Real Cost Savings for a Waterjet-driven Patrol Craft Design Using a CAESES-NavCad Coupled Solution

Donald MacPherson, HydroComp, Durham NH/USA, donald.macpherson@hydrocompinc.com
Stefan Harries, FRIENDSHIP SYSTEMS, Potsdam/Germany, harries@friendship-systems.com
Simon Broenstrup, FRIENDSHIP SYSTEMS, Potsdam/Germany
Joseph Dudka, HydroComp, Durham NH/USA

Abstract

Much of the commentary regarding hull form optimization found in industry journals and proceedings focuses on process and methodology rather than outcome. This paper intends to show the real savings in acquisition and life-cycle cost for a waterjet-drive patrol craft that can come from a systems-based optimizing solution that is within reach of even small design offices. Two commercially-available software tools are used as a coupled solution to optimize the hull form for minimum resistance, with follow-on selection of a suitable waterjet model. An optimization process is described herein using FRIENDSHIP SYSTEMS CAESES as hull form modeler and optimizing platform, with HydroComp NavCad Premium responsible for resistance and propulsion prediction. The paper also highlights NavCad's prediction of bare-hull resistance using a novel linear wave-theory code that has been validated for high-speed transom-stern craft, as well as its use of engine and waterjet components for propulsion analysis and selection of an installation of highest propulsion efficiency.

1. Introduction

This story is about a tender for a waterjet-driven patrol boat that was nearing completion of its design, and the speed predictions were coming up short. (The design requirements called for a 26 knot top speed, but projections were indicating barely 23 knots.) The contractor was insisting that the boat be installed with a higher powered engine model – with a resulting increase in capital cost, life-cycle fuel consumption, and weight. The supplier of the main engines, however, felt that the installed power should have been adequate (based on similar installations), and contracted HydroComp for an independent technical review of the Hull-Waterjet-Engine system with the intent of determining how much power would be needed to drive the hull at contract speed. A resistance prediction and propulsion analysis confirmed that the boat would not make the necessary speed with the given hull form installed with the selected engine and waterjet models. However, as the engine builder suspected, the bottleneck was not insufficient engine power. The problem was that neither the hull nor the waterjet were optimized for the target speed and loading condition.

FRIENDSHIP SYSTEMS AG (Potsdam/Germany) and HydroComp, Inc. (Durham NH/USA) have successfully completed an optimized waterjet-driven transom-stern patrol craft design by utilizing the companies' principal software tools as a coupled solution. Geometric hull form modeling and optimization was performed by CAESES® with hydrodynamic analysis conducted in HydroComp NavCad® via its use as an efficient "coupled solver". The resulting design meets the operational objectives without installing a higher powered engine. The following sections describe the procedure and techniques used for this study, which can be employed as a template for anyone using a CAESES-NavCad coupled analysis.

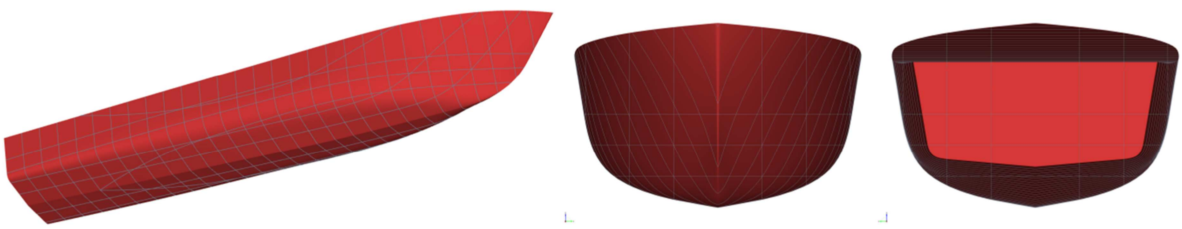


Fig. 1: Hull form of Parent (as imported to CAESES)

Table I gives a summary of principal dimensions of the initial (Parent) patrol boat, Fig. 1, along with bounds for modifications and the final (Proposed) design identified during the optimization. The Parent is a typical round-bilge hull with a immersed transom stern, featuring detached flow in the speed range investigated. The design was studied without appendages. However, the necessary added resistances (e.g., for windage drag) were accounted for within NavCad.

Table I: Principal dimensions and bounds for the optimization

	Parent design	**Lower bound**	**Upper bound**	**Proposed design**
Speed range of interest	Target speed 26 kn	15 kn	30 kn	Achieved 26 kn
LOA	29.00 m	0.96 LOA	1.05 LOA	30.30 m
LWL	27.44 m	0.96 LWL	1.05 LWL	28.62 m
Maximum beam at deck	6.80 m	0.96 B	1.05 B	6.27 m
Maximum B at DWL	5.74 m	0.96 B	1.05 B	5.52 m
Maximum draft T	1.40 m	Fixed to 1.4 m	Fixed to 1.4 m	1.40 m
Transom immersion	0.50 m	0.20 m	1.11 m	0.70 m
Transom’s deadrise	5°	1°	9°	3.3°
Displacement ∀	102 m^3	0.98 ∀ (constrained)	1.05 ∀ (constrained)	106.7 m^3
Center of buoyancy XCB (from transom)	0.503 LWL = 13.8 m	13.65 m (constrained)	14.49 m (constrained)	0.477 LWL = 13.65 m

2. Performance simulation for waterjet-driven transom-stern craft

For details about the system-level connectivity between the two tools, we refer readers to *Harries et al.(2015a)*. That paper introduced the steps to setup and run an optimizing calculation between CAESES and NavCad. In summary:

1. The tools each have clearly defined computational responsibilities. CAESES is the “design manager” of the coupled pair responsible for geometry creation and optimization, with NavCad conducting the hydrodynamic hull form and propulsor analysis.
2. The hull form shape parameters are developed in CAESES, describing the parameters that will be allowed to vary. Optimization parameters are also defined in CAESES.
3. The suitable resistance prediction parameters are set down in a master script. This allows data transfer to be reduced and limited to the geometric variables that have changed.
4. NavCad is launched in silent “server mode” and communication is established between NavCad and CAESES.
5. For each of the variants in the optimization study, CAESES interrogates the variant geometry and packages a script file to be sent to NavCad for analysis. Results are likewise returned in a text file and in diagrams for CAESES to pick up and use in its optimization algorithm and for design assessment.
6. Upon completion, CAESES passes a script call that closes the NavCad Premium server process.

Both CAESES and NavCad are run – and function – simultaneously. Each is launched under compliance of its own end-user licensing. While it is obvious that CAESES should remain running for the duration of a design or analysis study, a dedicated instance of the NavCad application process must also be running and "connected" with calculation authority remaining with CAESES. This insures that calculations are completed and returned properly without interruption.

3. Techniques for successful hull parameterization

Parametric modeling is widely recognized as the most efficient way to change geometry in an automated process. Different to an interactive approach in which, typically, low-level entities like points are modified (e.g., the vertices of a B-spline surface patch), a parametric model changes a larger extent of the geometry in a concerted way. In principle, two types of parametric models are distinguished: a) fully-parametric and b) partially-parametric modeling.

