REPORT FOR THE SENATE ECONOMIC REFERENCES COMMITTEE

SUBMARINE PROPULSORS

DEPARTMENT OF DEFENCE

INTRODUCTION

1. At the Senate Economics References Committee ("Committee") hearing of 7 June 2018, the Department of Defence was requested to provide an evaluation of views of Mr Aiden Morrison on submarine propulsors[1], which he has expressed through a number of reports and in testimony to the Committee. The Department welcomes these contributing views and the opportunity to comment on such reports to aid a broader understanding of issues related to defence technology and the development of Australia's Future Submarine capability.

2. The Department has examined Mr Morrison's report with the support of experts in Defence Science and Technology, and has consulted with external experts in pumpjet technology.

3. In summary, Mr Morrison's conclusions are based on analysis which does not fully address essential design parameters and considerations important to evaluating propulsor performance on submarines. Mr Morrison has also used surface ship data in part as evidence, which he has extrapolated to the submarine environment to form his conclusions.

4. In his testimony to the Committee, Mr Morrison stated, '*The key conclusions that I arrived at were that pump jets have a far lower efficiency than propellers at a low speed of travel in contrast to high speeds, where jets tend to become more efficient.*'

5. The Department maintains the view that this conclusion is incorrect in the case of submerged submarine for the following reasons:

a. The efficiency of a propulsor, whether it is a pumpjet or propeller, for a submerged submarine is related to the total submerged resistance and is essentially constant over speed, noting the submerged resistance of a submarine is dependent on the total skin friction and the shape of the submarine.

b. The efficiency of a propulsor, again whether it is a pump jet or propeller, for a vessel at the surface is related to the total underwater drag submerged resistance plus the wave making resistance, which means efficiency varies with speed for a surfaced vessel. A propulsor for a surface vessel will have been designed for a specific speed, with propulsor efficiency falling away at off-design speeds.

c. The efficiency of a well-designed submarine pumpjet will be similar to, or better than, a well-designed submarine propeller across the range of operating speeds.

d. Propulsors are designed for specific purposes. Pumpjets offer specific advantages for submarines, especially with respects to the acoustic signature.

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[1] Propulsor is a generic term for the device used to propel a marine vessel, including propellers, ducted propellers, water jets, and pumpjets.

SURFACED VERSUS SUBMERGED PERFORMANCE

6. There are two primary components of resistance to forward motion for a surface ship, the underwater drag created by the hull form and the wave making resistance. The underwater drag is comprised mainly of frictional resistance and is a form of drag due to the viscosity of the water and the shape of the body. Also, when a vessel is on the surface it will generate surface waves. The wave-making resistance is the resistance caused by the generation of these surface waves and is a function of the speed.

7. Deeply submerged submarines do not experience this wave-making resistance. This means that the propulsive efficiency for a submerged body will remain constant over the speed range; whereas the propulsive efficiency drops off for a surface ship as it moves away from the design speed. This is independent of the type of propulsor. Therefore, the propulsive efficiency of a pumpjet designed for a submarine does not vary significantly with the speed of the boat.

TYPES OF PROPULSORS

8. Propulsor designs depend on thorough knowledge of the specific application so as to be properly tuned for optimal performance. Submarine propulsor designs are not an exception. There are many devices similar (but different) to propulsors used on surface ships which reinforces the importance of clarity with respect the intended use. Modern propulsors, such as pumpjets, are predominantly employed on military submarines and torpedoes. Because countries that pursue submarines and related technologies keep design information closely held, the ability to critically review performance predictions in open forums is limited.

9. Modern submarine propulsion generally consists of an open propeller or a pumpjet, the latter being employed on submarines since late last century. Propellers were the initial propulsion devices fitted to submarines, and continue to be used today on smaller submarine classes. However, pumpjets have gradually increased in application and are now common on many large submarines. The design and characteristics of propellers and pumpjets are significantly different, requiring different design and analysis tools and methodologies.

