When thinking outside the (gear) box is not a good idea

Getting the right reduction gear ratio at the design stage saves problems in service, says Donald MacPherson, vice president and technical director of HydroComp

A good part of our consulting work is in what we call "forensic analysis". In other words, we are called on to figure out what is happening when a boat is not functioning as expected. Sometimes the problem is in the expectation itself but, more often than not, it is a fundamental mistake that impairs the propulsion system's ability to do its job.

I have an almost fanatical passion for good "systems engineering", and my plea to naval architects, ship operators or propulsion professionals is simple: proper early-stage decisions can be the difference between a well-behaved cost-effective system and one that is poorly functioning. If I had to point to the one most frequent deficiency in poorly functioning systems that are brought to us for review, it would be the inappropriate selection of reduction gear ratio.

Let's step back a moment, and look at this using a similar physical analogy – our automobiles. Those of us who drive cars with manual transmission will know the feeling of trying to start up in third gear instead of first, and of feebly running at full "red line revs" in third gear rather than fifth.

Imagine for a moment that your car only had one gear: you cannot have both maximum top speed and good low speed acceleration and control. A vessel with a single gear ratio with a fixed pitch propeller functions in much the same way. The combination of engine rpm, gearbox ratio and propeller size is a compromise to achieve the best system to suit the mission.

It is crucial to understand that a propeller's performance is not related to engine rpm, but to its own shaft rpm. In other words, the gearbox ratio is used to make an engine suitable for a particular propeller and vessel. When performance is sacrificed due to an inappropriate gear ratio, it is usually a ratio that is too low, resulting in shaft speeds that are too high. The implications of high shaft rpm are significant.

The potential efficiency of a propeller (regardless of whether its design is exceptional or mediocre) will be affected directly by how fast it spins. I do not have room to discuss the hydrodynamics of a blade's flight through water, but let me summarise with two graphs. The first graph represents three test propellers from a "series".

You can see that reducing shaft rpm (via a higher gear ratio) with a corresponding increase in pitch provides the potential for greater efficiency. Using the lowest pitch curve as a basis, approximately a 50 per cent increase in gear ratio (eg, from 2:1 to 3:1) will give the same performance with about 15 per cent less power required! These are real fuel savings that have nothing to do with a better engine, gear or propeller – just a better system.

The next plot will allow you a "quick and dirty" check on the suitability of a gear ratio by using a propeller's "tip speed" as a check. Tip speed is the circumference of the propeller diameter times the shaft rpm (corrected for dimensional units, of course). The curve shown here is a nominal suggestion for efficient performance, and you should double check your gear ratio if tip speed varies greatly from this line.

A further constraint must be applied to tip speed for considerations of cavitation and excessive vibration. The flattening of the line at high speeds is due to this type of constraint. The limit shown (at approximately 53 m/s tip speed) is for a typical open propeller on a transit craft. Applications for towing vessels, ducted propellers or high blade area propellers with many blades will all have different curves and limits.

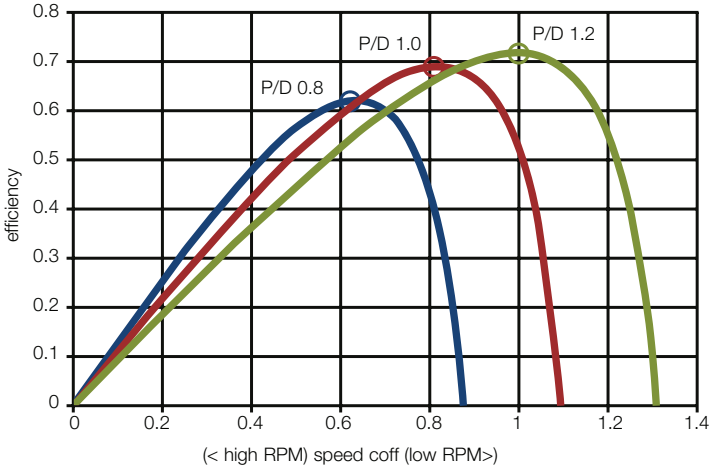
The decision to use a particular gear ratio that ultimately proves disruptive comes from many places. Sometimes it stems from whatever is in stock, so expand your search! Or, it was the highest ratio available for that engine model. If that is the case, change the engine!

Frequently, the decision comes from a ratio traditionally associated with a particular service. This is fine until the engine specifications in that service change. Don't forget that enginebuilders are good at packing additional power into the same space and that engine speeds also change.

With the tools available to naval architects and propeller professionals today, there is really no excuse for selecting an inappropriate reduction ratio. If you are responsible for making the decision about which gearbox to purchase, double check that the gear ratio is reasonable and appropriate.

A poor selection can stay with you for the life of the vessel, and the cost is too large to justify an off-the-cuff choice! *MP*

POTENTIAL PROPELLER EFFICIENCY



TIP SPEED CHECK