A fully-parametric model builds up geometry from scratch while a partially-parametric model uses an existing parent (or baseline) – for instance from a previous interactive modeling process – and just defines the changes parametrically. There are many potential techniques, all with pros and cons. The reader is referred to *Harries (2014)* for an overview and *Harries et al. (2015b)* for details. Most importantly, a fully-parametric model needs more time to set up but is very powerful, while a partially-parametric model is quicker to build but not quite as "sharp-edged". CAESES allows using a complete range of parametric modeling techniques, from FFD (Free-form Deformation) to building complex BReps (Boundary representation models), *Harries et al. (2015b)* and UberCloud.

Since a parent existed for the patrol boat and the acceptable time to come up with a parametric model was considered to be in the range of just a few hours, a partially-parametric modeling approach was chosen. From a naval architect's perspective several changes to the parent were considered to be potentially beneficial:

- Lengthening or shortening the hull (by simple scaling in longitudinal direction)
- Narrowing or widening the hull (by simple scaling in transverse direction)
- Increasing or decreasing the draft at the transom (by means of a surface delta shift)
- Increasing or decreasing the transom's deadrise angle (by means of a surface delta shift)
- Adjusting the deck contour in transverse direction, thus changing the design waterline (by means of a surface delta shift)

Some of the details of how these parametric modifications were realized within CAESES are discussed in Appendix A. Fig. 2 illustrates the regions where changes take place within the parametric model. It shows the so-called "design velocities" for four representative parameters that belong to the set of free variables chosen for the hydrodynamic optimization.

The color plots in Fig. 2 depict the magnitude of a surface's normal displacement for very small changes of one parameter at a time. Here, red (the upper two images) means outward displacement while blue (lower two images) relates to inward displacement when incrementing a parameter by a small positive value. For instance, changing the length of the boat as depicted in Fig. 2A affects the bow region the most while the side and bottom regions experience very little modifications. Meanwhile, changing the transom height does not change the bow at all while the transom is pushed upwards (i.e., inward with respect to the parent).

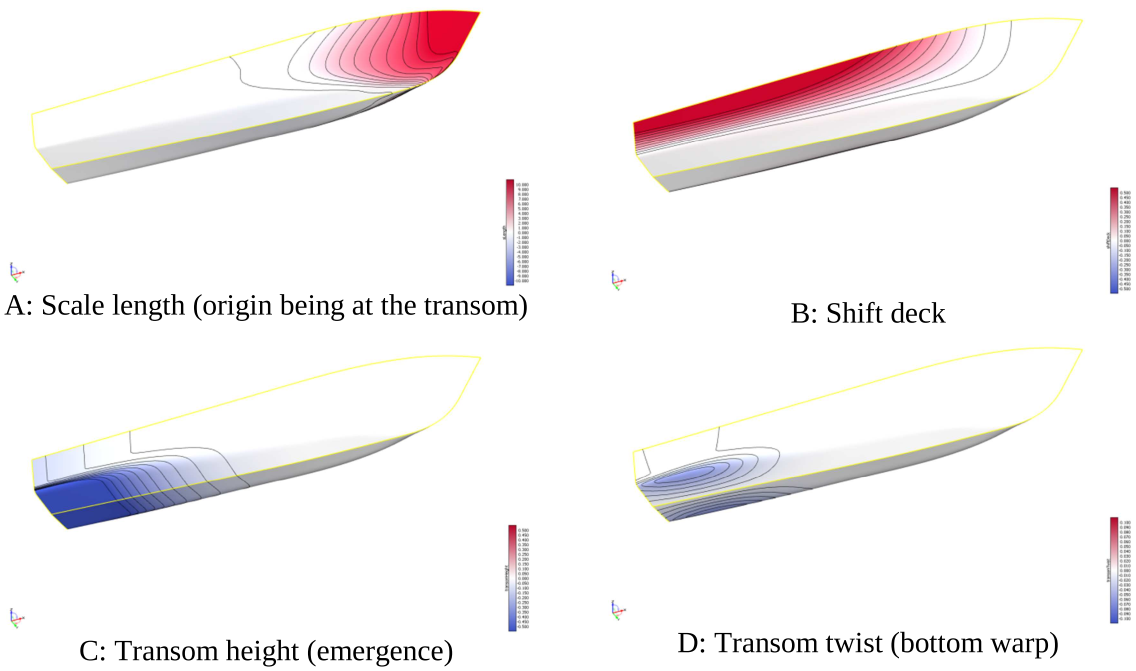


Fig. 2: Design velocities for selected parameters

4. Resistance prediction

The "simulation analysis" for this study starts with the determination of total resistance, including bare-hull, windage, and margins. The entire resistance prediction is conducted by NavCad, with data passed to it from CAESES and results returned for evaluation and optimization decisions. Over 40 parametric prediction methods are available in NavCad for a broad collection of vessel types, as well as a higher-order prediction code that nicely sits between parametric or statistical methods, and panel or even viscous CFD codes. Extremely fast, easy-to-use, and well-behaved, it was this code that was called on for the resistance prediction analysis in this study.

HydroComp has developed a novel implementation of a wave-theory bare-hull resistance prediction that has been deployed in the Premium Edition of NavCad. Inspired by thin-ship wave-making theory, it is a prediction of wave-making drag where the hull geometry is described by the longitudinal distribution of the immersed volume – unlike methods that use longitudinal distributions of the immersed surface (e.g., Michell's integral waterline cuts, panel codes, CFD). Calculation of viscous drag, including a thorough prediction of form factor and frictional drag coefficients, completes the computation of total bare-hull resistance.

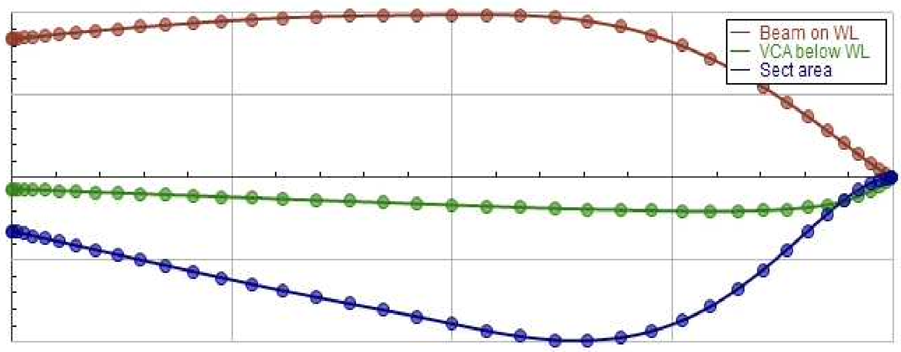


Fig. 3: Distribution of beam, immersion and sectional area

This code is called the “Prismatic Wave Drag” (PWD) method, in consideration of its fundamental use of the sectional area (i.e., “prismatic”) curve. It has proven very capable not only for traditionally slender forms but also for fast transom-stern craft. Its use as the computational foundation of a re-analysis of the Series 64 has shown its capability for craft of this type, *MacPherson (2015)*. Fig. 3 shows an example of the distribution data for the Parent hull (that is used by the PWD method).

