Jim Russell: Porpoising

Jim Russell, of **AeroMarine Research**, discusses the issue of porpoising, why it happens and how to fix it ...

Figure 1: The severity of porpoising can range from annoying to aggravating or even dangerous.

Wouldn't it be nice to know why your boat has a tendency to porpoise, and how you can improve or eliminate a porpoising problem? The causes of porpoising and how to correct it are frequently mystifying. Here is an explanation of porpoising, how to mitigate the potential for porpoising during the design stage and how to fix it when it's a problem.

What is porpoising?

Porpoising is the cyclic oscillation of a boat in pitch and heave, with persistent or increasing amplitude, occurring while planing on smooth water. Picture a porpoise leaping through the water and you get the image of what it's like in a powerboat. The severity can range from an uncomfortable ride to aggravating or even dangerous.

Porpoising can become more than just an annoyance in the high-speed range, and can lead to loss of control, passenger risk and payload damage. It can even cause structural hull damage when the action becomes so severe that the hull is repeatedly overstressed. Porpoising can result in 'diving' or 'stuffing' (tripping over the bow) when the lowest trim angles that occur in the 'bow-down' part of the porpoising cycle cause the boat's nose to dig in. So a way of determining a boat's susceptibility to porpoising is helpful to the performance boat designer.

Here are two examples of porpoising complaints:

1) 'My Mod VP-style sport tunnel boat has a "hopping" motion at about 70mph. It's like porpoising, but it goes away at about 80mph. What is wrong with my set-up?'

2) 'I have a 24ft vee-pad hull that porpoises at one speed and won't stop. Why is this?'

Why does a boat porpoise?

Any vee hull or tunnel hull can be susceptible to porpoising depending on its design and set-up, but some hull designs are more prone to porpoising than others. For example:

Flatter-bottom surfaces (vee or sponsons) are more prone to porpoising than steeper-deadrise hulls (a higher deadrise is better for avoiding porpoising).

Higher trim angles are more likely to initiate porpoising than lower trim angles (lower trim angles are better for avoiding porpoising).

There are several operating, set-up and design actions that we can take to minimise or prevent porpoising.

Figure 3: Porpoising occurs when lift is generated at a sufficiently high trim angle or sufficiently low deadrise that it causes a dynamic instability of the hull.

How it works

There are two factors that influence if or when a boat will porpoise:

1) Is the design predisposed to porpoising? Some hull designs are more susceptible to porpoising

Figure 2: Porpoising is the cyclic oscillation of a boat in pitch and heave with sustained or increasing amplitude.

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Porpoising is a function of the lift generated by your hull, the deadrise of your running surfaces and the trim angle that is needed to get that lift.

than others (e.g. lower deadrise, higher trim angles). There is a way to determine whether the design is likely to experience porpoising or not. It's good to know this at the design stage or when you're buying a new boat.

2) A trigger to initiate porpoising. When a hull experiences a significant change in the dynamic balance of forces, it will encounter some longitudinal instability, and if the hull design is one that is already susceptible to porpoising at this velocity, then the dynamic instability usually triggers the onset of porpoising. If there is no trigger or cause of instability, the hull may not porpoise at all.

Some boat designs are less prone to porpoising while others are very susceptible to it. Designs that are only moderately disposed to porpoising usually need a trigger to start the cycle. Other hull designs that are very vulnerable to porpoising at a critical velocity can begin porpoising all by themselves.

Design compromises: is the hull prone to porpoising?

For hull designs that have a tendency to experience porpoising, there is a particular combination of speed, hydrodynamic lift coefficient (efficiency), hull shape, hull deadrise and trim angle that will define the limits of porpoising.

Here's why the solution to porpoising is often a confusing issue:

