STUDY ON PROPULSION ALTERNATIVES

FOR

WINMOS ACTIVITY 2.2

Co-financed by the European Union
Trans-European Transport Network (TEN-T)

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1 INTRODUCTION

This study compares pros and cons of different propulsion alternatives and discusses the properties that are needed in icebreakers. Various propulsion alternatives chosen for this study are mostly based on the existing icebreakers. The goal of this study is not to select the single best propulsion alternative as it depends on various factors such as main dimensions, mission and special requirements set for the vessel. Propulsion selection should be considered individually for each specific project ship.

Auxiliary systems that improve icebreaking capability of the vessel such as air bubbling or heeling tanks that are not directly related to the propulsion are not discussed in this study. Machinery selection is also excluded from this study and diesel-electric propulsion is assumed in all cases.

The development of icebreaker propulsion has been based on the research and operational experience from the previous vessels, as well as new technologies that have allowed introduction of completely new types of propulsion such as azimuthing thrusters.

2 ICEBREAKER PROPULSION REQUIREMENTS

Ice-going vessels operate in such conditions that present various challenges to the propulsion system performance. Compared to their open water counterparts, ice-going vessels typically require more thrust, especially at lower speeds. In addition, broken ice pieces going under the hull affect how propellers and other propulsion related appendages should be designed to function reliably under all operational conditions.

Icebreakers are typically meant to operate in more severe ice conditions than normal ice-going vessels, which means that strength and thrust requirements for the propulsion system need even more special consideration. One distinctive characteristic of the icebreakers is the good maneuverability that should be achieved when operating in ice. Turning the vessel in ice requires significantly transversal thrust which can be easiest achieved by azimuthing thrusters. Operative situations that require good maneuverability include assisting other ships, cutting ships free from ice, changing direction (astern), operating in narrow ports, breaking out of channel and in general turning in thick ice. In addition to the raw power, some of these operations require precision and good controllability of both bow and stern of the vessel at various speeds.

If the icebreaker is specified to have dynamic positioning capabilities, requirements for propulsion system are even more difficult to fulfill with traditional shaftline and rudder arrangements. Redundancy requirements of higher DP classes results in a need of multiple transversal or azimuthing thrusters in both ends of the ship. In such cases, use of azimuthing thruster propulsion is highly efficient as it can be used to reduce the total number of thrusters needed. Azimuthing thrusters are discussed in more detail later.

3 PROPULSION ALTERNATIVES

3.1 SHAFT LINE AND RUDDER

Vast majority of operational icebreakers use traditional shaft line and rudder as propulsion and steering systems. Even though many new icebreakers have been recently built with azimuthing thruster propulsion, all icebreakers used shaft lines and rudders until early 1990’s when the Finnish multipurpose icebreakers Fennica and Nordica were built. Shaft line and rudder configurations might still be valid in certain situations like in cases where open water requirements prefers shaft line solution or in icebreaker applications for most extreme ice conditions like very thick multi-year ice.

3.1.1 One propeller in stern with a rudder

One propeller in stern with a rudder is the most basic propulsion and steering configuration. This layout was typical in very early icebreakers as well as smaller vessels such as tugboats.

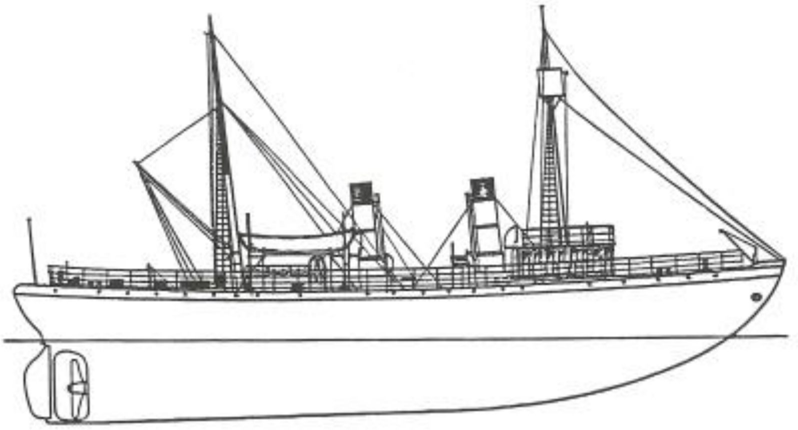

Figure 1. Icebreaker Murtaja, the first icebreaker of Finland, had the most basic propulsion layout.

