.

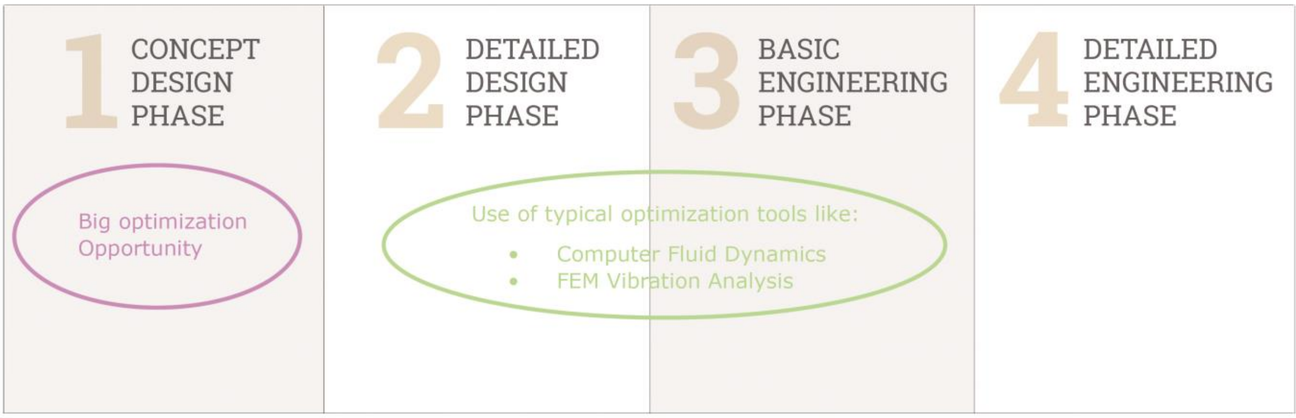

Figure 2 [*Typical phases in design & engineering process*]

While these design considerations usually affect the styling, the general arrangement, the naval architecture, structural arrangement, and mechanical engineering at the same time, as indicated in Figure 2, the biggest gain in this optimization process can be achieved if the various disciplines involved in yacht design and engineering are included in the concept design phase from day one. In other words, when applying a holistic design approach.

4. THE DESIGN PROCESS

The linguistic explanation of 'Holistic' is indicated in Figure 3. In line with this explanation, the holistic design approach takes all aspects into account at the same time. This result can only be achieved when the stylist and naval architect work closely together from day one of the project. Each of them putting their own

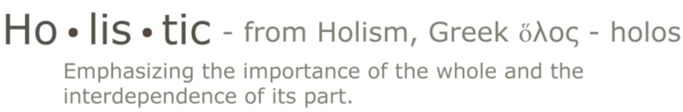

Figure 3 [*Holistic definition*]

specialized experience and expertise in the concept design phase. When both specialized experts co-create in the right design process, the result will be more then the sum of each individual part.

4.1. Naval Architecture Workflow

As indicated, in order to achieve the proper result it becomes crucial that a proper design process is followed. For Naval Architects, the basic of such a process is indicated in Figure 4. As can be seen in this diagram, the contribution of the naval architects in this stage of the project consists of two main tasks:

1. Naval Architecture work;
2. Ship Design work.

The main difference between these two tasks can be found in the same diagram as well.

The Naval Architecture work is commonly known and includes mathematical calculations, algorithms, equations etc. All being executed in order to obtain the performance from the drawings and main particulars. This work includes resistance calculations, stability calculations, weight calculations etc., the real number crunching work. It will be obvious that this part of the Naval Architect's work requires a crucial in-depth knowledge of the true story behind various equations and algorithms. Only with this knowledge there is true value in the results of the mathematics.

