NAVAL ARCHITECTURE

Humans have been building boats for millennia. Many of the complex considerations relating to travel on the water have been solved but modern boats are different than boats from previous eras in terms of their size, their technology and their construction material. Consider, for example, a piece of wood. If you throw that piece of wood in the water, it will float. But warships are no longer made of wood – try throwing a piece of steel in the water. It'll sink like a rock. How does a ship built out of a material that doesn't float, float? You may not know why a steel ship floats, but that has long since been figured out – 2,000 years ago Archimedes explained how bodies immersed in liquid float.[1]

Marine architecture is the science of the design of all types of marine vessels – personal, commercial and military – from cargo ships, cruise ships, surface warships, submarines, power boats/yachts, offshore drilling platforms, floating wind turbines to unmanned/autonomous vessels. Marine architects work with marine scientists, seafarers, marine engineers and international organizations that set maritime safety standards. They need some knowledge of stability, hydrostatics, hydrodynamics, strength and structural design, classification society rules, safety of life at sea rules, resistance and power generation and general layout.[2] In addition, there will be considerations of performance and cost of building the ship.

In this Briefing Note we can't possibly cover all the aspects involved in designing a ship. What we will do here is simply illustrate the complexity of the considerations involved in *naval* architecture and the design of warships.

Obviously, a naval architect does not need to re-invent the wheel. There are certain principles that have long since been determined, and many things that have been learned over the years, often as a result of unfortunate circumstances like a ship sinking. For example, it became clear long ago that watertight closures on a ship are important to ensure that water cannot spread, and help prevent battle-damaged warships from sinking.

Despite many design advances over the years, warships are often unique and the calculations need to be revised to adapt to their particular characteristics. When designing a new ship, one of the first things you need to ask is for what purpose the ship will be used. Why does that matter? Well, the design of a cruise ship (to maximize passengers and their pleasure) is different from a cargo ship (to maximize cargo space and efficiency of operation) and a warship (to fight and survive a war). Cargo ship and warship crew members appreciate it if the motion of the ship can be reduced – but this is crucial on passenger ships. Obviously, a warship is less focused on the comfort of personnel than a cruise ship. This will be reflected in the design of the ship. With the different purposes of a ship come different crew sizes, and crew size affects the design of the

[1] To explain briefly, a ship in water is acted upon by two forces – weight and buoyancy. Weight is the downward pressure of the ship on the water, buoyancy is the upward force of the water. These forces have to balance. There are also other considerations such as surface area and whether the ship forms a sealed air pocket.

[2] Soumya Chakraborty, "What is Naval Architecture: Careers, Courses And Jobs For Naval Architects," Marine Insight, Last updated on 11 January 2021, available at https://www.marineinsight.com/naval-architecture/what-is-naval-architecture/.

ship. As well, different countries have different rules and regulations about space allocated to crew which will also affect the design.

Even if we focus only on warships here, this question must still be asked – for what purpose will the warship be used? With what missions is the ship going to be tasked? How long will it be at sea? At what speed is it expected to go? What combat capabilities will it need? Will it need to incorporate stealth provisions to reduce sonar and radar signatures (which includes, for example, quiet propulsion, smooth flow of water under the hull, the shape of the superstructure)? These considerations will affect the design. To use a Canadian example, the Royal Canadian Navy is building three new classes of ships – the Arctic and Offshore Patrol Ships, the Joint Support Ships and the Canadian Surface Combatants – and the answers to these questions will differ for each of these ships.[3]

A naval architect does not decide these questions. In the case of warship procurement, the government will provide details of what the ship is to do – i.e., the desired specifications and features of the ship. It will send out a Requests for Proposals to which shipbuilders will respond with their design, and the government will choose from among the proposals. After that, the naval architect will work on the changes that the government wants incorporated in the initial design. A number of preliminary designs may be worked up to indicate the range of possibilities within the parameters listed in the government's Statement of Requirements. The information from existing ships can provide the basis for the design, including weight and displacement, hull volumes, speed and power, stability, freeboard, sea-keeping performance, etc.

A second consideration is where the ship will be operating. This matters to the design for a number of reasons. For example:

- will it encounter ice? If so, the hull needs to be strengthened, and that will increase the weight of the ship, which will affect other elements. (This would apply to Canada's new Arctic and Offshore Patrol Ships.)
- will it operate only in shallow water? If so, that means the hull will be of a different design than a ship that sails on the open ocean.

For operating on the open oceans, you need a warship that is strong enough to withstand significant stresses. A ship is subject to forces operating on it from several directions at once – including up and down ('heave') and side to side ('sway'). When building a ship, the material of its hull and the structural supports must be strong and flexible enough to withstand bending and twisting without buckling. And it must have a little extra strength to withstand extraordinary natural circumstances it might encounter. Another consideration for a warship is the ability to withstand battle damage. This influences structural design (reinforced hull, arrangement of bulkheads, machinery, engineering and living spaces). And, oh yes, the hull must not be so heavy because of this strengthening that the ship is difficult to manoeuvre or takes too much fuel to propel!