As explained above, there are two main factors that influence whether

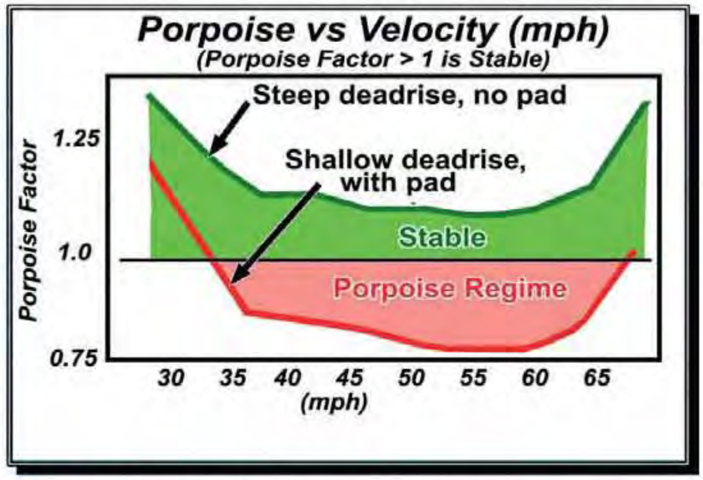

Figure 4: A hull design and set-up can be analysed to predict velocities where the hull is either 'stable' or in 'porpoise mode'.

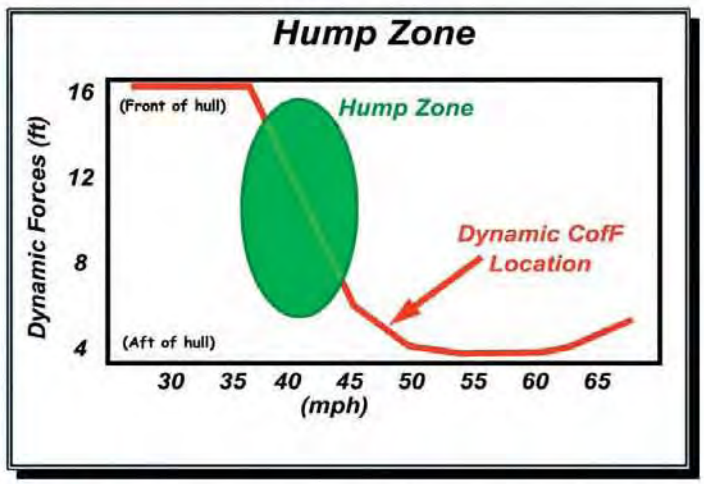

Figure 5: The 'dynamic centre of forces' is the combination of all lift and drag forces, and its location changes through the operating velocity range.

Reducing your trim angle in some way will always help a porpoising problem.

a design is prone to porpoising: a higher deadrise and lower trim angles are both better for avoiding porpoising. These two influences are confusing because they seem contradictory, and here's why ...

Boat planing surfaces with higher-deadrise hull bottoms (better for porpoising) usually require operation at higher trim angles to compensate for their reduced lift efficiency - but that higher trim angle has a greater tendency to initiate porpoising.

So even though a higher-deadrise vee hull should have less tendency to porpoise than a low-deadrise bottom, since this high deadrise needs to operate at bigger trim angles, this in fact makes it more susceptible to porpoising. So there is no simple rule of thumb in designing to avoid porpoising!

This apparent contradiction makes designing porpoise-resistant hulls challenging. It's also why we often see well-known hull manufacturers with boats that are surprisingly susceptible to annoying porpoising. (There is an engineering method for assessing whether a design is predisposed to porpoising at any velocity: we use the 'Tunnel Boat/Vee Hull Design Program' performance software.)

Onset of porpoising: when will it start?

We can predict the speed at which porpoising might begin. For a boat design/set-up that is prone to porpoising, the onset is usually triggered by a rapid change in the centre of all the lift, drag and thrust forces as the boat accelerates. This combination of all the acting forces is called the 'dynamic centre of forces'. The 'dynamic CofF' changes throughout the operating velocity range and is different for every boat design/set-up. Most hulls have a speed where this CofF goes through a rapid and major change. It's when this trigger occurs that we usually see the onset of porpoising.

On a performance vee-pad hull, the 'hump zone' is the speed at which the balance changes from lift mostly from vee surfaces to lift mostly from pad surfaces.

Hump zone

As speed increases, all performance boats experience a shift in the dynamic CofF as they accelerate through what is called the 'hump zone'. For a tunnel hull, the 'hump' or 'transition zone' represents the speed at which the amount of aerodynamic lift (air lift from tunnel and aerofoil) becomes more significant than the hydrodynamic lift (water lift from sponsons). On a performance vee-pad hull, the 'hump zone' is the speed at which the balance changes from lift mostly from vee surfaces to lift mostly from pad surfaces. Every boat and set-up has its own 'hump zone' transition velocity.

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Porpoising: why it happens and how to fix it ...