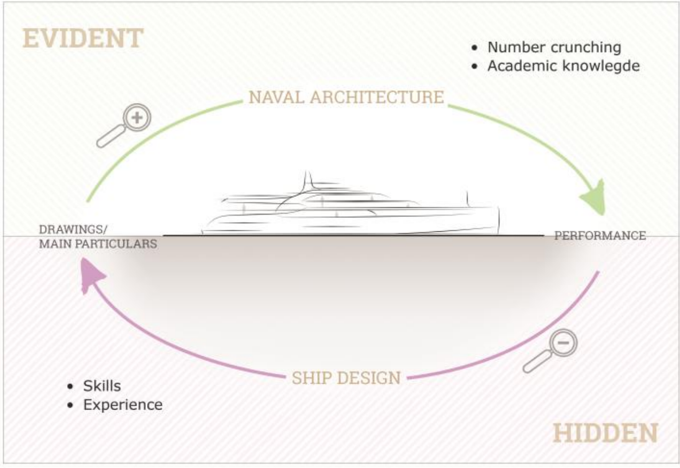

Figure 4 [*Naval Architecture workflow*]

The second part of the Naval Architecture job is the ship design task. This might be the less common, say the more unknown part of the Naval Architect's expertise. The design task is way apart from the 'comfortable' number crunching, it is the helicopter view on the total design, the zoomed out perspective. This is the part of thinking along with the designer, to support him or her in giving valuable information to the design process.

So when we combine these two tasks we get a very valuable tool in the development of the optimum design.

4.2. The Smarter Design Process

We all are familiar with the design spiral as commonly known, see Figure 5. This spiral is a flow from outside towards the center representing that the Naval Architect's work is getting more and more detailed as time passes.

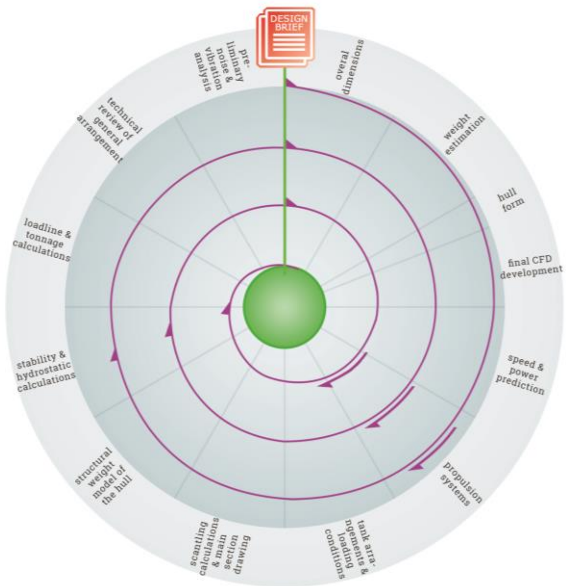

Figure 5 [*Classical design spiral*]

We believe that is not a correct representation of the happening in the co-creation of a design between the designer and the Naval Architect. If we take the distance between each axes for the effort the Naval Architect gives in his or her work, the process should start in the center of the spiral and working the way out towards the end of the spiral. In the conventional spiral there is a clear end of the spiral. You could even debate this. Is there an end towards the work of a Naval Architect. Is it not the case that his or her expertise is also valuable during the build and commissioning?

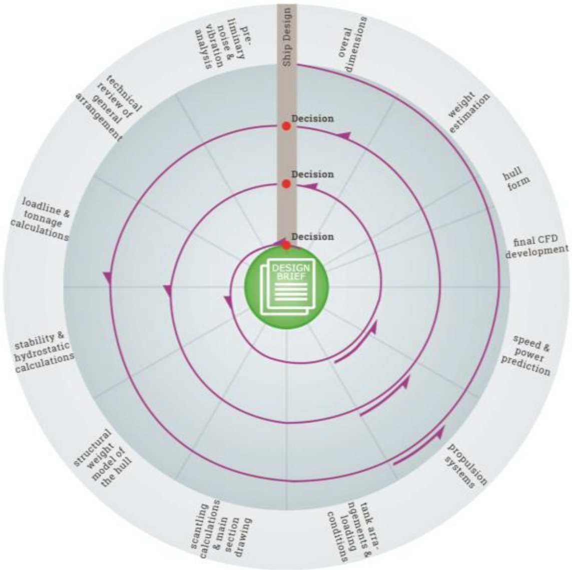

Figure 6 [*Smarter design spiral*]