5. Optimization for minimum resistance

Various approaches can be taken within CAESES to drive formal optimization processes, see *Harries (2014)*. For the patrol boat a combination of Design-of-Experiments (DoE) and a deterministic search strategy was selected. Firstly, a Sobol DoE (i.e., a quasi-random exploration of the design space) was undertaken to investigate the design space and to identify favorable parameter combinations. Secondly, several T-Search local optimizations (i.e., a deterministic pattern search) were run to fine-tune the hull form further.

Fig. 4 gives an impression from the assessment of designs within CAESES’s DesignViewer. Input parameters, hydrostatic data and the corresponding hull form are shown along with output data and diagrams from NavCad, allowing the rapid assessment of design candidates. Since the evaluation of any single variant would not take more than a few seconds on a standard notebook computer, several hundreds of variants could be easily investigated within the course of a day.

Fig. 5 depicts the correlation of objectives and free variables in an overview chart within CAESES. The investigation was done by means of a Sobol with 500 variants. While some free variables show little influence on performance (e.g., shiftDeck for the Telfer coefficient at both 22 and 30 kn), other free variables are very important (e.g. transomHeight). (The Telfer coefficient is defined as resistance times LWL divided by displacement times velocity squared.)

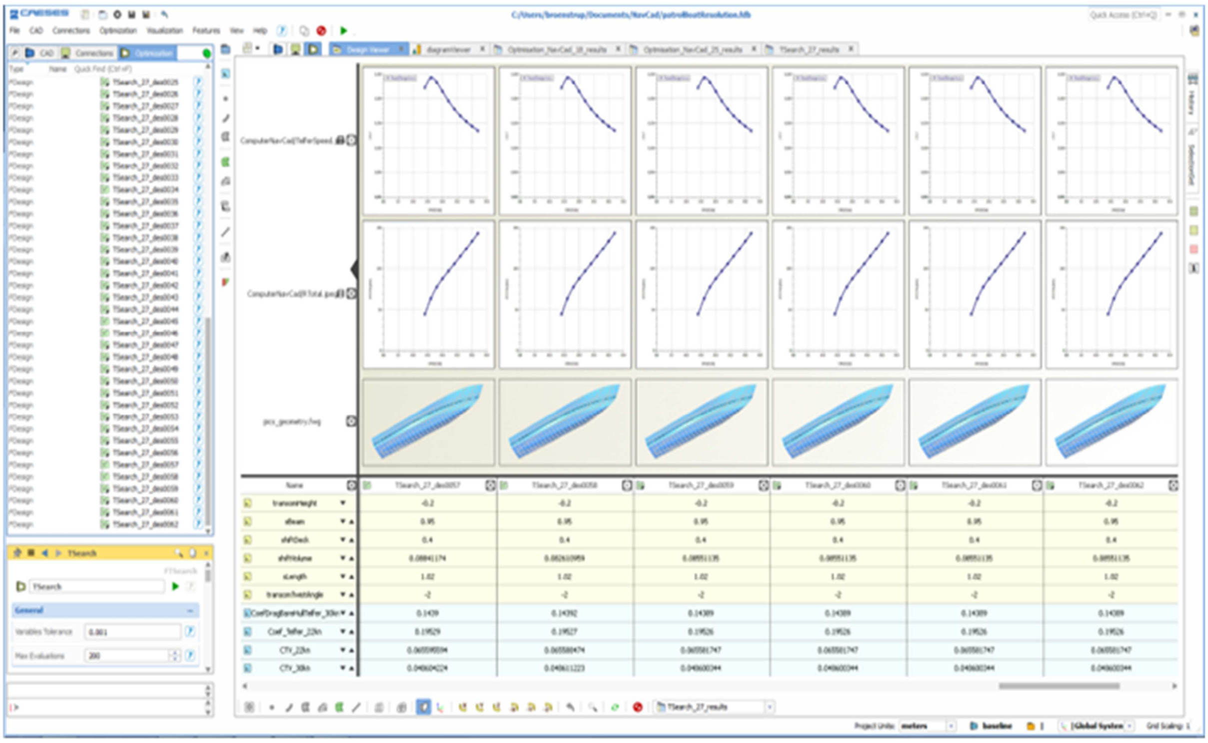


Fig. 4: DesignViewer within CAESES for comparing and assessing variants, showing results from NavCad

