Practical designer-guided hull form optimisation

Making designer-guided hydrodynamic hull form optimisation part of the design process ensures it will be system-ready and benchmarked, argues HydroComp's Don MacPherson

Design 'optimisation' can be a two-edged sword. It can achieve substantial beneficial outcomes, but it can also consume design resources in a fruitless hunt for perfection.

In naval architecture, where many disciplines – stability, hydrodynamics, capacity, producibility – all compete in the evolution of a design, design studies will never deliver a singular 'numerically optimum' outcome for any one discipline. Certain disciplines, such as safety of life at sea, will appropriately have priority to others. Depending on how you cast the role of a naval architect, the design priorities also fall on any task that best fulfills the objectives of a client's business plan. The best we can hope for is to get reasonably close to an optimum while not handicapping the other disciplines too much. To do this we must set aside the idea of a single optimum for the task at hand and remember that there is typically a broad area of compromise options that achieve close to optimum outcomes. It is in this very messy sandbox (and I love its messiness, by the way) that we approach hydrodynamic hull form optimisation.

Of course, we must remember the primary objective of the optimisation, which in most cases is to achieve minimum fuel consumption. One must model the 'Vessel-Propulsor-Drive' (VPD) system and then fit any component optimisation into this system. HydroComp's NavCad software is at the forefront for this type of hydrodynamic and propulsion system simulation, and also a powerful tool for optimisation of the system's components. NavCad has long been known for its propeller system matching that solves for optimum propeller characteristics, but perhaps less known is that NavCad is also an effective platform for hull form optimisation.

As noted, the objective function of a VPD system optimisation should rightly be minimum fuel consumption, so a comprehensive hull form optimisation would typically include a search for improvements in Vessel-Propulsor interaction. However, a more limited focus on reduction in vessel hull form resistance can be extremely valuable, as it will directly relate to a reduction in the Propulsor-Drive thrust requirement and corresponding fuel consumption. In fact, it is fair to say that a majority of research on 'hull form optimisation' is related to drag reduction.

'Designer-guided' optimisation

While there are a variety of iterative high-order approaches and techniques available for an automated optimisation, the need to juggle the various disciplines does not always allow for the 'optimum' hull to actually be used in service (if it did, all hulls would be long and slender with pointy ends). We therefore propose that 'designer-guided' optimisation is necessary to achieve a deliverable pragmatic compromise solution. Of course, a designer-guided solution can then be refined as justified. Analysis with higher-order codes or model testing can follow to further improve the hull using the knowledge gained in the designer-guided investigations.

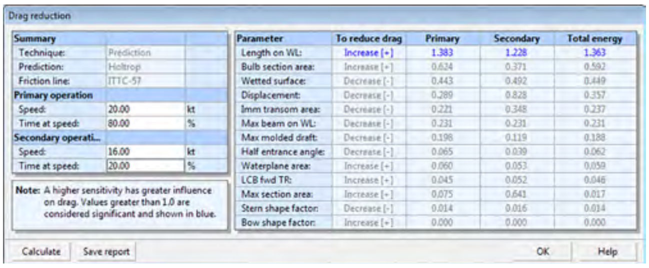
Principal parameter optimisation

Some of the biggest improvements in hull form resistance can be achieved by understanding the influence of the significant hydrodynamic parameters. A ship's resistance in different speed regimes will be affected by parameters in different ways. A great example of this is an immersed transom. At low speeds, the water wants to be rejoined easily at the stern, so a transom with substantial immersed section area is detrimental. On the other hand, a transom that promotes clean separation is greatly beneficial at high speeds. Similar influences can be evaluated for center of gravity and entrance angle, for example.

To put this into an appropriate 'energy value' perspective (that better models total power and fuel use), NavCad uses a weighted energy analysis for two operational speeds. It then runs a comparative matrix of significant parameters, ranks their influence, and presents a summary to the naval architect. This provides initial design guidance for where drag reduction might be found – if it is compatible with the requirements of the other design disciplines (see Figure 1).