The figure of the smarter design spiral shows clearly that:

- The first iterations are finished much quicker than the last iterations. The sequence of the iterations is high, the time between each of them is short;
- The further the progress, the more time each iteration takes and their sequence is getting longer. The further the progress the more time it takes to execute each iteration;
- The level of work and detail is increasing per iteration;
- Most likely the amount of people working per iteration will increase as well. Ideally the spiral starts with a very limited amount of naval architects (preferably one!) were gradually more people can be added to the team;
- The impact of the alterations to the design should decrease per iteration. With every new iteration, the impact of the changes should be reduced. As a result of that, the decisions which have big impact on the design should be taken at the beginning of the design process, while gradually the impact of the decisions is reduced;

The smarter design spiral starts with the Owners requests and intended use of the yacht. Summarized in the design brief. For this design brief, based on reference yachts (read: experience!) the first main dimensions are determined along with a first hull form. For these main particulars the essential performance is checked (the hard core naval architecture) based on which the main particulars can be adjusted again.

Having a closer look at this figure, we can add one important conclusion as well: The right decisions need to be taken at the right moment. When decisions are delayed in the process, they will pop up later and force you to go back to the part of the process where this decision needed to be taken in the first place. This will result in redoing part of the process. The impact of a set-back is large and getting larger as we move on. The further in the process, the more effect this rework will have in terms of money and capacity.

The main conclusion here: the duration of a proper yacht design process cannot be decreased by skipping some elements (deliberately reducing the amount of iterations) trying to save time. Not even by adding more resources in the beginning of the process. In this respect, the proper design process follows the general rule:

‘*What 1 woman can do in 9 months, 9 women cannot do in 1 month*’

This leads to the question; how to effectively reduce the duration of the yacht design process. The answer is easy: aim at first time right, focus on the center of the spiral in the co-creation process. Put an experienced Naval Architect with access to a proper reference database beside the designer this will lead to a reduction of the number of required iterations and hence reduce the duration of the design process while keeping the quality of the design AND performance.

5. DESIGN RATIO´S

5.1. Main Particulars

As indicated and very commonly known main particulars affect the performance of any yacht. Some of these main particulars are directly related to the profile and layouts and are therefore usually determined in the very early beginning of the design process.

One of the most important design particulars is the amount of volume for a certain amount of length, or the amount of gross tonnage per length: $\frac{GT}{L_{oa}}$. This ratio is influenced by the amount of superstructure which is put on the hull. While the amount of Gross Tonnage usually represents a certain amount of weight, this figure has a rather significant effect on the performance of the yacht.

In addition to the Gross Tonnage per length ratio, in general, the influencing parameters can be distinguished for seakeeping and wavemaking behaviour.

5.1.1. Wavemaking resistance

The design ratios which significantly affect the wavemaking resistance are: the weight per length ratio, the length over beam ratio, the prismatic coefficient and the longitudinal location of the centre of buoyancy.

For motor yachts, the most dominant factor for the performance is the ratio between the waterline length and the weight of the yacht, often indicated as the slenderness ratio: $\frac{L}{\sqrt[3]{\nabla}}$ (Gaillarde, Toxopeus, Verwoest, & Hooijmans, 2006). This ratio actually gives an indication on how much weight is ´carried´ per length. While the internal volume of the yacht directly effects the weight, this figure is significantly influenced by the GT per length ratio. A higher slenderness ratio implicates a relative longer waterline length, which means a relative lower Froude number. The Froude number is an important factor in the wave making resistance. This means the higher slenderness ratio will decrease resistance. Longer and light boats have relatively less resistance.

The second coefficient which affects the resistance is the prismatic coefficient, C_p. The ideal prismatic coefficient is dependent on the Froude number, however, for hull speeds, the optimum C_p is approx. 0.59 to 0.60. For displacement yachts, a higher C_P will increase the calm water resistance.