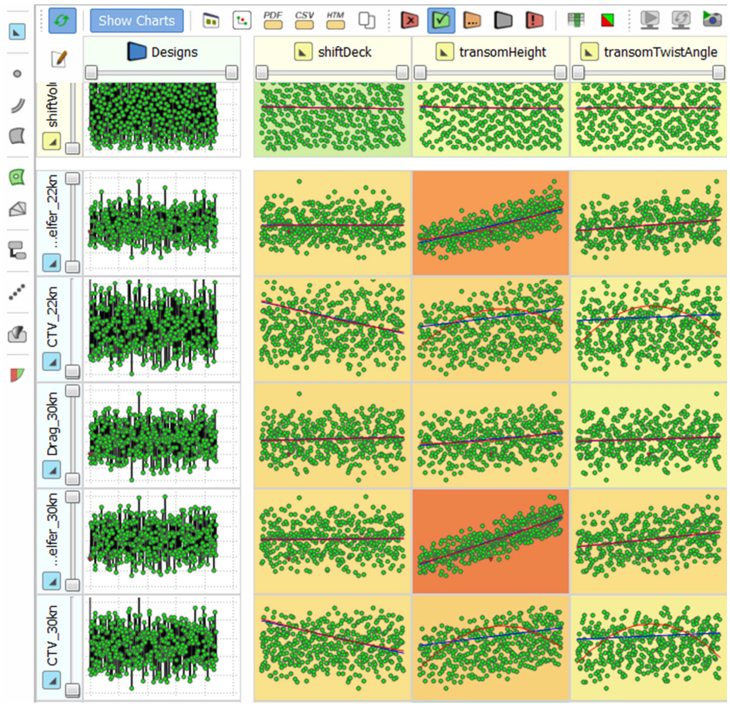


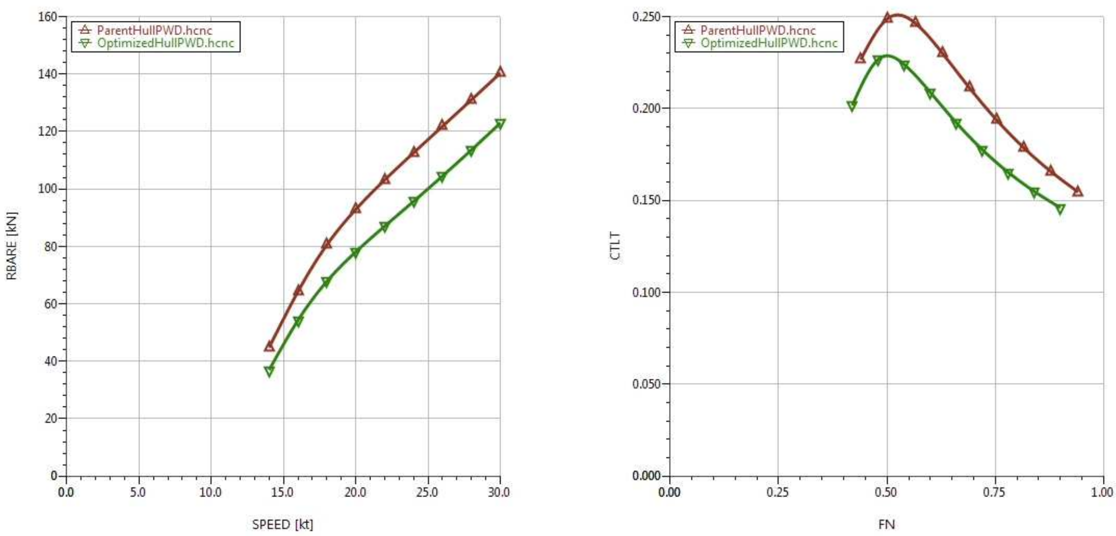
Fig. 5: Correlations between objectives and free variables from a Sobol DoE

5.1 Parent versus optimized hull form

The optimization study recommended new hull geometry (see also Table I) with

- a slightly more slender hull,
- LCB shifted aft,
- greater immersed transom area, and
- a narrower entrance angle.

The resistance improvement is shown in Fig. 6A. The accompanying plot in Fig. 6B represents the hydrodynamic comparison of the total bare-hull's Telfer coefficient versus Froude number. These figures clearly demonstrate the successful – and substantial – reduction in drag with the CAESES optimization running the NavCad PWD analysis.

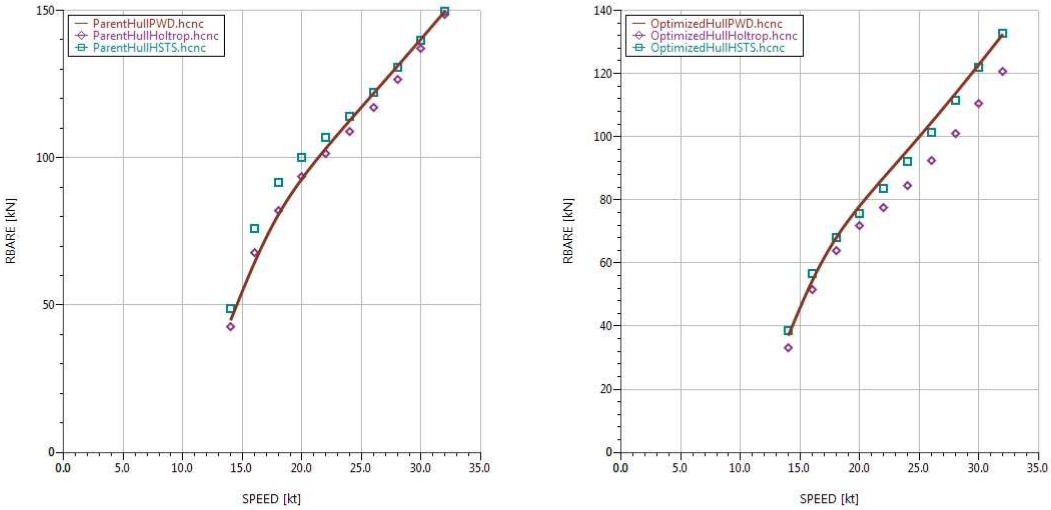


Figs. 6A & 6B: Parent and Proposed comparison of resistance and Telfer coefficient

5.2 Validation

None-the-less, it is still necessary to question the fidelity of the PWD analysis for the Parent and Proposed hull forms. It is completely possible that a mathematical optimization may push the geometry outside the scope of reliable prediction of any method. Therefore, a “confidence check” is recommended using lower order parametric methods. With its library of some 40+ parametric hull resistance methods to call on, NavCad can again be employed not only for the prediction but also to check its reliability.

Using NavCad’s “Method Expert” utility, it was confirmed that two parametric resistance prediction methods were suitable to use as a cross-check of results – the HSTS (highest rated) and Holtrop methods. The Holtrop method was flagged with a user note that it does have a known tendency to underpredict for hulls of substantial immersed transom area. We can see in Figs. 7A and 7B the very good correlation of both magnitude and slope between the distributed volume PWD method and the two parametric methods, giving high confidence in the optimization predictions. (It also shows how the Holtrop method underpredicted drag for the Proposed hull with its nearly 40% greater immersed transom area.)



Figs. 7A & 7B: Resistance of Parent and Proposed hull computed from different NavCad methods

6. Propulsion analysis

Once the resistance prediction was completed for the optimization study of candidate hulls, NavCad was called on to complete a propulsion analysis. Not only was hull drag optimized in the study, but the available analyses in NavCad allowed for selection of a higher efficiency waterjet.

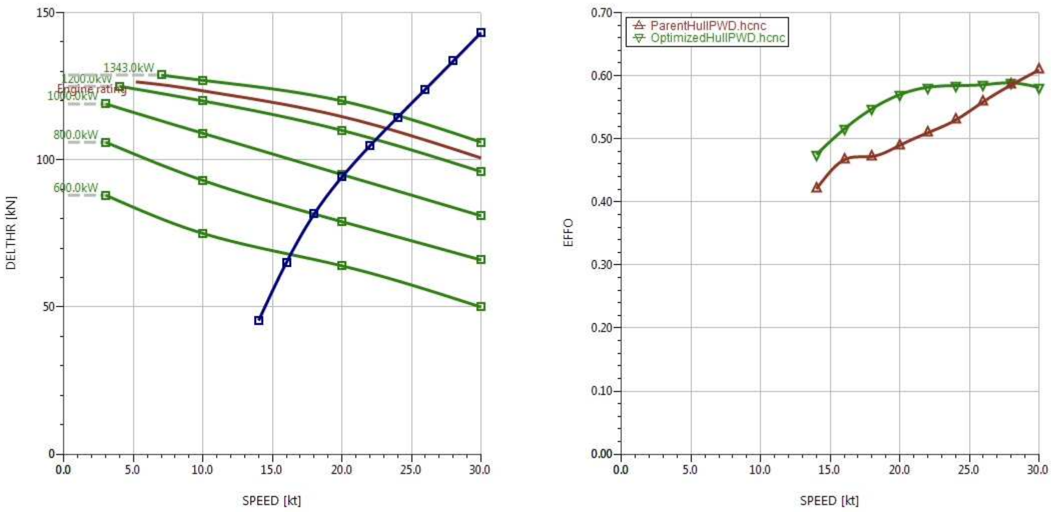
The propulsion analysis was completed exclusively within NavCad, although it could have been conducted using the connectivity with CAESES. A full scripting API supports preparation of propulsion component data, as well as running the propulsion system analysis.