Hull form wave-making optimisation

Hull form resistance can be simplified into two general parts – viscous and wave-making. Put another way, it is made up of a frictional drag related to the surface and boundary layer properties, plus the resistance caused by the movement of the water's mass around the ship. Depending on the speed range and characteristics of the



Summary		
Technique:	Prediction	
Prediction:	Holtrop	
Friction line:	ITTC-57	
Primary operation		
Speed:	20.00	kt
Time at speed:	80.00	%
Secondary operati...		
Speed:	16.00	kt
Time at speed:	20.00	%

Note: A higher sensitivity has greater influence on drag. Values greater than 1.0 are considered significant and shown in blue.

Parameter	To reduce drag	Primary	Secondary	Total energy
Length on WL:	Increase [+]	1.383	1.228	1.363
Bulb section area:	Increase [+]	0.624	0.371	0.592
Wetted surface:	Decrease [-]	0.443	0.492	0.449
Displacement:	Decrease [-]	0.289	0.828	0.357
Imm transom area:	Decrease [-]	0.221	0.348	0.237
Max beam on WL:	Decrease [-]	0.231	0.231	0.231
Max molded draft:	Decrease [-]	0.198	0.119	0.188
Half entrance angle:	Decrease [-]	0.065	0.039	0.062
Waterplane area:	Increase [+]	0.060	0.053	0.059
LCB fwd TR:	Increase [+]	0.045	0.052	0.046
Max section area:	Increase [+]	0.075	0.641	0.017
Stern shape factor:	Decrease [-]	0.014	0.016	0.014
Bow shape factor:	Increase [+]	0.000	0.000	0.000

Figure 1 – Drag reduction by parametric assessment

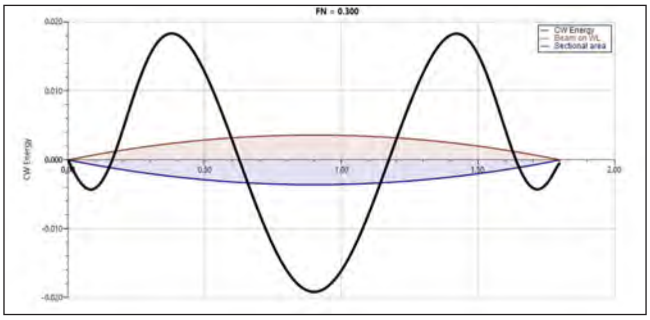


Figure 2 – Longitudinal contribution to wave-making energy (FN=0.30)

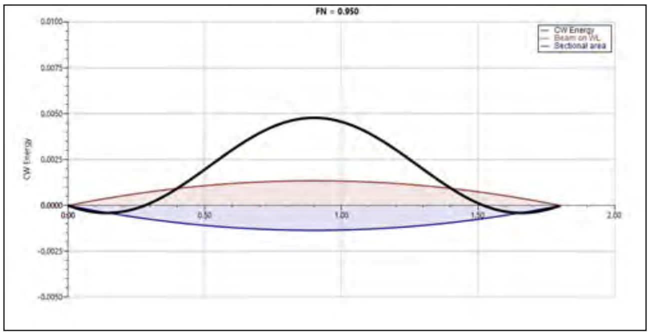


Figure 3 – High speed wave energy plot (FN=0.95)