At the speed that the transition ('hump') occurs, the hull will always experience some longitudinal instability - and this often triggers the onset of porpoising. The hull experiences a dynamic CofF shift through the 'hump zone'. When driving your performance boat, you can usually feel the change when your hull enters the 'hump zone' velocity. This transition velocity can be accurately determined (by analysis) for any hull design and set-up, and can be altered by hull design, weight distribution, propeller selection and engine/hull set-up. The best performance hull designs minimise the 'hump zone' to one that is quite mild.

The onset of porpoising is usually triggered by a significant change in the dynamic CofF. On most boats, this trigger is the velocity that defines the 'hump zone'. We can determine the velocity at which any hull will experience its 'hump zone', and whether this is also likely to trigger porpoising.

So what do I do about it?

Porpoising is a function of the lift generated by your hull, the deadrise of your running surfaces and the trim angle that is needed to get that lift. If the hull design/set-up is prone to porpoising, the onset will occur at a velocity that triggers a change in the dynamic CofF. This change in forces is often the 'hump zone' built into your boat design. The change can also be due to weight shifting or even wind or wave conditions.

The resolution to a porpoising problem with a hull design is almost always addressed by causing the boat to run with less trim. If a boat is porpoising at a given speed and load, lowering the trim angle will reduce or eliminate the porpoising. There are several ways to get there, but the bottom line is to reduce the trim angle at the velocity of porpoising onset. Even if the hull design is operating in 'porpoising mode' through a full range of velocities, reducing trim in some way will improve or resolve the problem.

The onset of porpoising is usually triggered by a significant change in the dynamic CofF.

Above: A porpoising boat can be hard to steer.

Resolutions to an existing porpoising problem:

- Reduce trim angle
- Change static weight locations
- Change dynamic forces location
- Raise engine height
- Clean up hull bottom condition
- Optimise propeller selection
- Design with higher deadrise (bottom surfaces)
- Trim tabs

Reduce trim angle: When your boat begins porpoising, lowering the trim angle (using the engine trim buttons) will usually reduce or eliminate it. While this might seem like an unattractive method to correct the performance of the hull, it will at least get you and your passengers through the uncomfortable ride experience - even if it's only a temporary fix.

Changing trim angle while driving through the 'hump zone', even if less efficient, will also provide a better ride experience and, when well controlled, can reduce the range of the 'hump zone' substantially, thereby eliminating porpoising.

Change static weight locations: The onset of porpoising is influenced, in part, by the weight balance in the boat. Altering the deadweights in your boat (fuel, battery, payloads, etc.) can affect the speed and trim angle at which porpoising will initiate.

Weight distribution changes can also have a positive effect on the speed at which porpoising may initiate. Often such changes alone can avoid the onset of porpoising at your normal cruising speed.

Weight distribution changes can also have a positive effect on the speed at which porpoising may initiate.

Change dynamic forces location: Changing motor height, engine setback or propeller selection can all alter the dynamic balance of the hull - often reducing the porpoising effects. These are similar effects to changing trim angle and also help mitigate porpoising.

The resolution to a porpoising problem with a hull design is always addressed by causing the boat to run with less trim.

Raise engine height: Raising the engine to get the prop shaft higher will shift the dynamic CofF forward and reduce trim angle. Changing the setback of the engine can often alter the dynamic balance of the hull at the porpoising velocity so as to reduce the effect of porpoising or change the onset velocity to a speed where it's less annoying. Note that more HP also reduces trim angle.

Clean up hull bottom condition: Sometimes unplanned 'hooks' or 'rockers' in the hull's bottom surfaces can exaggerate the performance effects through the 'hump zone'. These variances in the hull bottom can sometimes be the trigger that initiates porpoising for a boat that is predisposed to it. Cleaning up the bottom lines can often solve the porpoising problem.

Optimise propeller selection: Propeller selection can often change the dynamic balance of the hull/set-up. For example, a change to a prop that provides more aft

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Higher-deadrise hulls are less susceptible to porpoising.

lift can alter the dynamic balance of the hull, and similarly change the speed at which porpoising begins – often eliminating the problem. Changing propellers to a set-up with less bow lift can reduce porpoising.