In modern icebreaking operations, transversal bow thrusters would be preferred to achieve acceptable maneuverability and bow control. Large tunnel thrusters may require changes in bow hull form that could increase ice resistance of the vessel. In heavy ice conditions it is also uncertain how well tunnel thrusters could perform as they can be easily blocked by ice reducing thrust.

On the other hand it is beneficial that all of the propulsion power is in the aft for increased propulsion efficiency. One propeller and rudder is also cheap and requires relatively small amount of space inside the ship. The biggest drawback of a single propeller is the amount of thrust required by icebreakers. In theory it is possible to increase power of the shaft line and/or use a nozzle around the propeller, but in practice this would be technically challenging solution that results in a decreased overall efficiency. Using a nozzle to increase the thrust of the single propeller has its own problems that will be discussed later.

3.1.2 One propeller in stern with a rudder, one bow propeller

This alternative is slightly better that previous as the power can be divided between two propellers. Diameter of the propellers can be small enough to reasonably fit them to the hull. This configuration was the basis for some of the first Finnish icebreakers from the 1890s and early 1900s.

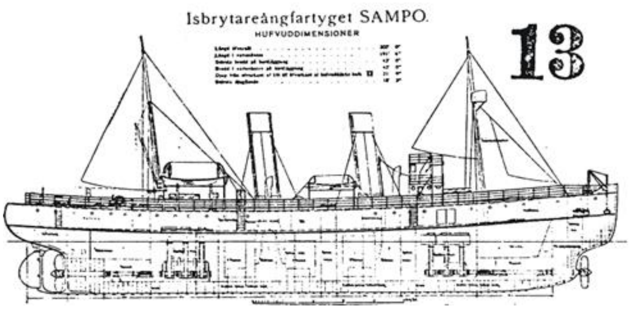

Figure 2. Icebreaker Sampo with two propellers, one in the stern and other in the bow.

With the additional shaft line and propeller this alternative is more expensive than the previous alternative. Propulsion efficiency is worse due to the bow propeller and maneuverability is not as good as only about half of the total power is used to create turning force with the single rudder. Furthermore, shaft line in the bow makes it more difficult to fit any tunnel thrusters for increased maneuverability.

3.1.3 Two propellers and rudders in stern, one/two bow propeller(s)

The configuration with one bow and two stern propellers was piloted in early steam-powered icebreakers (Wäinämöinen, Jääkarhu) and in the first Finnish diesel-electric icebreaker, Sisu. The number of bow propellers was increased to two in the first post-war icebreaker, Voima, and all subsequent icebreaker classes (Karhu, Tarmo and Urho class) used the same configuration. Prior to Urho class, all icebreakers had only one centerline rudder.

Major benefit is that the bow propellers flush the hull reducing friction and break the ice into smaller pieces, which is especially beneficial in heavy ridges. Bow propellers improve controllability of the bow and can be even used to turn the vessel by applying asymmetric thrust with two stern and two bow propellers.

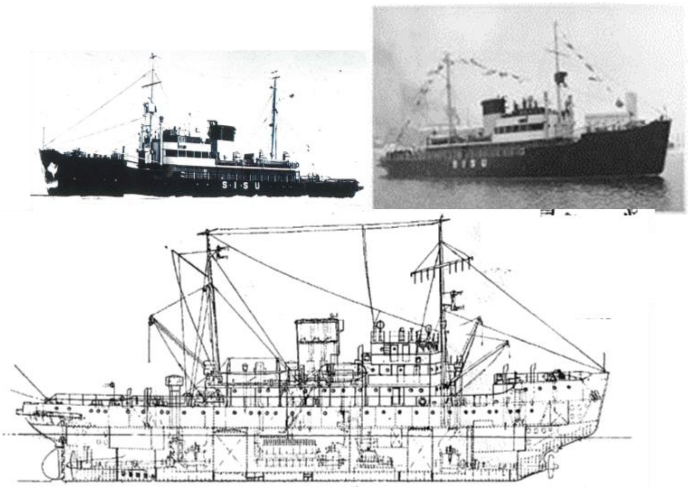

Figure 3. Icebreaker Sisu from the 1930s with one bow propeller the two in stern.