6.1 Methodology of waterjet analysis

Traditional waterjet analysis is a simple graphical lay-over of a waterjet’s thrust curves onto the hull’s required (delivered) thrust curve. If there is sufficient thrust, then the waterjet is deemed acceptable. This was the approach taken by the original designers, but is has one serious deficiency – it does not show the efficiency of the propulsor. NavCad’s analysis employs the same published thrust data, but it exposes the waterjet propulsor efficiency so comparisons can be made between competing product models, *MacPherson (2000)*.

NavCad does not treat waterjets in the same way as propellers, since there are no comparable test frameworks (e.g., KT and KQ curves) for waterjets. In other words, NavCad employs waterjets as a component, whose performance is specified by the manufacturer. (This is similar to how engines are treated, for example. The manufacturers define the specified deliverable power under test conditions – sometimes corrected by naval architects for non-test conditions when deemed appropriate.) The published speed-thrust-power curves are entered as a waterjet component file, along with the impeller power demand data. A surface map is then built from this point cloud data to convert the waterjet thrust map and impeller data to "propeller-equivalent" J-KT-KQ coefficients. This allows a waterjet to be treated in NavCad like any other propulsor.

Still, a traditional waterjet plot can be prepared in NavCad, as shown in Fig. 8A for the Parent design. Intersection of the demand and thrust curves indicates the top speed is approximately 23.0 knots.



Figs. 8A & 8B: Waterjet thrust demand and propulsor efficiency plots

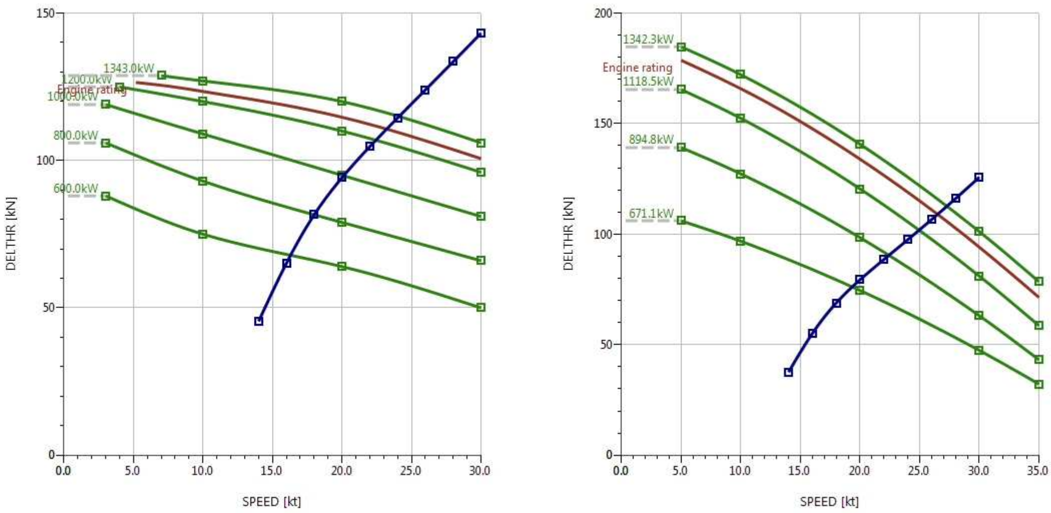
6.2 Waterjet efficiency

As noted, NavCad exposes a waterjet's propulsor efficiency as part of the analysis. It is important for anyone working on a waterjet-driven craft to understand that waterjets as a component are optimized for a particular speed range. Fig. 8B illustrates the speed-dependency of efficiency for the Parent and Proposed waterjets under consideration in this study.

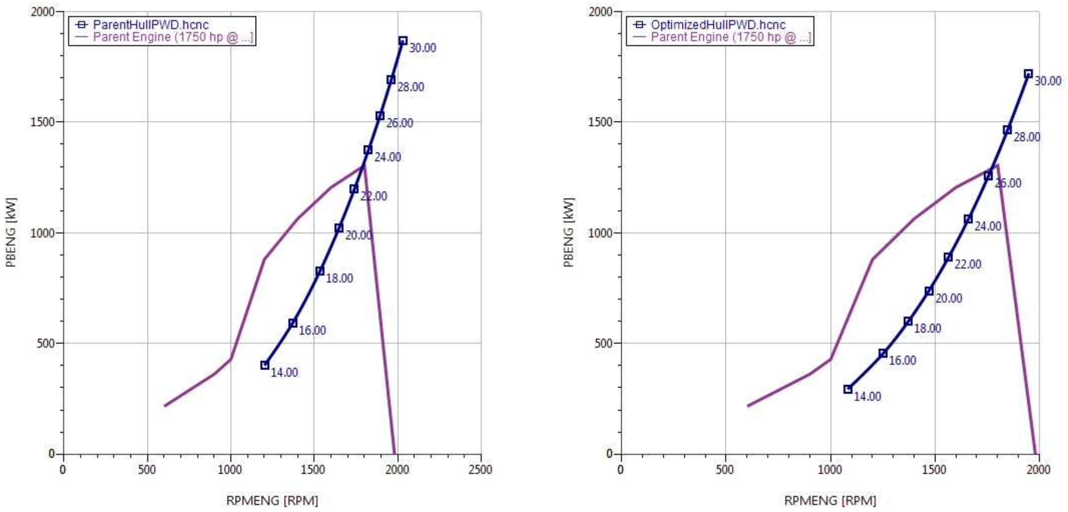
The original (Parent) waterjet model was considered and promoted as a high-efficiency waterjet. This was true, but it was designed for high-speed operation greater than 40 knots. You can see that its efficiency is still increasing at 30 knots. On the other hand, the new (Proposed) waterjet model was designed for 20 to 30 knots. It has lower peak efficiency than the Parent model, but its efficiency is higher in the speed range of interest. It is only by NavCad's calculation of waterjet propulsor efficiency that a designer can make a rational selection of a waterjet model for highest operational effectiveness and lowest fuel consumption.

6.3 System analysis of Parent and Proposed designs

Successful selection of a waterjet model and its corresponding propulsion system analysis does not end with the thrust curves. A proper match of engine, impeller, and gear ratio are also needed. Engine power curve information is entered in NavCad as a component file from the manufacturer's published literature. Gear ratio is selected from the available options and matched to an impeller selection. The propulsion system analysis then utilizes all defined parts of the Hull-Propulsor-Engine system to determine equilibrium RPM, power, thrust, efficiency, and fuel consumption. Figs. 9 and 10 show important system performance figures for the Parent (original) and Proposed (optimized) designs.



Figs. 9a & 9b: Waterjet thrust demand for Parent and Proposed hulls



Figs. 10A & 10B: Engine load for Parent and Proposed hulls

7. Conclusions

The CAESES-NavCad optimized hull form with a proper waterjet (selected based on considerations of “speed-dependent” efficiency) increased the operational speed from approximately 23.0 knots to 26.5 knots – <u>meeting the design objectives without installation of a larger engine</u>.

