Case Study: Application of NavCad to the Design and Optimization of a Waterjet-Driven Patrol Boat

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ABSTRACT

The traditional approach to predicting the performance of a boat with waterjets is to simply plot a drag curve against the waterjet's published thrust-power curves to graphically determine maximum speed. This approach, however, does nothing to expose information about the boat's performance or whether the particular waterjet model is the best choice for the application. In addition, a proper analysis must incorporate engine RPM into the analysis, as full rated power is not available throughout the RPM range.

This case study will illustrate how NavCad can be used to evaluate the performance of a waterjet-driven vessel, but also to seek out reduction in drag, to quantify the suitability of the waterjet model, and to identify the optimum reduction gear ratio.

INTRODUCTION

Our office was asked to review a 90 ft (27 m) patrol boat for an engine manufacturer. Initial predictions by the boat designer indicated that the boat would not make the target speed, and they were asking the engine builder to suggest a higher powered engine model. The engine builder felt that the installed power should have been adequate (based on similar installations), and we were asked to provide an analysis of the design and the suitability of the waterjet.

The initial vessel design had the following basic parameters:

- 90 ft (27 m) LOA
- 23 knot design speed, with 20 knot cruise
- Round-bilge with immersed transom
- 1750 BHP diesel engine, 1800 RPM
- 2.75 : 1 reduction gear ratio

We received information about the vessel geometry and loading, as well as specifications for the engine, gear and waterjet. Using NavCad, the total resistance was predicted and the propulsion power determined with the waterjet.

A NOTE ON METHODOLOGY

The methodology applied by NavCad for modeling waterjet performance is explained in a technical paper by the author [MacPherson, 2000].

PERFORMANCE OF THE INITIAL DESIGN

Our analysis confirmed the suspicions of the designer – the boat would not make the intended speed. As this was a waterjet-driven boat, the easiest way to illustrate this was by the traditional plot of the vessel drag against the waterjet's thrust-power-speed curves. The following plot was developed within NavCad.

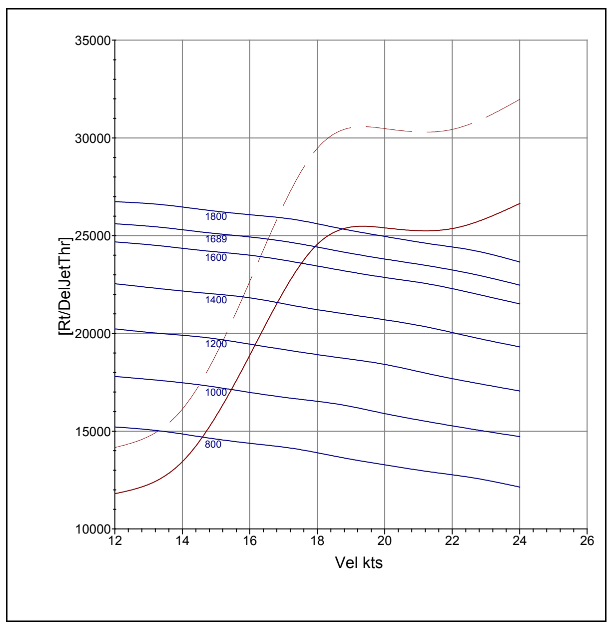


Figure 1 – Resistance vs Delivered Thrust

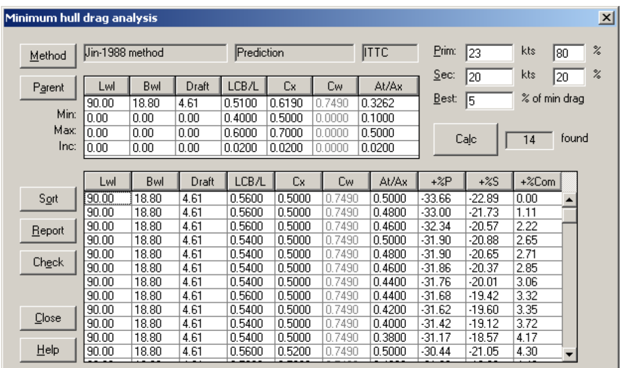
The "waterjet" lines on the plot represent delivered thrust (published thrust less the thrust deduction) for a given shaft power. The "vessel" lines are the total vessel drag (bare-hull plus any wind and seas drag), as well as the drag with a user-defined margin. The speed predicted from this plot is 18 knots for the 1689 SHP (1750 BHP less the gear efficiency).