A naval architect also has to consider the size and shape of the hull below the water in relation to the parts that are above the water. The design ensures that the ship has a centre of gravity that allows it to right itself in rough waters. Without vertical and horizontal stability, a ship could capsize in heavy weather. A consideration – relating to the question of where the ship will operate – is that in polar regions, ice can build up on the ship, and this can add significant

[3] See the relevant Briefing Notes for each of these ship classes, available at https://www.navalassoc.ca/naval-affairs/briefing-notes/.

weight and change the balance of the ship. As well, when warships receive mid-life updates, care must be taken not to change the balance of the ship with additions to the superstructure.

The issues of weight and balance have continuing importance for a naval architect. But how do you calculate the weight of a ship that does not yet exist? Based on known data, a naval architect can estimate the weights of the hull, propulsion and auxiliary machinery, piping systems, electrical and electronic gear, fuel, water, stores, crew, among other things. It is likely that the actual weight of the ship will not agree exactly with the estimated values because some equipment or armaments may be added or removed during construction period. Depending on how large the difference is, the ship may float slightly differently from that contemplated by the designer but if the difference is small, it may not be a problem. For a submarine, however, a difference is a big problem. The calculations of weight and buoyancy for a submarine are much more complicated than for surface ships. (Because submarines are so complex, let's focus here on surface ships.)

How will the ship move? Here design of propulsion and steering systems comes into play. What propulsion system best fits the size, weight and purpose of the ship? Should the engine be a diesel, electric, gas turbine, nuclear, or perhaps a combination thereof? What type of propeller should be used? The means of propulsion is related to weight and purpose, and will differ among ship types. A warship needs to have certain speed parameters as determined by its missions. Warships also have requirements to be manoeuvrable and need to be able to stop and turn quickly if necessary. Ships usually move forwards but entering/exiting harbours or rivers or docks also requires the ability to reverse. Again, the naval architect does not have to re-invent the wheel. It may be possible to select the features of a propeller based on test results of models. The key takeaway here is that the propulsion system is affected by and will affect many of the other elements of ship design.

One of the considerations relating to propulsion is overcoming resistance and friction of the water. There is more resistance in water than in air – as you will know if you've ever taken an aquacise class. The shape of the hull will help with the resistance/friction, and there are other smaller steps to reduce friction – for example, the difference between rivets and welding, different paint types and clearing the hull of marine organisms.

Warships have requirements for offensive and defensive weapons and need the hull strength to survive a missile hit. A naval architect must calculate the weight of the weapons, and the force of their recoil, to determine where they can be located on the ship to distribute the weight (but also where they are most effective). The architect must also be cognisant of the power requirements of the weapons, surveillance and navigation equipment. An additional consideration is the strength of the deck to accommodate the weight and thrust of aircraft as they take off and land, and the hangar that accommodates them.

Building a scaled-down physical model has long been routine during the design process. A small-scale model allows you to test at least some of the elements, and indeed very few new design large ships are built without first testing them in a model. Using a model can help to evaluate the ship's stability and manoeuvrability, the structures needed to support the forces the ship will experience, and the power needed to propel it through the water. Obviously models cannot replicate real world conditions in every sense – for example, waves can be reproduced in a test tank, but not the highly irregular waves that occur in the real world (i.e., waves of different heights and lengths traveling in several directions). But models can answer some questions for the architect.

The sophistication of the models and the testing facilities has grown rapidly with technology, and modern-day naval architects enjoy the benefit of this. To supplement small-scale models, Computer-Aided Design systems are now widely available and virtual reality software is a key part of the design process.[4] With this technology the architect – and customer – can examine the design from all angles before building starts.[5] This 3-D imaging makes it much easier to see how the multiple elements of a ship fit together and address potential problems.

Conclusions

We have only scratched the surface here by noting a few of the considerations inherent in designing a warship. Warships must float (hull integrity), move (propulsion and power) and fight (weapons and sensors), and these elements must all be considered in the ship design. Naval ships must be built to withstand the challenges of the sea and the violence of the enemy, protect the crew, and carry on with the mission despite battle damage. Naval requirements, technology, manufacturing processes, safety regulations and the models to test the design have changed in the past 100 years. And naval architecture pulls it all together.

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[4] See David Dunlop, "CSC Visualization Technology," available at https://www.navalreview.ca/2020/12/canadian-surface-combatant-visualization-technology/.

[5] For example, Lockheed Martin/BAE opened Canada's first Visualization VR 2 Suite for the Canadian Surface Combatant (CSC) in Ottawa in November 2020.