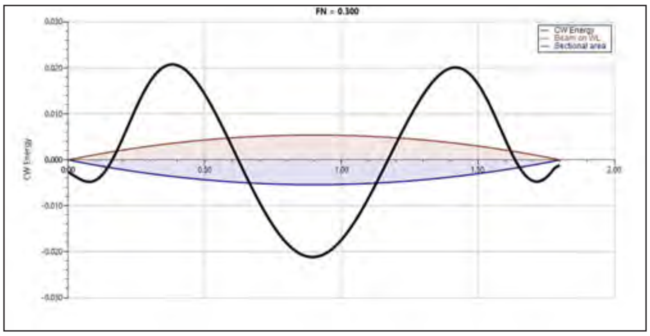


Figure 4 – Minimal viscous influence at moderate speeds

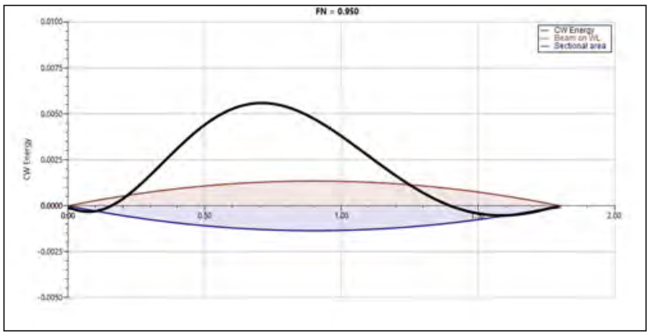


Figure 5 – Substantial viscous influence at high speeds

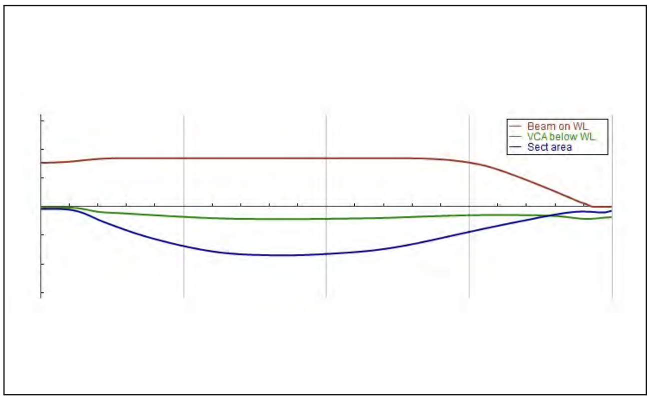


Figure 6 – RoPax distribution of immersed volume for ADVM calculation

ship, the relative proportion of these two parts of total resistance can vary greatly. The resistance of slow ships will tend to be mostly viscous, so hull form improvements typically are about reducing wetted surface area (as producibility and other disciplines allow). Fast ships, on the other hand, demonstrate predominantly wave-making drag, so the hunt for drag reduction is successful when smoothing the path of the water around the ship and past a transom.

All prediction solutions for wave-making drag (including model testing and panel or grid-based codes) provide a computation of the total wave-making resistance. Designer-guided optimisation can now employ a practical means of design feedback about how the longitudinal distribution of hull shape influences wave-making resistance. The foundation of this feedback is found in HydroComp's integration of wave-making drag in the 'Analytical Distributed Volume Method' (ADVM) of NavCad Premium.

Visualisation of wave-making energy

The analytical prediction of wave-making resistance is based on the Kelvin system of generated transverse and divergent waves. There are many excellent references on this topic so no more will be said here, except that they are systems which reflect the local shape of the immersed volume (such as inflections and shoulders) and go in and out of phase with each other depending on the shape and speed. For example, the following is a plot from NavCad Premium of a symmetric Wigley hull (a very well-known mathematical hull form frequently used for analytical studies) that illustrates the longitudinal phase-based peaks and valleys of the wave-making resistance along the ship's hull. The total wave-making energy is the integration of this curve (Figure 2).

As a ship increases in speed and exceeds the point where the speed-based wave length is longer than the ship's length, the shape of the energy curve will have a principal central hump (Figure 3).

Note that the the plots on Figures 2 and 3 were calculated without a viscous boundary layer shape or sinkage-trim correction. These will alter the magnitude of the wave-making energy and shift the peak aft as shown on Figures 4 and 5.

Using longitudinal wave energy plots for designer-guided optimisation

The ability to graphically observe the influence of hull shape on wave-making resistance gives naval architects a powerful tool to identify possible problem areas and optimise the hull form.

