Is the future really hybrid?

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We all know the arguments about climate change, the need to cut greenhouse gasses and reduce our dependence on fossil fuels. We all know about the global climate treaties – Kyoto in 1997 and Copenhagen (almost) in 2009. Some of us may even know of the subsequent EU 20-20-20 declaration, committing the EU to reducing greenhouse gas (GHG) emissions by 20% by 2020 and increasing renewable energies to 20% by the same date. The sharper EU watchers might be aware of the climate change road map (2011) looking forward to 2050 in which GHG emissions will be reduced by 85%. This document states that we will all "drive electric or hybrid cars and live in cleaner cities with less air pollution".

Are these statements just political rhetoric or do they really have an impact on boat users – and therefore on boat builders?

The real purpose of these big treaties is to pave the way for legislation which makes emissions reductions mandatory. It is this legislation that drives new technology and this new technology directly affects us. A modern diesel car for example, is clean running and delivers more than 60 mpg. Although it is easy to moan about too much EU interference in our lives, would any of us really want to go back to diesel engines belching black smoke and struggling to achieve 20 mpg?

It is the same with our boats. The harsh reality is that, sooner or later, we are going to have to get used to a world where we cannot afford, or simply cannot obtain, the diesel fuel that we need to drive our boats. This won't be tomorrow or 5 years time, probably not even 10 years but it is coming and we have to figure out what we are going to do about it.

At present, the only technically viable alternative to fossil fuel is to use electrical energy for propulsion because electricity can be obtained from a multitude of sources, not just diesel. Amps are amps, regardless of whether they come from a diesel generator, a fuel cell or renewables. The marine environment does not want for energy, our problem is capturing and storing it.

Back to the EU. Europe is very good at legislating with one hand and providing the means for industry to respond with the other. By means of its large strategic research programmes (known as Framework programmes), the EU makes funding available to carry out the research necessary to develop the technologies that we will need in the future, diesel challenged world. It is this funding that is currently being used to explore the use of hybrid propulsion in smaller marine craft under the HYMAR project.

HYMAR is managed by ICOMIA (the International Council of Marine Industry Associations) on behalf of its European members and the project's aim is to provide solid, objective data about marine hybrid propulsion systems.

The first challenge is to understand diesel engine fuel efficiency. HYMAR has been using a Malo 46 sailing boat as the project trials boat, which has a modern, highly optimised hull and a modern Volvo Penta diesel. The combination of the two poses a real efficiency challenge for any hybrid system.

After many months of gathering data under different conditions and with a wide range of propellers, it is evident that, ***when loaded correctly***, a diesel engine will always be more fuel efficient than a hybrid. Intuitively, this makes sense; with a diesel engine on the shaft, there is only one energy conversion from diesel fuel to propeller shaft torque. This is achieved with an efficiency of around 35% so when the propeller efficiency of about 60% is also taken into account, the maximum theoretical efficiency of the **total propulsion system** is roughly 21%.

What is rather surprising is that this peak propulsion efficiency is rarely achieved. Diesel engines operate best over a relatively small range of torque and revs and if they are not loaded within this range, their efficiency falls. Propeller efficiency is also less at lower speeds and this combination of both engine and propeller losses worsening at the same time means that propulsion efficiency drops rapidly as soon as you move away from the optimum point. By the time the boat is at a speed of 6 knots, propulsion efficiency is down to 15%, and when manoeuvring, it drops to 2% or less. This is a frightening figure – for every 100 litres of fuel consumed, in the marina we are only getting 2 litres worth of useful propulsion effort.

So are hybrids any better? At first sight, the numbers look worse. The problem lies in the number of energy conversions required before diesel fuel is converted into useful work at the propeller. Assuming a diesel generator is being used, there are five conversions before you turn the propeller:

1. Diesel fuel is converted to crankshaft torque (35%)
2. Crankshaft torque is used to turn a generator to create electrical energy (90%)
3. Electrical energy is then stored as chemical energy in a battery (90%)
4. Chemical energy from the battery is converted back to electrical energy (90%)
5. Electrical energy is used to turn an electric motor to create torque (90%)
6. …. which turns the propeller (60%)

If the losses of all of these elements are added together, the maximum theoretical propulsion efficiency is about 15%, much less than the diesel.