10. Generally, pumpjets are not used on surface vessels. Although propellers are yet the most common device used on surface ships, there are a number of other devices that, at least, look similar to pumpjets. These include ducted propellers and water jets. However, the design and characteristics of these devices are significantly different to submarine pumpjets. The following brief descriptions of each device highlights their fundamental differences.

a. Propellers are the most common propulsion device fitted to both surface ships and submarines. They are used extensively in smaller submarines and in some larger submarines. There are many types of propellers. Those fitted to submarines are optimised to the flow around the submarine's aft body. Those designed for surface ships are usually designed to operate within a given speed range. Both types may be optimised to also reduce noise and cavitation.

Figure 1: Submarine Propeller

b. Ducted propellers consist of a shroud which is usually designed to accelerate water flow into the propeller to improve performance. The shape of the propeller blades in a ducted arrangement will be different to an open propeller and includes a relatively small gap between the blade and the duct. The duct may be fixed or connected to the rudder, thus rotating with the rudder to support manoeuvring. These are used on tugs, trawlers, auxiliary propulsion and on some big surface ships. A major benefit of ducted propellers is the increase in thrust at very low speed that is beneficial to vessels such as tugs and trawlers.

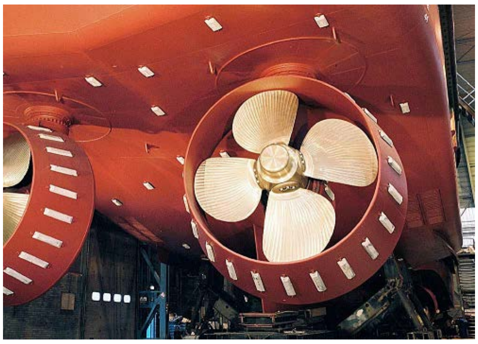

Figure 2: Ducted Propeller (Rolls Royce)

c. A water jet propulsion unit consists of a pump that draws in water through an inlet underneath the vessel and discharges it through a nozzle at the transom, driving the vessel forward by the reaction force. The pump may be either: axial flow (high mass flow and low head rise), mixed-flow, or radial flow (low mass flow and high head rise). Water jets are used on high speed surface craft, when cavitation due to the speed of the ship would reduce the efficiency of a normal propeller. Steering is usually achieved by changing the direction of the stream of water as it leaves the jet unit. Astern operation is usually achieved by lowering an deflector into the jet stream.

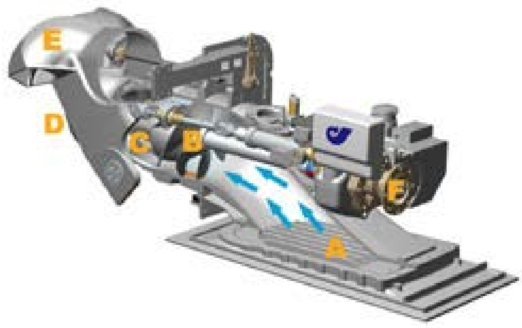

Figure 3: Water jet (Hamilton Waterjets)

d. Pumpjets are used on submarines and torpedoes. They generally consist of two rows of blades, one a stator and the other a rotor, both shrouded by a circular duct. Depending on the design and application, the stator maybe located before the rotor (pre-swirl) or after the rotor (post-swirl), while the duct can be accelerating, decelerating, or neutral. The pumpjet is mounted external to the hull of a submarine and its designed is integrated with the hull form. It has a high flow rate, low head rise axial pump and is different to a ducted propeller or a water jet.

Figure 4: Pumpjet (Turbosquid)

11. All propulsion devices need to be matched and optimised to the hull with which they will operate. Many devices can be designed and tested in an ‘open water’ condition (i.e. without the interaction with the hull). They are then matched and optimised to the hull and operating conditions. However, pumpjets cannot be developed from open water testing. The interaction between the aft part of the submarine and the propulsor is much more important than the interaction between a propeller and the hull of a surface ship for the computation of the propulsive efficiency. Pumpjet design is fully integrated with hull form design to optimise performance.