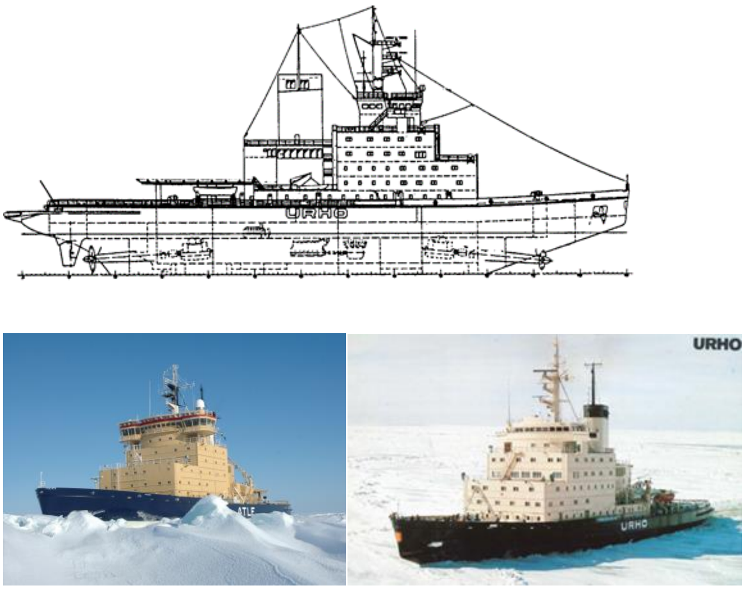

Figure 4. Icebreaker Urho with a total of four shaft lines, two in the stern and two in the bow.

Additional shaft lines and propellers mean that the ship is more expensive, shaft lines and propellers require more space and the overall propulsion efficiency is worse due to the bow propellers. These are the main reasons why Otso, a replacement of the Karhu class, was designed with twin stern screws.

3.1.4 Two aft propellers and two rudders

By excluding bow propellers, it is possible to simplify arrangement and reduce cost of the vessel. Good comparison can be made between IB Otso (15 MW) and IB Urho (16.2 MW). Even with less propulsion power, Otso has slightly better level icebreaking capability ahead than Urho with two bow propellers. However, it should be noted that Otso was also fitted with various auxiliary systems to reduce ice resistance, like air bubbling and stainless steel ice belt. On the other hand, Urho has better capability of penetrating ridges with the aid of the bow propellers that flush the hull and break the ridge. Consequently, it is also easier for assisted ships to follow Urho through heavy ridges as the ice is broken into smaller pieces.

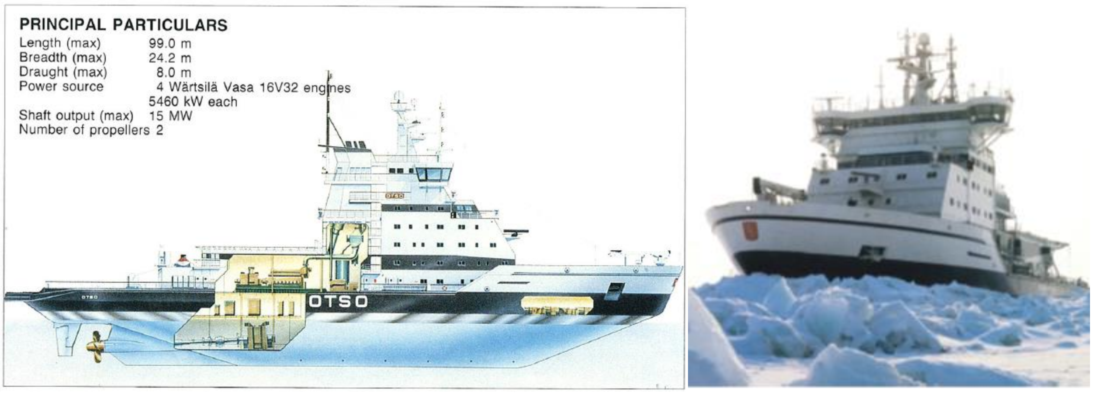

Figure 5. Icebreaker Otso with two shaft lines in the stern.