The original Parent hull with its specified high-speed waterjet would indeed have needed an engine of some 10% to 15% more power to meet the design speed. Of course, this directly translates into a comparable increase in fuel consumption – but the increase also would have needed to consider the heavier displacement required for the larger engine, increasing the fuel consumption at design speed even more. Naturally, the initial capital expense would also be greater with a larger engine.

Conservatively, let us assume the engine-only cost of the Parent design to be 100 000 €. The original expectation by the client was to install an engine some 20% larger, which we can scale proportionally to a cost of approximately 120 000 €. So, for the pair of engines needed the client receives a saving of capital expenses of at least 40 000 €, additional savings stemming from a lighter design not yet accounted for.

Operational expenses are even larger. The fuel consumption predicted in the NavCad analyses for a mean cruising speed of 20 knots is 252 l/h per engine for the Parent hull and 185 for the Proposed hull. Given a representative operating demand of 500 hours-per-year for a patrol craft at a cost of marine diesel fuel of ~1.25 €/l – www.globalpetrolprices.com/diesel_prices/Europe – an estimate of the savings of operating cost with the Proposed hull and waterjet will be 84 000 € per year.

8. Outlook

This study was based on a single design point of 26 knots minimum top speed with least resistance and highest waterjet efficiency as optimizing objectives. However, it could also have looked beyond one speed to a multi-mode duty-cycle propulsion analysis. For example, minimum propulsor power was the optimizing objective of an AUV study previously conducted with a CAESES-NavCad solution, *Harries et al. (2015a)*. NavCad's operating modes analysis can deliver weighted results, including a number of Key Performance Indicators (KPIs), to evaluate and compare optimized hulls and propulsion components for a ship's entire mission profile. The hull form optimization function could thus have been extended from the minimization of bare-hull resistance to a comprehensive minimum energy load for the propulsion system across its full duty-profile.

This study clearly demonstrates how a CAESES-NavCad pairing can provide a very cost-effective and time-efficient capability for any naval architectural office. This coupled solution is a powerful instrument for finding improvements in hull form and propulsion components at any stage in a design.

References

ABT, C.; HARRIES, S. (2007a), *Hull variation and improvement using the generalised Lackenby method of the FRIENDSHIP-Framework*, The Naval Architect, RINA

ABT, C.; HARRIES, S. (2007b), *A new approach to integration of CAD and CFD for naval architects*, 6th Conf. Computer and IT Applications in the Maritime Industries (COMPIT), Cortona

HARRIES, S. (2014), *Practical shape optimization using CFD*, Whitepaper, www.caeses.com

HARRIES, D.; MACPHERSON, D.; EDMONDS, A. (2015a), *Speed-power optimized AUV design by coupling CAESES and NavCad*, 14th Conf. Computer and IT Applications in the Maritime Industries (COMPIT), Ulrichshusen

HARRIES, S.; ABT, C.; BRENNER, M. (2015b), *Upfront CAD – Parametric modeling techniques for shape optimization*, Int. Conf. Evolutionary and Deterministic Methods for Design, Optimization and Control with Applications to Industrial and Societal Problems (EUROGEN), Glasgow

MacPHERSON, D. (2000), *Selection of commercial waterjets: New performance coefficients point the way*, SNAME New England Section, Boston

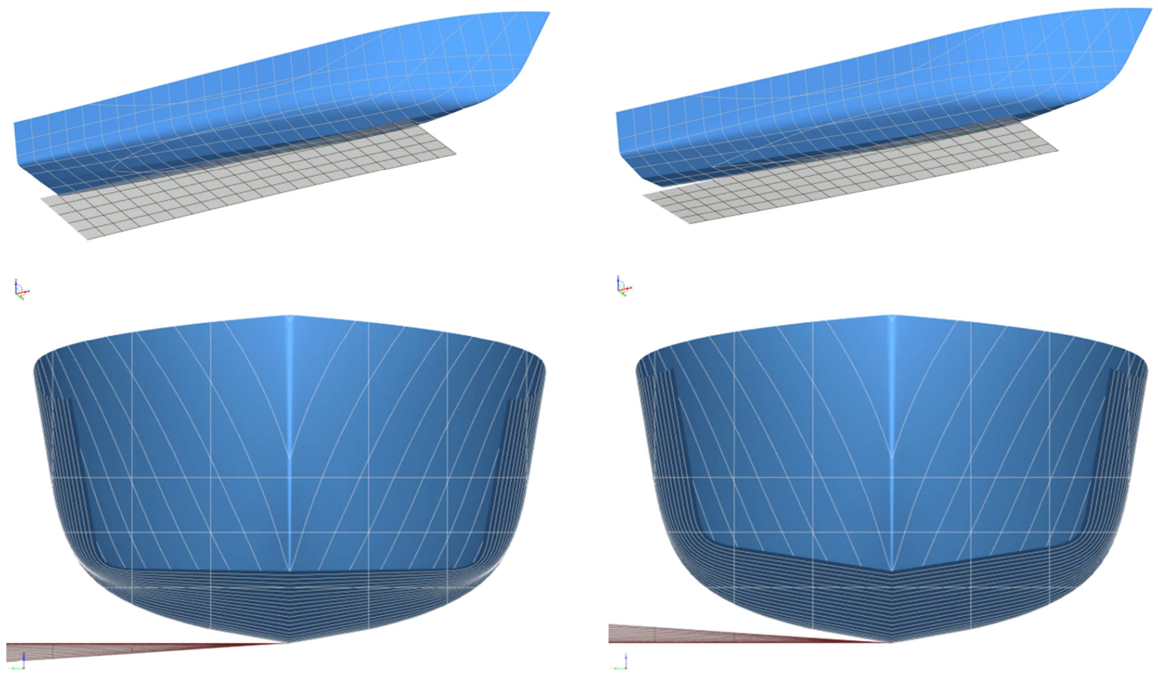
MacPHERSON, D. (2015), *A critical re-analysis of the Series 64 performance data*, 13th Int. Conf. Fast Sea Transportation (FAST), Washington, DC.

Appendix A – Hull form parameterization

The Parent geometry was available as a collection of NURBS surfaces and was imported to CAESES via an IGES-file (as shown in Fig. 1). Subsequently, a partially-parametric model was set up, utilizing several of CAESES' standard "transformations" such as scaling, curve delta shifts and surface delta shifts. Furthermore, an advanced swinging of sections, the so-called Generalized Lackenby, *Abt and Harries (2007)*, was applied in order to capture constraints on displacement and longitudinal center of buoyancy.

CAESES offers an image technology in which a variant is created by assigning a transformation to a source which may be either the baseline shape (any curve, offset, surface, tri-mesh, grid etc.) or any image from a previous parametric modification. In this way transformations can be flexibly combined to define a complex parametric model even from several rather simple modifications.