RoPax Ferry

In a past article, we described a design study for a 145m RoPax ferry (*The Naval Architect,* January 2018) with the longitudinal distribution of immersed volume as shown on page 39. As described in the article, the predicted resistance of the ship was greater than expected (by comparison to other hulls of comparable size and mission), and the inflection at the stern was considered as a possible source of the added resistance (Figure 6).

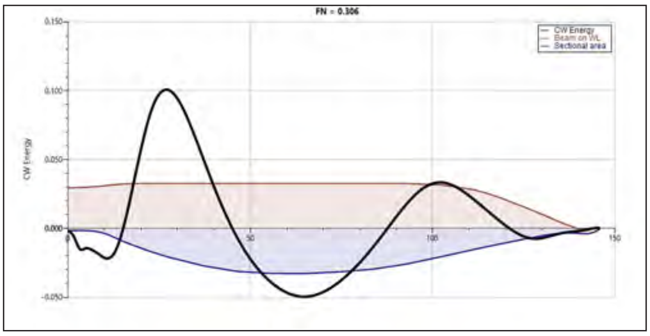


Figure 7 – Original RoPax hull energy plot

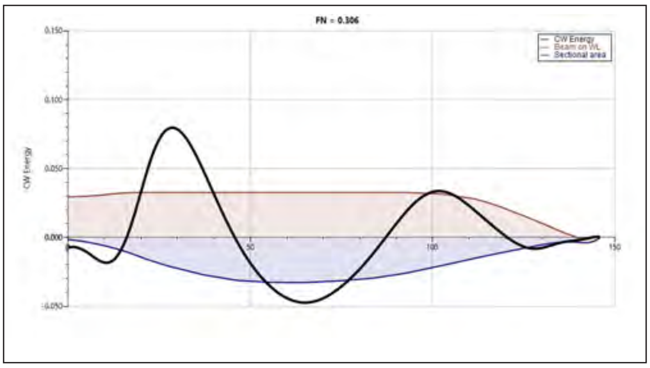
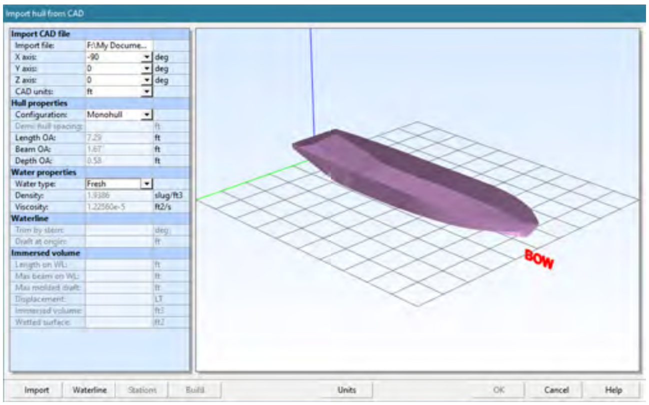
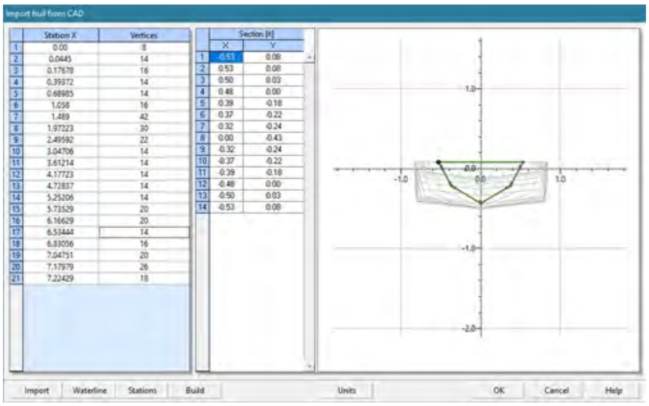