Design with higher deadrise: Higher-deadrise hulls are less susceptible to porpoising. Wider planing surfaces (vee-hull, vee-pad, sponson pads or centre-pod surfaces) can also reduce the tendency to porpoise. Admittedly these modifications are more complicated than some of the other tips, but designing for enhanced performance is always a better idea than fixing a problem. A small hull design change can sometimes do the trick, if you're adept at doing this kind of work.

Trim tabs: Adding trim tabs (or, to be more extreme, 'whale fins') will also improve a porpoising problem, but these will also affect the overall performance of the hull. Adding transom wedges can often help too, since they will allow for more negative trim travel, if it's required. One should be cautious when using trim tabs, especially at higher speeds, as the tabs can create instabilities and represent a potential 'trip' source when manoeuvring or turning. Tabs should be retracted when hulls are at higher velocities.

One should be cautious when using trim tabs, especially at higher speeds

The bottom line

Porpoising will happen under two conditions: first, if the design of your boat is predisposed to porpoising; and second, when the hull experiences a significant trigger, such as a change in longitudinal instability. If the hull is one that is already susceptible to porpoising at this velocity, the dynamic instability usually triggers the onset of porpoising.

The good thing is that we can calculate whether a design is prone to porpoising, and we can analyse performance to predict the velocity at which we are likely to see its onset.

There are several operating, set-up and design actions that we can take to minimise or prevent porpoising. Reducing your trim angle in some way will always help a porpoising problem.

Safe performance boating and wear your kill chord!

LINKS FOR REFERENCE:

The fully illustrated, 13th edition of the book Secrets of Tunnel Boat Design, with over 200 pages of design practices and formulae and over 160 photographs, is now available.

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ABOUT AEROMARINE RESEARCH

Jim Russell is a professional engineer with a mechanical and aeronautics background.

Currently living in Canada, he has done extensive aerodynamic research at the University of Michigan, OH, and the University of Toronto, Canada, and marine research at the NRC water channel laboratory in Ottawa, Canada. His published works and papers are highly acclaimed and are specifically related to the aerodynamics and hydrodynamics of high-performance catamarans and tunnel boats, as well as vee and vee-pad hulls.

Russell has designed and built many tunnel and performance boats. As a professional race driver, he piloted tunnel boats to Canadian and North American championships. He has written powerboating articles for many worldwide performance magazines and has covered UIM and APBA powerboat races. He has appeared on SpeedVision's Powerboat Television as a guest expert on 'tunnel hulls', and was performance/design technical consultant on National Geographic's Thrill Zone TV show and editorial consultant on the Discovery Channel's What Happened Next?

Russell is the author of the books Secrets of Tunnel Boat Design and Secrets of Propeller Design. His company designed and published the well-known powerboat design software 'Tunnel Boat Design Program' and 'Vee Boat Design Program' specifically for the design and performance analysis of tunnel boats, powered catamarans, and performance vee and vee-pad hulls. 'Jimboat' is recognised for his advanced aerodynamic and hydrodynamic research and consulting on powerboat design, performance analysis, safety analysis, accident investigation, expert witness and education/training.

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<u>About AeroMarine Research – Jim Russell bio:</u>

Jim Russell is a professional engineer with a mechanical and aeronautics background. Currently living in Canada, he has done extensive aerodynamic research at University of Michigan, OH and University of Toronto, Canada and marine research at the NRC water channel laboratory in Ottawa, Canada. His published works and papers are highly acclaimed, and are specifically related to the aerodynamics and hydrodynamics of high performance catamarans and tunnel boats, vee and vee-pad hulls. Russell has designed and built many tunnel and performance boats. As a professional race driver, he piloted tunnel boats to Canadian and North American championships. He has written power boating articles for many worldwide performance magazines and has covered UIM and APBA powerboat races. He has appeared on SpeedVision's '*Powerboat Television'* as a guest expert on 'Tunnel Hulls', was performance/design technical consultant on National Geographic's '*Thrill Zone*' TV show, and editorial consultant on Discovery Channel's '*What Happened Next*' TV show. Russell is the author of the "Secrets of Tunnel Boat Design©" book, "The Wing in Ground Effect - Their relation to Powerboats©", book, and the "Secrets of Propeller Design©" book. His company has designed and published the well-known powerboat design software, "Tunnel Boat Design Program©" and "Vee Boat Design Program©" specifically for the design and performance analysis of tunnel boats, powered catamarans, performance Vee and Vee-Pad hulls.