There is a fundamental difference between the two systems however. A well designed hybrid system will run at 15% most of the time, whereas a diesel engine rarely runs at 21%. The opportunity for hybrid propulsion therefore exists in the operational area where the diesel is less than 15% efficient; on the Malo, this means below 6 knots. So, for pure fuel efficiency, the ideal situation is electric propulsion below 6 knots and diesel propulsion above that. This is exactly the configuration offered by parallel hybrids from companies such as Steyr Motors, ZF and Nanni

Diesel, where both the diesel engine and the electric motor/generator are on the same propeller shaft but can be used independently of one another

In order to achieve the high degree of system optimisation needed to deliver consistently high efficiency, all of the component parts have to be efficient in their own right and must be made to interact in the most efficient manner possible. This means that a high level of sensing and control is required and a whole boat energy management approach has to be taken. There are similarities to a modern car where manual intervention in the operation of the engine and its systems – such as altering the ignition timing or the fuel mixture - is now inconceivable.

Whole boat energy management has been explored extensively by HYMAR partner Triskel Marine and a fully operational trial system is in use on the test boat. This collects data from the entire vessel regardless of format, processes it and then automatically chooses the most cost effective source of energy, which could be from the batteries, from renewables or from the generator. Simultaneously, all boat data, including navigational data, is transmitted throughout the vessel allowing iPad type remote screens to be used as fully interactive user interfaces.

In terms of individual system components, probably the most challenging element is the energy storage. To run a generator at its optimum, it has to be correctly loaded, which means that the batteries have to be able to absorb high levels of energy quickly. Similarly they need to be able to deliver their power quickly in order to meet the demands of electric propulsion. Battery choice is therefore a question of balancing total life cost with charge/discharge rates, efficiency, cyclic life, management complexity and energy density. Not an easy mix. Advanced lead acid batteries based on thin plate pure lead (TPPL) technologies, such as those from HYMAR partner Enersys, deliver acceptable performance at a reasonable price. Lithium ion technologies, such as those from Mastervolt, have significant performance advantages but at a high price. Lithium polymer batteries, just becoming available for marine use, but at yet greater expense, are even more efficient. Ultimately, battery choice depends on the specific application but the important message is that there are viable options.

A lot has been said in the past about propellers for electric propulsion systems, not all of it based on sound science. From a propeller point of view, there are only two relevant differences between electric and diesel drive:

1. An electric motor delivers high torque at low shaft speeds
2. An electric motor can also act as a generator. To take advantage of this for regeneration on a sailing boat, the propeller has to be capable of operating as a turbine.

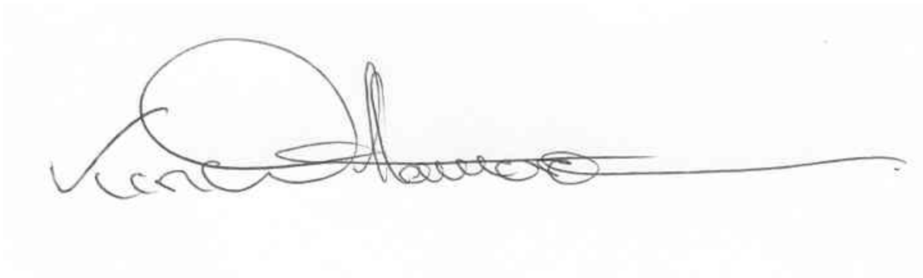
By using advanced mathematical modelling from INSEAN, coupled with extensive practical testing Bruntons has developed a new, self pitching propeller specifically for hybrid use. It has a flatter torque curve than a conventional propeller, allowing the electric motor's low speed torque to be used effectively. The blades also reverse completely to allow efficient regeneration. Further refinements are still being made but the evidence indicates that the overall efficiency of this hybrid-optimised propeller, including regeneration, is greater than a conventional propeller. This gain feeds directly into the total system efficiency.

Are hybrids part of the answer to the grand challenges posed by global treaties? The evidence clearly shows that hybrids are a positive step towards sustainable marine propulsion. Parallel hybrids in particular offer a good combination of fuel efficiency, flexibility, engineering quality and acceptable cost without taking too great a technical risk. In addition, these systems offer real benefits for consumers:

1. For boats which spend a lot of time at variable or low speeds the percentage saving in fuel is significant
2. For planing boats, parallel hybrids offer the opportunity to use smaller main engines that are optimised for the vessels' intended cruising speed with electric boost to get over the bow wave while accelerating
3. Domestic power on board is plentiful and cheap
4. Both internal and external noise and vibration are substantially reduced while under electric power

5. Cold running of diesel engines in confined areas such as marinas can be reduced
6. A ‘single fue’l boat is possible if electric cooking and outboards are adopted

The technology needed to deliver cost effective and reliable marine hybrid systems is now emerging. All the signs are that the market is ready.



Ken Wittamore
HYMAR project Manager