As we view this plot, two things stand out – there is a significant resistance hump, but after this hump the drag curve is pretty flat out to about 24 knots. So, it does appear that a modest 10% to 15% increase in power might solve the problem. This, of course, means a new waterjet model and increased fuel use.

VESSEL DRAG

As a regular step in our prediction of drag for almost any project, we use NavCad to perform a "Minimum Drag" analysis. This analysis allows us to see how a change in a vessel parameter affects drag. It gives us a way to find improvements to the hull form.

The following screen shot illustrates this analysis for the subject vessel.



	Lwl	Bwl	Draft	LCB/L	Cx	Cw	At/Ax
	90.00	18.80	4.61	0.5100	0.6190	0.7490	0.3262
Min:	0.00	0.00	0.00	0.4000	0.5000	0.0000	0.1000
Max:	0.00	0.00	0.00	0.6000	0.7000	0.0000	0.5000
Inc:	0.00	0.00	0.00	0.0200	0.0200	0.0000	0.0200

Lwl	Bwl	Draft	LCB/L	Cx	Cw	At/Ax	+%P	+%S	+%Com
90.00	18.80	4.61	0.5600	0.5000	0.7490	0.5000	-33.66	-22.89	0.00
90.00	18.80	4.61	0.5600	0.5000	0.7490	0.4800	-33.00	-21.73	1.11
90.00	18.80	4.61	0.5600	0.5000	0.7490	0.4600	-32.34	-20.57	2.22
90.00	18.80	4.61	0.5400	0.5000	0.7490	0.5000	-31.90	-20.88	2.65
90.00	18.80	4.61	0.5400	0.5000	0.7490	0.4800	-31.90	-20.65	2.71
90.00	18.80	4.61	0.5400	0.5000	0.7490	0.4600	-31.86	-20.37	2.85
90.00	18.80	4.61	0.5400	0.5000	0.7490	0.4400	-31.76	-20.01	3.06
90.00	18.80	4.61	0.5600	0.5000	0.7490	0.4400	-31.68	-19.42	3.32
90.00	18.80	4.61	0.5400	0.5000	0.7490	0.4200	-31.62	-19.60	3.35
90.00	18.80	4.61	0.5400	0.5000	0.7490	0.4000	-31.42	-19.12	3.72
90.00	18.80	4.61	0.5400	0.5000	0.7490	0.3800	-31.17	-18.57	4.17
90.00	18.80	4.61	0.5600	0.5200	0.7490	0.5000	-30.44	-21.05	4.30

Figure 2 – Minimum Drag Analysis

This unique feature of NavCad is a powerful design tool. Seven principal geometric parameters are listed in the upper table. Length, Beam and Draft were fixed for this project, but we were interested to see how changes in LCB, CX and AT/AX (transom immersion) affected drag. A weighted distribution was also defined for the two principal speeds – 80% at 23 knots, and 20% at 20 knots.

We set up a range of these three parameters to investigate. The resulting evaluation indicated that a very significant reduction in speed could be found (potentially more than 20%!) by reducing CX, shifting LCB a bit aft, and increasing transom immersion.

From the stand-point of speed and power, a re-design is warranted. Such a re-design should allow the vessel to make speed without any change in the propulsion system. (Other considerations may dictate the geometry, but at least we know what potential speed-power improvements might be possible.)

WATERJET PERFORMANCE

One of the important benefits of NavCad's integrated approach to evaluating waterjet performance on a vessel – as opposed to a simple thrust-drag plot – is that it allows you to see equilibrium RPM and propulsor efficiency at each speed.

Unlike propeller curves, efficiency is hidden in the waterjet curves. As part of its system analysis, NavCad determines and displays efficiency. The following NavCad plot is the equivalent open-water propulsor efficiency for the waterjet.