Fig. A1 may serve to explain one of these simply transformations, namely a surface delta shift. It shows the partially-parametric modification imposed to increase or decrease the twist angle of the transom, introducing a warp in the bottom region of the hull. A ruled surface (shown in grey in Fig. A1 beneath the hull) defines the shift the Parent shall experience into the vertical direction (i.e., the baseline's surfaces as sources). While the shift is supposed to be its maximum at the transom, it gradually fades out towards the forebody (thereby ensuring curvature continuity in the transition from the modified to the unmodified region). Any point of the original surface under the influence of the surface delta shift receives a $\Delta z(x, y)$-value according to its original x-y position, shifting it to the new coordinates $(x, y, z+\Delta z)$. As can be readily appreciated from the transom view (lower row of Fig. A1) the deadrise is modified quite substantially, basically flattening out the transom or more strongly pronouncing the flare angle. Furthermore, the shift going to zero towards the maximum section, the changes are confined to the stern (as in "design velocity" in Fig. 2).



A: Hull (blue) along with surface (grey) so as to modify transom area by a twist of –4°

B: Hull (blue) along with surface (grey) so as to modify transom area by a twist of +4°

Fig. A1: Surface delta shift for introducing transom twist

The entire parametric model is thus modified by combining a variety of these transformations. Fig. A2 depicts a screen shot of the CAESES DesignViewer with a comparison of variants created by means of five free variables, one of which being the transom twist as discussed in some detail. The DesignViewer allows browsing quickly through parameter sets, constraints, associated shapes and simulation results, Fig. A2.

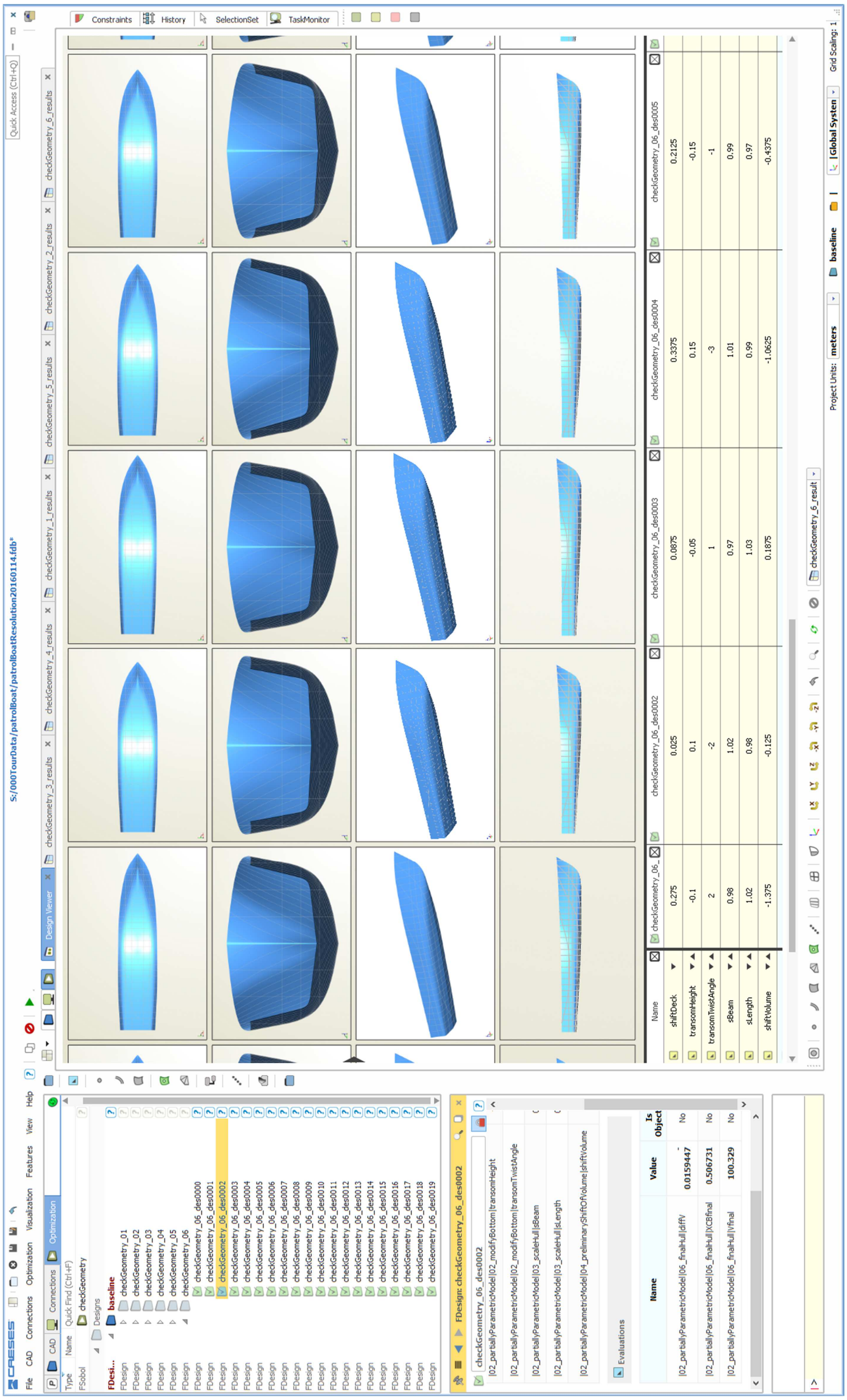


Fig. A2: Different variants realized by a parametric model, shown in CAESES Design-Viewer