The longitudinal location of the centre of gravity in relation to the waterline length is important for the wavemaking resistance as well. The optimum LCB location is related to the Froude number. At the same time, the location of LCB should match the longitudinal location of the centre of gravity. While LCG is mainly the result of the general arrangement, the general arrangement directly affects the location of LCB as well.

In addition to these design ratios, a bulbous bow can significantly reduce the wavemaking resistance. In-house calculations, proven in sea trials, show that a CFD optimized bulbous bow can improve the performance with 10% to 15%.

5.1.2. Seakeeping

While the slenderness ratio has a significant effect on resistance, it also affects the seakeeping behaviour. In addition, the B/T ratio and the shape of the bow are examples of main particulars which affect the seakeeping capabilities of a yacht.

Where a higher slenderness ratio reduces the resistance, in general, a higher slenderness ratio reduces the motions in the vertical plane (heave and pitch) and therefore reduces the vertical accelerations as well, (Gaillarde, Toxopeus, Verwoest, & Hooijmans, 2006). This increases the comfort level at sea.

As described by Dallinga (Dallinga & Kanerva, 1993) and Gaillarde et al. (Gaillarde, Toxopeus, Verwoest, & Hooijmans, 2006), the beam over draft ratio significantly influences the seakeeping behaviour as well. Like the slenderness ratio, increasing the B/T ratio decreases the motions in the vertical plane and the vertical accelerations. This results in increased comfort in seagoing conditions.

The effect of the bow on the seakeeping capabilities can be found in the damping effect of the bow on the pitch motions. The amount and way of damping is related to the centreline longitudinal section as well as the transverse sections in the bow area. The stem line; a negative bow and bow flare, they all influence the seakeeping behaviour.

In addition to these ratios the general arrangement itself strongly affects the comfort level on board as well. The vertical accelerations vary over the length of the yacht. In general, obviously, the highest accelerations can be expected near the bow and stern of the yacht, while the area of lowest accelerations will be approximately at $^1/_3$ from the aft. This means that in accommodation spaces which are located at the ends of the yacht, the comfort level will be less compared to the accommodation spaces located at $^1/_3$ from the aft.

5.2. Underwater trends

Knowing the main particulars which affect the performance, it is interesting to see the trends of these particulars over the last years.

As described here above, an important design ratio is the slenderness ratio. The trend of this ratio from the year 2000 to today is given in Figure 7. This graph clearly shows that the weight per length is significantly increased over the last years.

As a result of this, the trend lines of the block coefficient and prismatic coefficient have increased as well over the last years, see Figure 8 and Figure 9.

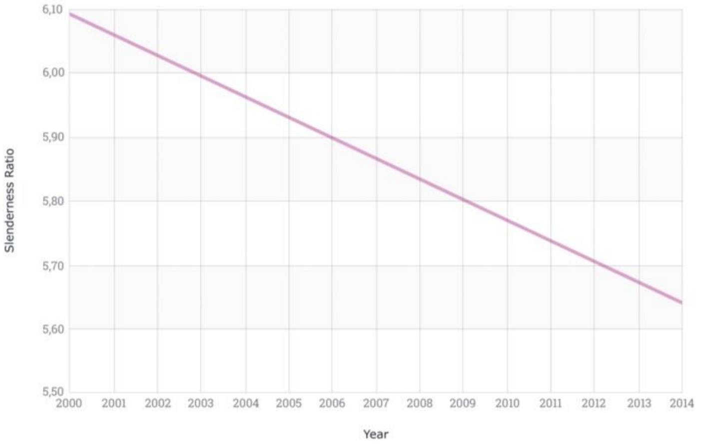

Figure 7 [*Trend line average Slenderness Ratio. Source: MARIN*]