Both vessels have decent maneuverability with two rudders. Otso has the advantage that the full propulsion power is used to turn the vessel with rudders. On the other hand the bow propellers of Urho help to keep the bow directionally stable even in heavier ice conditions. Otso was later fitted with a bow tunnel thruster as controllability of the bow was found out to be insufficient. To fulfill DP requirements, Otso would require at least two similar sized tunnel thrusters - one to each end. If redundancy is also required for DP, the number of tunnel thrusters is increased even more. Multiple tunnel thrusters require modifications to the hull with large fore- and aft foot that can increase ice resistance and thus required propulsion power. One possibility is to use retractable transverse thrusters that were designed to be used in the original Aurora Borealis concept. However, this would increase the price of the vessel significantly.

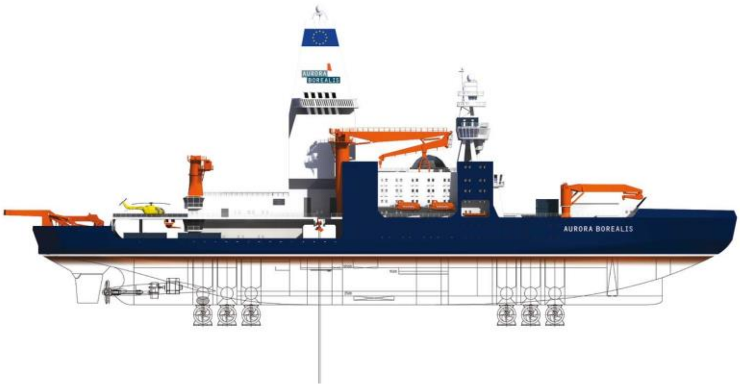

Figure 6. Thruster arrangement on Aurora Borealis

3.2 AZIMUTHING THRUSTER PROPULSION

There are two main types of azimuthing thrusters. The propulsion motor can be either located inside vessel so that it is connected to the propeller with angular transmissions (mechanical thruster or Z-drive), or the propulsion motor can be located inside propulsion unit that is outside the hull (pod thruster).

Propeller in the mechanical thruster can be either driven by electric or diesel motor. However, all known icebreakers with mechanical thruster use electric propulsion motor. First icebreaker with mechanical thrusters was Finnish icebreaker Fennica build in 1993.

In pod thrusters, electric propulsion motor is mounted at the propeller shaft itself. Pod thruster is relatively new propulsion alternative and it was designed in Finland in late 1980’s especially for icebreaking purposes.