Appendix B – Connection between NavCad and CAESES

A number of steps need to be taken to create a "coupled solution" between NavCad and CAESES, see also *Harries et al (2015a)*. Naturally, this effort is only needed when quite a few variants, say a dozen or more hulls, are to be investigated systematically. If a designer is just interested in quickly analyzing two or three variants it may certainly be more practical to independently use CAESES and NavCad one after the other.

```
File.New
File.Open "C:\Users\broenstrup\Documents\NavCad\ParentDesign.hcnc"

Hull.LengthWL 28.6146 m
Hull.BeamWLMax 5.51507 m
Hull.DraftSubmergedMax 1.41017 m
Hull.Displacement 106.715 t
Hull.XBuoyancyFwdTr 13.6489 m
Hull.AngleHalfEntDeg 18.9179
Hull.AreaWaterplane 129.824 m2
Hull.AreaSectAtTr 7.71203 m2
Hull.HullAreaSectMax 14.3036 m2
Hull.HullWettedSurface 158.362 m2
Hull.ImmersionDraftAtTr 0.709451 m
Hull.BeamWLAtTr 4.8061 m

Hull.StationDistribution.Count 38

Hull.StationDistribution.XPosition 0.01 0.767 1.524 2.281 3.038 3.795 4.552 5.310 6.067
6.824 7.581 8.338 9.095 9.852 10.610 11.367 12.124 12.881 13.638 14.395 15.152 15.910
16.667 17.424 18.181 18.938 19.695 20.452 21.210 21.967 22.724 23.481 24.238 24.995 25.752
26.510 27.267 28.024  m

Hull.StationDistribution.BeamWL 4.806 4.866 4.924 4.981 5.036 5.090 5.142 5.192 5.240 5.285
5.328 5.369 5.407 5.440 5.467 5.488 5.502 5.511 5.513 5.512 5.511 5.509 5.496 5.457 5.372
5.211 4.966 4.689 4.388 4.074 3.753 3.424 3.067 2.652 2.164 1.589 0.976 0.413  m

Hull.StationDistribution.AreaSect 2.891 2.985 3.078 3.172 3.265 3.359 3.452 3.544 3.637
3.730 3.823 3.916 4.009 4.103 4.196 4.289 4.383 4.479 4.582 4.698 4.834 4.993 5.154 5.287
5.358 5.328 5.172 4.935 4.638 4.295 3.919 3.507 3.045 2.515 1.894 1.189 0.568 0.133  m2

Hull.StationDistribution.CentroidBelowWL 0.984 0.975 0.966 0.957 0.948 0.939 0.930 0.920
0.910 0.900 0.890 0.880 0.869 0.857 0.845 0.833 0.819 0.804 0.788 0.770 0.750 0.727 0.703
0.679 0.656 0.633 0.614 0.597 0.584 0.574 0.569 0.567 0.568 0.575 0.597 0.637 0.765 1.041
m

SpeedPerformance.Speed 14.00 16.00 18.00 20.00 22.00 24.00 26.00 28.00 30.00 32.00 kt

Analysis.CalculateResistance
Output.Start "C:\Users\broenstrup\Documents\NavCad\patrolBoatResolution\23_TSearch\
TSearch_23_des0032\ComputerNavCad\Output_Values.txt"

SpeedPerformance.AddToOutput Count
SpeedPerformance.AddToOutput Speed
SpeedPerformance.AddToOutput CoefDragBareHullTelfer
SpeedPerformance.AddToOutput CoefDragBareHullWeightRatio
SpeedPerformance.AddToOutput DragTotal
Output.End

Graph.SetAxisXY Speed RTotal
Graph.SaveAsJPEG "C:\Users\broenstrup\Documents\NavCad\patrolBoatResolution\23_TSearch\
TSearch_23_des0032\ComputerNavCad\RTotal.jpeg"
```

Fig. B1: Example script (excerpt) for executing NavCad (data items that are replaced during the optimization are highlighted in yellow)

For the assessment undertaken in NavCad by means of the PWD-method, several parameters and data items need to be provided: for example the length and entrance angle of the design waterline (at rest), maximum beam and, importantly, sectional data such as the number of stations and their longitudinal positions along with each section's area and immersed centroid, see Fig. B1. In order to gather and provide the input data for NavCad a small feature was written in CAESES that saved all necessary data items (using strings for ease of transfer). The "feature" technique within CAESES enables the user to package operations into higher-order objects. These "features" can then be carried out, for instance, to compile and write data to tailor-made output files.

In an automated study many hulls are created and evaluated, typically in the range of a few hundred. Hence, NavCad is asked time and again to perform exactly the same type of simulation for every variant about which the optimization strategy requests information. Therefore, in the "coupled solution" NavCad is run in a server mode on the basis of input data fed to NavCad via its API scripting language. CAESES provides the scripts and then triggers a design assessment by NavCad. NavCad then executes the script, compiles results and diagrams and, finally, lets CAESES know that the assessment is completed.

From a practical point of view it is best to run NavCad for the Parent design once manually before any major optimization is undertaken in an automatic mode. (NavCad's "build script" feature can also be of assistance to prepare an initial script template for the NavCad project.) This helps setting up scripts and the necessary input data as needed. The NavCad script typically contains information about the type of calculation to be performed and what data are to be saved in the output file. For the patrol boat optimization both numerical data such as the resistance at a certain speed and diagrams for post-processing were provided by NavCad, Fig. 4. Fig. B1 gives an excerpt of the corresponding NavCad script.

The integration of NavCad within CAESES is shown in Fig. B2, where the location of the NavCad executable first needs to be specified. Then, CAESES needs to know a) the name and content of the script file, here just "skript.txt", b) the name and content of the output file, here "Output_values.txt", and c) the names of the diagrams that NavCad will create, here "Pbeng.jpeg" and "RTotal.jpeg". During the optimization, CAESES replaces the entries in the script file that change from one variant to the next. Importantly, these are the principal dimensions and the sectional data as shown in Fig. B1, see highlighted data items. Furthermore, CAESES reads and interprets the output file, taking in the results from NavCad for each variant. While doing an optimization, a folder is created for every variant that contains all inputs, outputs, screen-shots, diagrams etc. for possible further processing.

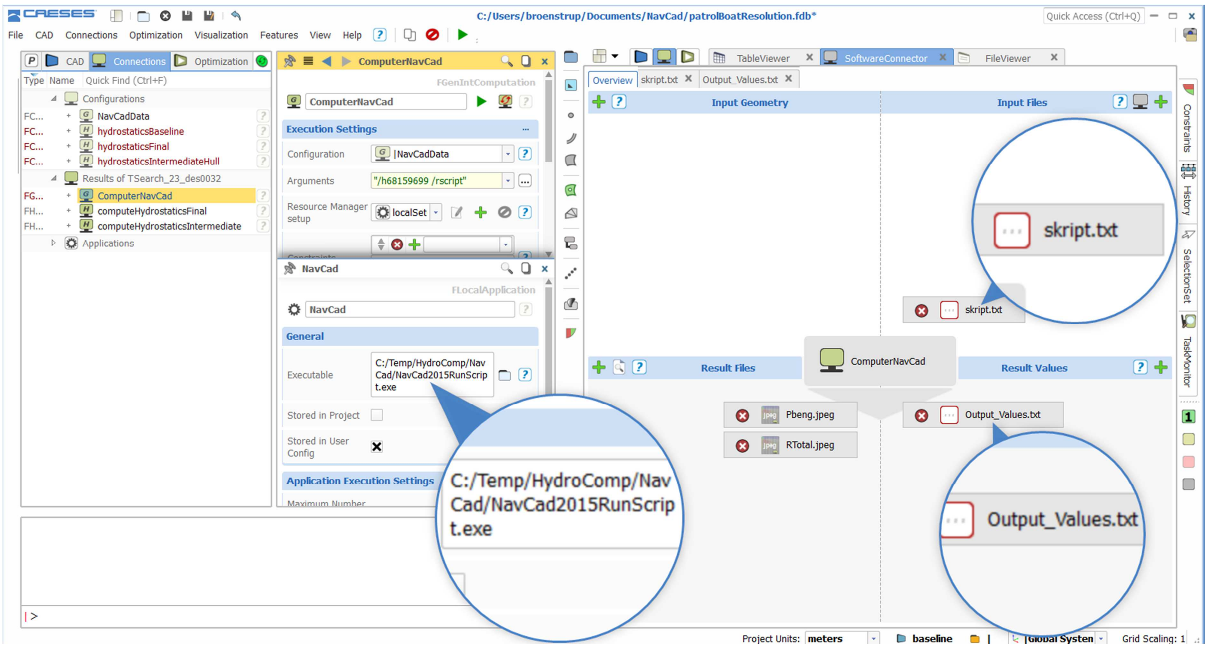


Fig. B2: CAESES SoftwareConnector for integration of NavCad