Figure 8 – Modified RoPax hull energy plot



Import CAD file		
Import file:	F:\My Docume...	
X axis:	-90	deg
Y axis:	0	deg
Z axis:	0	deg
CAD units:	ft	
Hull properties		
Configuration:	Monohull	
Demi-hull spacing:		ft
Length OA:	7.29	ft
Beam OA:	1.67	ft
Depth OA:	0.58	ft
Water properties		
Water type:	Fresh	
Density:	1.9386	slug/ft3
Viscosity:	1.22560e-5	ft2/s
Waterline		
Trim by stern:		deg
Draft at origin:		ft
Immersed volume		
Length on WL:		ft
Max beam on WL:		ft
Max molded draft:		ft
Displacement:		LT
Immersed volume:		ft3
Wetted surface:		ft2

Figure 9 – Hull CAD import for data capture (step 1)



	Station X	Vertices
1	0.00	8
2	0.0445	14
3	0.17678	16
4	0.39372	14
5	0.68985	14
6	1.058	16
7	1.489	42
8	1.97223	30
9	2.49592	22
10	3.04706	14
11	3.61214	14
12	4.17723	14
13	4.72837	14
14	5.25206	14
15	5.73529	20
16	6.16629	20
17	6.53444	14
18	6.83056	16
19	7.04751	20
20	7.17979	26
21	7.22429	18

	Section [ft]	
	X	Y
1	-0.53	0.08
2	0.53	0.08
3	0.50	0.03
4	0.48	0.00
5	0.39	-0.18
6	0.37	-0.22
7	0.32	-0.24
8	0.00	-0.43
9	-0.32	-0.24
10	-0.37	-0.22
11	-0.39	-0.18
12	-0.48	0.00
13	-0.50	0.03
14	-0.53	0.08

Figure 10 – Extracted offsets (step 2)

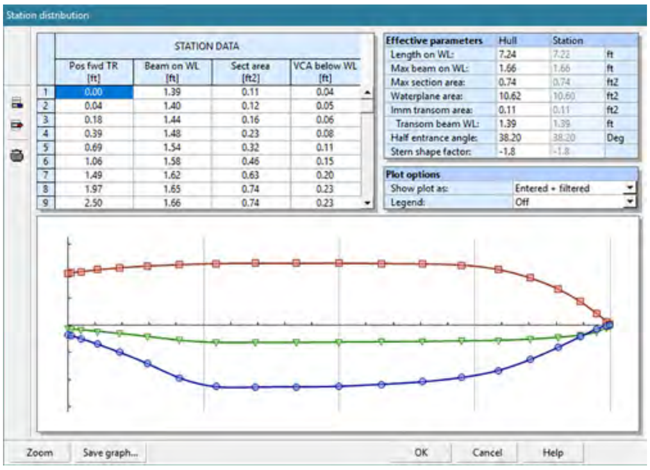
Using the most recent ADVM prediction method update, the longitudinal energy plot can be quickly developed for this hull at its design speed. As compared to the flow-friendly Wigley hull (Figure 4), you can see in the figure below a substantial peak toward the stern just upstream of the hull inflection. You will also note the larger wave-making magnitude of the RoPax hull due to its less streamlined sectional area curve (notably due to the sharp forward shoulder, prolonged mid-ship, and the stern inflection – see Figure 7).

This upstream influence of a transition is typical of hydrodynamic bodies. For example, a 2D foil study can confirm that a downstream inflection would cause an upstream pressure increase. Using knowledge of this tendency for designer-guided optimisation, the naval architect can look for peaks that are "out of character" and look downstream (toward the stern) for hull form characteristics that might be modified.

A simple revisit to the original RoPax CAD model allowed the naval architect to revise and smooth the stern inflection. The wave energy plot for the modified stern is shown below. This small re-design – guided by the ADVM method and its corresponding wave-making energy plot in NavCad Premium – delivered a 35% savings in wave-making resistance and a 14% total resistance reduction (Figure 8).