12. Propulsion devices on submarines are optimised to meet a number of criteria. These include performance, thrust, efficiency, vibration, and acoustic signature. When considering these criteria, it is essential to consider their relative importance with regard to the operation and mission of the platform. The design will driven by optimisation of the platform for its intended roles.

ADVANTAGES AND DISADVANTAGES OF PUMPJETS

13. Pumpjets are not common on small diesel–electric submarines as they are much heavier than conventional propellers and are therefore not compatible with the weight balance of small submarines. However, as the size of the submarine increases, a pumpjet can be accommodated, bringing its attendant advantages over conventional propellers.

14. The stators within the pumpjet are designed to remove the rotational flow imparted by the adjacent rotors that generates hydrodynamic loss. In other words, energy has been utilised to rotate the flow rather than propel the vessel, thus reducing efficiency. In practice, the propulsive efficiency of a pumpjets can be in the range of 5%-20% more than equivalent propellers.

15. An accelerating duct will generate forward thrust, especially at low speeds, hence its use on ducted propellers on surface ships operating at low speeds (tugs and trawlers). Decelerating ducts on the other hand reduces internal velocity, thus improving the cavitation performance. For a pumpjet, the duct and the stators contribute to improve the regularity of the wake around the aft part of the submarine . For a submarine, an accelerating duct is attractive as it generates additional forward thrust, further increasing efficiency.

16. Submarine propellers (like all their surface counterparts) operate in the non-uniform wake generated behind the hull, often increased by appendages such as devices used for steering or depth-keeping. This generates fluctuating forces on the propeller thus increasing the acoustic noise signature of the submarine. The highly skewed blades of a typical submarine propeller (see Figure 1) help to reduce the unsteady loading associated with flow non-uniformity. However, due to the stator blades and duct, the flow within a well-designed pumpjet is relatively uniform, reducing the fluctuations and the radiated noise. The larger number of blades and the ability to load the blades right up to the tips allow for a smaller diameter than the equivalent open propeller, which reduces the tip speed and cavitation. A well-designed duct and stator will also reduce the cavitation susceptibility and improve acoustic performance.

17. Despite the lower diameter, a pumpjet is usually heavier than the equivalent propeller. Pumpjets have a more complex and larger diameter hub, which is longer than a fixed pitch propeller. These, together with overall weight, results in the pumpjet being mounted further forward on the submarine than a propeller as the architect will design a shorter afterbody than for a submarine equipped with a propeller. The design of the pumpjet and the design of the aft shape of the submarine must be optimised as a whole and the good performances of the pumpjet depend strongly on the capacity of the designer to reach this optimum.

18. The astern performance of a pumpjet is less than a conventional open propeller, mainly due to the shape of the duct, which is designed for greater efficiency in the ahead condition.

SUMMARY

19. The performance of a submarine pumpjet cannot be derived from a comparison with the performance of surface vessel propulsors. Propulsors are designed for differing purposes and with the goal of optimising the performance of a vessel for its intended role. This is especially the case when it comes to pumpjets for submarines. The predicted performance of a submarine pumpjet needs to be assessed with regard for the hydrodynamic performance of the submerged submarine,

having considered how the design of the pumpjet has been matched to the hull design to optimise the overall performance of the submarine for its intended roles. It is also true that pumpjet design has advanced over many years with particular focus on the characteristics of all propulsor components. Notably many of these characteristics are classified and must remain so to protect all of the benefits that Australia will leverage to promote the regional superiority of the Future Submarine.

20. Australia's geostrategic circumstances continue to require a larger conventional submarine than those currently produced for export to other parts of the world. The design of the Future Submarine is progressing to plan, and its size remains appropriate to the inclusion of a pumpjet that can be designed to optimise the performance of the submarine for its intended roles.

21. Similar considerations apply to decisions about other technologies for the Future Submarine, including battery and other propulsion technologies. Such decisions will be informed by the intended applications of such technologies when assessed against the missions that the Future Submarine will undertake, alongside assessments of technical risk that will impact cost, schedule and performance.