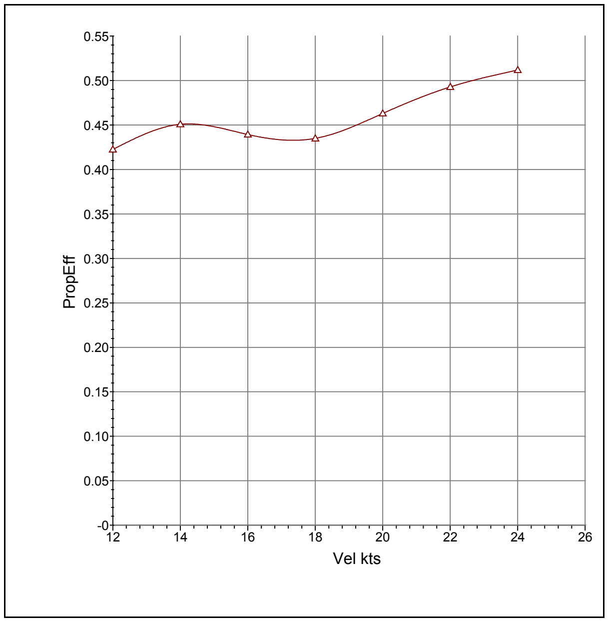


Figure 3 – Waterjet Efficiency

Again, two things are striking about this plot – the efficiency across the desired speed range is only 0.43 to 0.50, and the efficiency is rising as speed increases. Waterjet peak efficiencies are commonly 0.55 to 0.60 (or more).

This particular waterjet may also be capable of higher efficiency, but only at higher speeds. In other words, this waterjet model was probably designed for operation at 40 knots or so, and is unsuitable in the 20-23 knot target speed range. The use of another waterjet model – one that was designed for the lower speed range – will very likely allow the vessel to reach speed without a change in hull form or engine.

Note: The wavy efficiency line is due to the small scatter in the published input thrust-power-speed data at the lower speeds. The effect on results is insignificant.

REDUCTION GEAR RATIO

As mentioned, the NavCad analysis also provides the equilibrium RPM at each speed. This is the RPM needed at the waterjet to provide the steady-state resistance-thrust match at each speed. Multiply this by the reduction ratio, and we get the engine RPM. The following NavCad plot shows the power-RPM curve for the waterjet-driven vessel plotted against the engine's rated power curve.

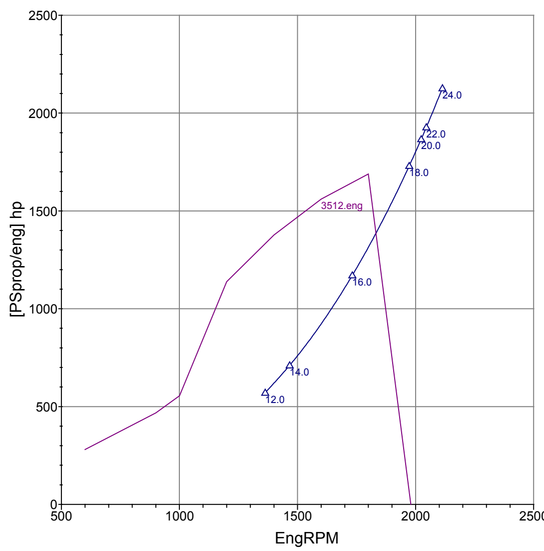


Figure 4 – Power vs RPM Curves

We learn from this that the application is RPM-limited to slightly less than 17 knots. Even though we have enough power to run 18 knots, the engine cannot spin up to enough RPM to apply that power. There are two possible solutions for this – using a different impeller with a higher "pitch", or lowering the gear ratio to reduce the engine RPM at each speed.

CONCLUSIONS

The traditional graphical approach to matching a waterjet to a vessel is clearly obsolete. For the design described in this case study, the graphical approach would have indicated an 18 knot operating speed with the installed engine, gear and waterjet. The solution to increasing speed to the target 23 knots was to have been an increase in engine power of some 20% or more.

Unlike the graphical approach, a physics-based solution, like that described here using NavCad, offered significant advantages to all parties involved – the designer, waterjet and engine manufacturers, and certainly the owner/operator. The most cost-effective action was for the designer to modify the hull design with characteristics that reduced drag over the speed range (such as greater immersed transom).

If the hull could not have been modified, then another waterjet model might be considered. The calculated propulsor efficiencies indicate that a waterjet designed for lower speed operation could use 15% to 20% less power.

Finally, even with improvements in the hull form and waterjet selection, an improper selection of the gear ratio can keep the system from performing to the best of its ability.

REFERENCES

MacPherson, D.M., Selection of Commercial Waterjets: New Performance Coefficients Point the Way, *SNAME New England Section*, Feb 2000

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