Data requirements and workflow

The hull form data necessary for the parametric "minimum drag" analysis or for the ADVM method (and the wave energy plot) can most easily be captured using a new "hull import from CAD" utility in NavCad. The process starts with a user-generated STL file, which is a comparable data source as used by CFD and higher-order analyses. This creates a version of the geometry based on faceted panels. The following screenshots illustrate the import of a CAD file in STL format for a research vessel : import, offsets, and captured data (Figures 9, 10 & 11).



	STATION DATA			
	Pos fwd TR [ft]	Beam on WL [ft]	Sect area [ft2]	VCA below WL [ft]
1	0.00	1.39	0.11	0.04
2	0.04	1.40	0.12	0.05
3	0.18	1.44	0.16	0.06
4	0.39	1.48	0.23	0.08
5	0.69	1.54	0.32	0.11
6	1.06	1.58	0.46	0.15
7	1.49	1.62	0.63	0.20
8	1.97	1.65	0.74	0.23
9	2.50	1.66	0.74	0.23

Effective parameters	Hull	Station	
Length on WL:	7.24	7.22	ft
Max beam on WL:	1.66	1.66	ft
Max section area:	0.74	0.74	ft2
Waterplane area:	10.62	10.60	ft2
Imm transom area:	0.11	0.11	ft2
Transom beam WL:	1.39	1.39	ft
Half entrance angle:	38.20	38.20	Deg
Stern shape factor:	-1.8	-1.8	

Plot options	
Show plot as:	Entered + filtered
Legend:	Off

Figure 11 – Captured parametric and longitudinal station distribution data

Conclusions

Through the application of a 'designer-guided' optimisation strategy, naval architects can evaluate proposed hull form geometry both in parametric and distributed volume domains. Only by keeping the naval architect in the design loop can the hull form geometry effectively be optimised for hydrodynamic objectives within the scope of competing disciplines.

Of course, this does not eliminate the potential for additional improvements using higher-order CFD or model testing. In fact the opposite is true. By incorporating designer-guided hydrodynamic hull form optimisation into a naval architect's regular design process, the design will be system-ready, pre-qualified, and benchmarked. This makes additional follow-on analyses more effective by devoting resources where they are most useful – by calculating just what is needed, instead of using resources for a hull geometry that may prove to be restricted by the other disciplines of naval architectural design. *NA*

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Maritime Safety Award

The safety of the seafarer and protection of the maritime environment begins with good design, followed by sound construction and efficient operation. Naval architects and engineers involved in the design, construction and operation of maritime vessels and structures can make a significant contribution to safety and the Royal Institution of Naval Architects, with the support of Lloyd's Register, wishes to recognise the achievement of engineers in improving safety at sea and the protection of the maritime environment. Such recognition serves to raise awareness and promote further improvements.

The Maritime Safety Award is presented annually to an individual, company or organisation that in the opinion of the Institution and Lloyd's Register, is judged to have made an outstanding contribution to the improvement of maritime safety or the protection of the maritime environment. Such contribution may have been made by a specific activity or over a period of time. Individuals may not nominate themselves. Nominations are now invited for the 2018 Maritime Safety Award.

Nominations of up to 750 words should describe the nominee's contribution to:
- safety of life or protection of the marine environment, through novel or improved design, construction or operational procedures of ships or maritime structures
- the advancement of maritime safety through management, regulation, legislation or development of standards, codes of practice or guidance
- research, learned papers or publications in the field of maritime safety
- education, teaching or training in maritime safety issues

Lloyd's Register

The closing date for nominations is 31st December 2018.

The Award will be announced at the Institution's 2019 Annual Dinner.

Nominations may be made by any member of the global maritime community and should be forwarded online at: www.rina.org.uk/maritimesafetyaward

or by email to: maritimesafetyaward@rina.org.uk

Queries about the Award should be forwarded to the Chief Executive at: hq@rina.org.uk