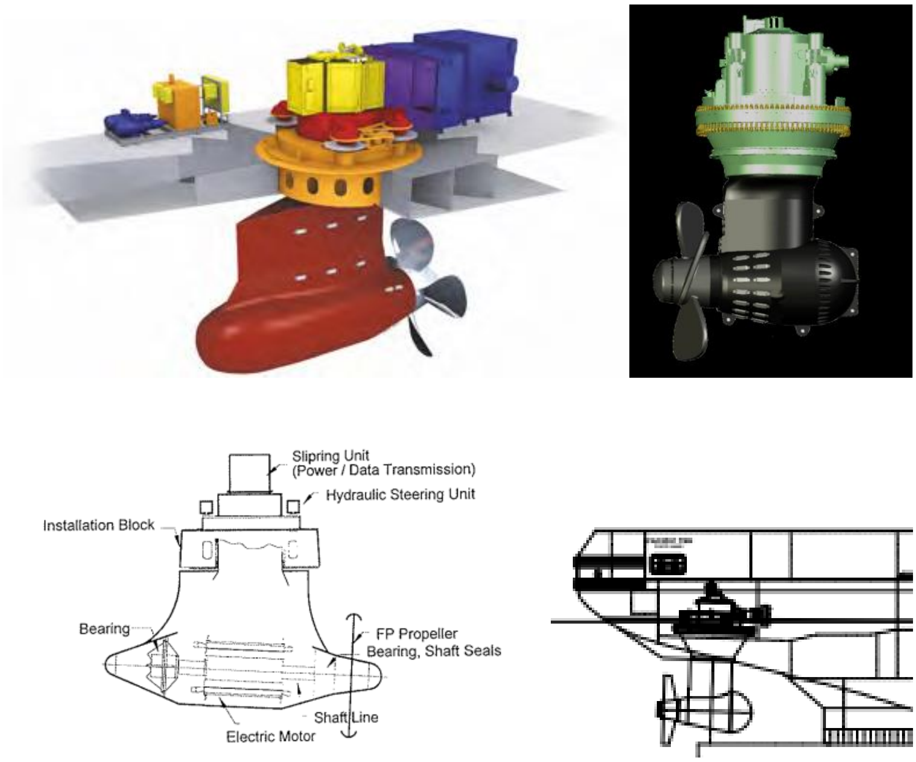

Figure 7. Principle of podded thruster (left) and mechanical thruster (right).

Both azimuthing thruster types provide more or less similar advantaged over traditional shaft lines and rudders. Azimuthing thrusters give excellent maneuverability in all directions with different power levels and speeds. They can be used to clear ice around the hull to reduce friction and prevent the ship from getting stuck.

For icebreakers it is beneficial that the direction of thrust can be changed without changing direction of rotation of the propeller. This allows ramming with constant power by turning the thrusters. The propeller flush also helps to break the ridge around the ship hull.

Azimuthing thruster propulsion provides excellent DP capabilities, especially if they are used in both stern and bow. If redundancy is required, at least two thrusters or additional transversal thrusters would be needed in both ends of the ship.

Operational difference between mechanical and pod thruster is not significant in icebreakers. Decisive difference can be that the pod thrusters require less space inside the hull as propulsion motors are mounted inside the thrusters. But then again mechanical thrusters are typically smaller and easier to fit under the hull.

3.2.1 One azimuthing thruster in the stern

The most simple azimuthing thruster propulsion configuration is to use just one stern thruster. However, as with the single shaft line and propeller, it is difficult to generate enough thrust for an icebreaker with just one propeller. As a result, this alternative is not studied any further.

3.2.2 Two azimuthing thrusters in the stern

This alternative has become somewhat standard propulsion configuration for recent icebreaking vessels. Several built references include Fennica, Nordica, Botnica, Svalbard, Neuwerk, Arkona, Mackinaw and several Russian icebreakers. This propulsion configuration fulfills the requirements of maneuverability and icebreaking capability for icebreakers. DP can be achieved relatively easily with added transversal tunnel thrusters in the bow.

Figure 8. Examples of vessel with two azimuth thrusters in stern

3.2.3 Three azimuthing thrusters in the stern

Three stern thrusters are operationally very similar to the previous alternative. A third propulsor does not give any significant benefits but increases price of the ship. It may be also impossible to fit all three aft propulsors in the smaller hulls.

However, three aft thruster propulsors may be the only solution if two propulsors are simply not enough to produce required thrust or draught limit of the vessel restricts the size of the propellers.

3.2.4 Bow Azimuthing thruster propulsion alternatives

Adding one or more azimuthing thrusters to the bow would considerably increase maneuverability and bow control of the vessel. It is heavier and more expensive than typical transversal tunnel thrusters, but has the benefit of giving additional thrust and bow flushing in ice breaking. It also gives the normal benefits of a bow propeller when penetrating ridges. Similar benefits could be achieved if the vessel has azimuthing thrusters in the aft and penetrates heavy ridges astern, but having thruster(s) in the bow gives more flexibility when operating in heavier ice conditions. New icebreaker for the Finnish Transport Agency will have a propulsion configuration of two stern and one bow azimuthing thrusters. Similar propulsion configuration has been chosen for Gazprom Neft’s new icebreakers that support loading operations in an offshore oil terminal in the Gulf of Ob in the Russian Arctic.