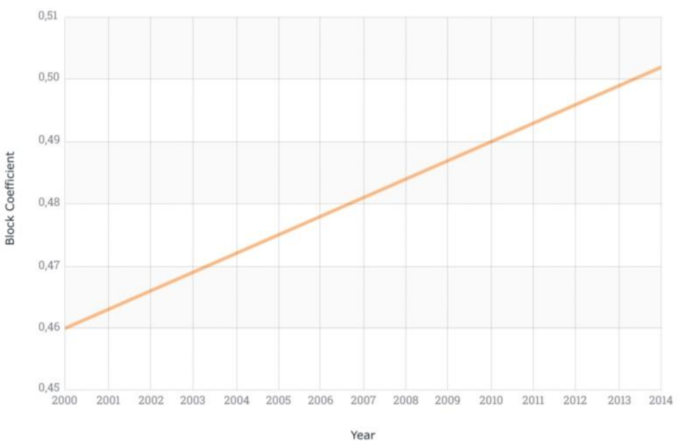

Figure 8 [*Trend line C_B. Source: MARIN*]

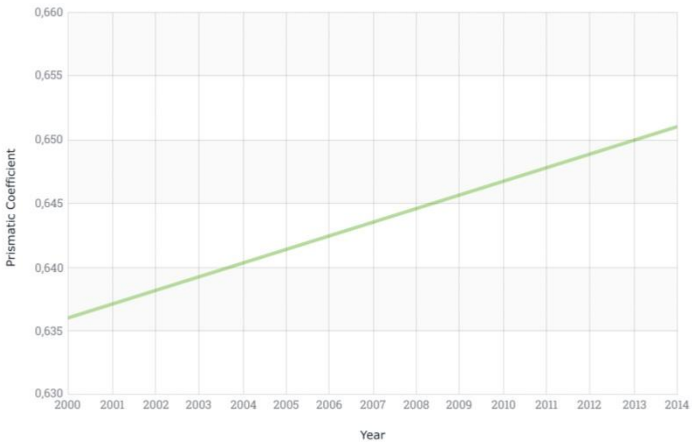

Figure 9 [*Trend line C_P. Source: MARIN*]

With the description of these design ratios as indicated in the graphs above, the effect of these trends on the performance is evident. While today's Naval Architects are trying hard to compensate the unfortunate effects of these trends by means of optimization of the details and appendages, it would of course be much more effective to get these design ratios right in the first place.

6. TO THE OWNERS BENEFIT

The main aim for the world wide yachting industry is to serve the yachting Owners with the development of the right products. Here comes the question: what is a right product? Is a yacht with a truly splendid exterior and interior design but being uncomfortable a right product? For any yacht which is made for sailing, even short distances, performance is somehow somewhere important. With performance we mean speed-power balance, stability, motions, but also functionality and safety. The Owners who spend money (some even lots of it) to develop a product deserve to receive value for money, not only in the design! Besides the fact that no matter how beautiful a yacht design is, when you get seasick on board or have an annoying AC system, you will tend to like the yacht just a bit less. A pity and for sure not deserved.

The yachting industry's common understanding of holistic is combining exterior and interior design. We strongly believe that this is just half way. Adding naval architecture and engineering to the yacht design process results in the True Holistic Approach.

Taking the smarter spiral (see Figure 6) and add a (system) engineer to the process, have him or her take a look at the design, giving input and support will lead to an even better design. In the end we all know that HAVC space requirements will happen, so why not better take this into account from day one. Obviously this again requires a hands-on approach from all the team members. Typically an engineer is easily distracted by details. In this phase it is all about the main concept along with respect for all the elements involved. Does this make the stylist's life harder? Does it border her or his creativity? Yes it might..... on the other hand; wouldn’t it make the stylist life more valuable and interesting? In the end, all the systems and functionality will be there anyhow. So better have the stylist take this into account, up to a certain level for sure. Stylist; you are there to serve the Owners of this world so better do it properly. Join forces with a Naval Architect and an engineer and put the stakes high(-er). You will be surprised on how much experience you will gain yourself in this process!

7. CONCLUSION

As we all see a growing trend that yachts are getting more and more complex along with demands to get deliveries sooner. This really calls for a true holistic approach working in a smarter design spiral to ensure the Right Product First Time Right: Better Boats in Less Time!

ACKNOWLEDMENTS

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