The Three Modes of Cavitating Performance

A HydroComp Technical Report

Report 137

Overview

Consider the following boat – 37 feet (11 m) length, twin 330 hp (250 kW) engines, and 18 inch (460 mm) 3-bladed propellers. This is representative of a large class of "sport fishing boats" that are intended to run at speeds in excess of 20 knots. By all accounts, they perform well for their owners.

Yet, when evaluating the performance, or trying to size propellers for these boats, the numbers just do not make sense. **Why? Cavitation and lots of it.**

Propellers begin to cavitate when there is too much thrust for the propeller to carry. Virtually all propellers for modern boats run with some amount of cavitation – and some run with tremendous amounts. How can a heavily cavitating propeller do its job? To answer this, we will need to look into the *three modes of cavitating performance* – sub-cavitating, trans-cavitating, or super-cavitating.

Suction face and pressure face forces

Propellers supply thrust to a boat by transferring lift from the blades through the hub and up the shaft line. Propeller blade lift is similar to the lift that is found on any foil moving through a fluid – such as an airplane's wing. The following graphic shows the two contributors to thrust – lift from the suction face (negative up) and pressure face (positive up).

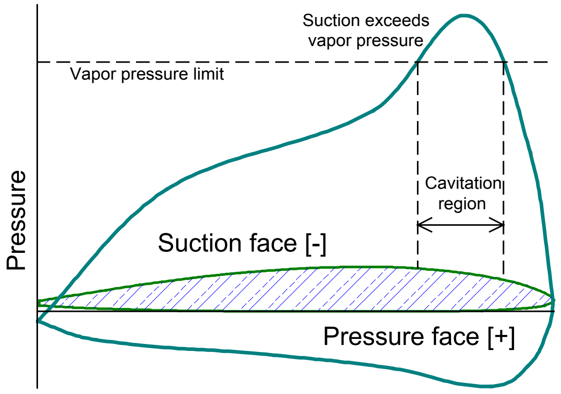

Figure 1 – Blade pressures and cavitation region

Inception of cavitation

When the magnitude of the suction (negative) pressure exceeds the water's vapor pressure – that suction which triggers the change of state from liquid to vapor – bubbles of water vapor begin to form on the blade surface. You can see this *cavitation region* illustrated in the graphic.

As thrust increases, the magnitude of pressure on both the suction and pressure faces increase. The increasing suction means that the cavitation region will grow and more of the blade surface will cavitate.

If the vapor bubble cavity is small, the water flow over the blade is unchanged, and the suction and pressure forces are unaffected. However, once the cavity grows to a size that water actually separates from the blade, water flows will change and suction face lift, total thrust and efficiency are lost.

Three modes

If cavitation is so low that it does not affect water flow and total thrust, it is *sub-cavitating*. As thrust is lost due to increasing cavitation and flow changes, it is in a *trans-cavitating* mode. The point where cavitation is so extreme that the water flow has fully separated from the suction face is called *super-cavitating* (or fully-cavitating).

The change in water flow and separation from the blade also results in a reduction in the amount of torque that is necessary to keep the propeller rotating. In other words, the vapor cavity makes it easier to spin the propeller. This is what allows the "overspin" that is seen in propellers that are heavily cavitating.

It is difficult to apply a measure of when a propeller leaves its sub-cavitating mode, but here are some rough guidelines based on the predicted percentage of cavitation:

< 15% = sub-cavitating (no loss)
15% - 40% = begin trans-cavitating (minor loss)
40% - 100% = trans-cavitating (significant loss)
100% = super-cavitating

It is important to point out that cavitation is not necessarily "bad" in all cases – it is often part of the intended design performance. Many propellers operate at such high thrust loading that extensive cavitation is unavoidable. In these cases (outboard propellers for speedboats, for example), the propeller relies predominately on lift from the pressure face, and the propeller's section shape and other geometry is designed so that it exploits this characteristic.

Some propellers that were designed for sub-cavitating performance have been successfully used in trans-cavitating applications. (This is the case in the opening example.) These propellers, however, were not originally designed for trans-cavitating operation, so they cannot be expected to achieve high efficiencies in these modes.

Propellers on boats operating at high speeds tend to be able to carry more cavitation before thrust loss begins. Propellers operating with high-thrust at low-speed, however, show a more significant loss of thrust and efficiency. It is very important to note that such cases are not limited to traditional "bollard" conditions, such as for tugs or trawlers. Planing boats can also lose thrust to cavitation when trying to accelerate through the hump speed and get up on plane. High cavitation during these dynamic speeds can result in significant thrust breakdown.

Performance analysis and propeller sizing

The analysis of propeller performance is very well behaved for the sub-cavitating mode. A large body of research is available for propellers in this mode, and most propeller analysis and sizing software is based on sub-cavitating performance.

In comparison, very little work has been done over the years for the trans- and super-cavitating modes. One reason for this is that propellers operating with high cavitation are often unstable, and small changes in thrust loading or water flow can result in large changes in RPM. Cupping a propeller further complicates the underlying hydrodynamic analysis. **For these reasons, the prediction of propeller performance when operating in trans- and super-cavitating modes is not always reliable.**

While there are no consistent prediction models available for highly-cavitating propellers at this time, work is being conducted by HydroComp to develop better numerical prediction models for these conditions. For the time being, this simply means that it will be necessary to apply a bit of care to the interpretation of results when the propeller is heavily cavitating.

Calculation guidelines

All HydroComp software (NavCad, PropExpert, SwiftCraft, SwiftTrial) uses prediction formula for the loss of thrust, torque and efficiency in these cavitation modes – but the reliability of the prediction models is less as cavitation increases. We have identified a simple parameter – a *power loading index* (PLI) – that you can use to estimate when you might expect to find difficulty with the prediction. PLI is simply *engine power divided by diameter squared*. In units of HP and Feet, we find these confidence ranges to be a good guide:

PLI	Confidence
< 50	Best
50-75	Good
75-100	Fair
> 100	Poor

In the case of our original example, the PLI is 330 hp / (1.5 ft)^2 = 147. Therefore, the confidence in an analysis or propeller sizing for this boat would be poor.

Conclusion

No practical calculation models are currently available which will allow you to analyze or size propellers operating at extreme levels of cavitation. The existing cavitation prediction methods are limited in their usefulness at very high levels of cavitation, and using conventional calculations and software for these propellers in these modes is risky. Until we have better calculation models for these modes, use the enclosed guidelines to help you determine when you should – or should not – use conventional calculation methods or software for a particular application.

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