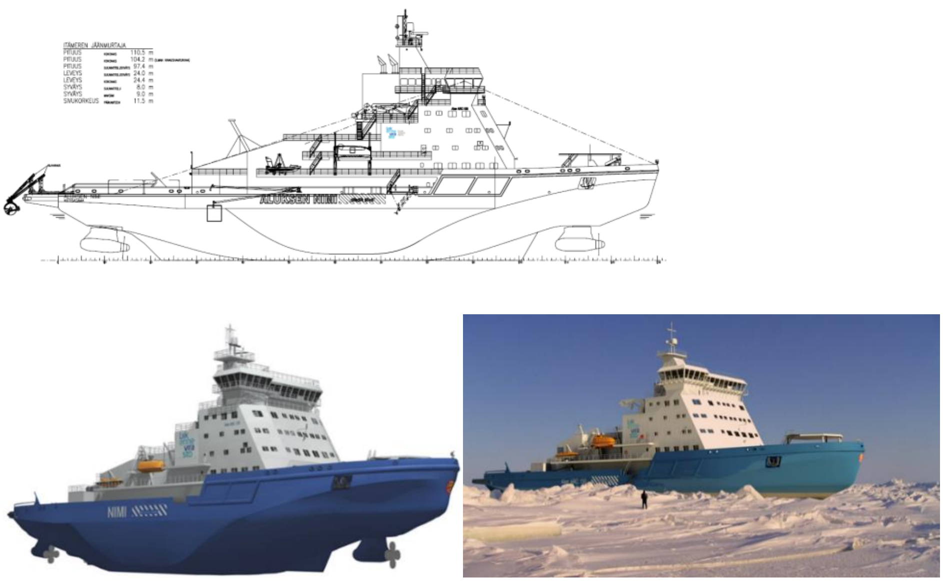

Figure 9. Propulsion configuration of two stern and one bow azimuthing thrusters.

3.2.5 Hybrid configurations

Hybrid configurations include different combinations of shaft lines and azimuthing thrusters. Most notable combinations are two azimuthing thrusters and one shaft line, or one thruster and two shaft lines. The former is being built in Russian LK-25 and the latter in a Canadian polar icebreaker CCGS John G. Diefenbaker. As mentioned earlier, the reason for the third propeller is the amount of thrust required for polar icebreakers. Installing the third propeller to the bow was not considered viable for a line icebreaker operating in heavy arctic ice conditions.

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Figure 10. Different variants of hybrid propulsion configurations.

3.3 NOZZLES

Nozzles are discussed here separately as in theory they can be fitted in all mentioned propulsion alternatives. When it is not possible to increase diameter of a propeller, using a nozzle is a relatively simple way to increase available thrust without increasing power. Nozzles are commonly used in vessels that require high amount of thrust at low speeds, such as tugs, offshore vessels and icebreakers. However, especially in icebreakers, use of nozzles has been debated due to the problems presented by ice. In addition to the increased thrust, nozzles protect the propeller blades from direct ice block impacts, which is beneficial especially in mechanical thrusters to reduce stress on gears.

However, ice pieces can cause serious problems for icebreakers when stuck between propeller blade and the nozzle. Large pieces of ice may not fit through the nozzle at all and thus pile up in front of the propeller causing thrust breakdown and heavy vibrations. This happens easily in heavy ice conditions and ridges where the increased thrust would be needed the most. It is possible to reduce the amount of ice going to the propellers with hull form and appendages, but experience shows that it is impossible to completely keep the propellers and nozzles clear of ice. The situation is even worse when going astern. Another method of preventing thrust breakdown is to clear the nozzle by reversing thrust and flushing the stuck ice pieces away from the propeller, but this naturally reduces available thrust in desired direction.

As a conclusion it should be noted that the nozzles are not very common in existing icebreakers, especially not in those designed to operate in heavier ice conditions. Multipurpose icebreakers Fennica and Nordica were fitted with nozzles but the third vessel Botnica was built with open propellers.

Figure 11. Icebreakers with ducted propellers.

4 SUMMARY

Icebreaker propulsion has been developing constantly with operational experience and introduction of new technologies that have allowed use of solutions that were not possible or otherwise considered viable with previous generations of icebreakers. It is also common for new icebreaker concepts to have secondary roles that require increased maneuverability and adaptability to various operational conditions.

Azimuthing thrusters have become an attractive propulsion alternative for icebreakers operating in the Baltic Sea and even for vessels designed to operate in Arctic multi-year ice. Azimuthing thrusters provide various technical benefits that cannot be achieved with traditional shaft lines and rudders. As a result, most icebreakers today are built with azimuthing propulsion.

Ultimately the propulsion selection should be made according to requirements for specific project, and considering suitability of different alternatives. Especially the number of propellers or thrusters is highly dependent on the size and propulsion power of the vessel.