Australian Government
Department of Defence
Science and Technology

Australia’s requirement for submarines

Janis Cocking, Chris Davis and Christopher Norwood

DST GROUP | Science and Technology for Safeguarding Australia

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This report is to better inform knowledge about submarine technology.

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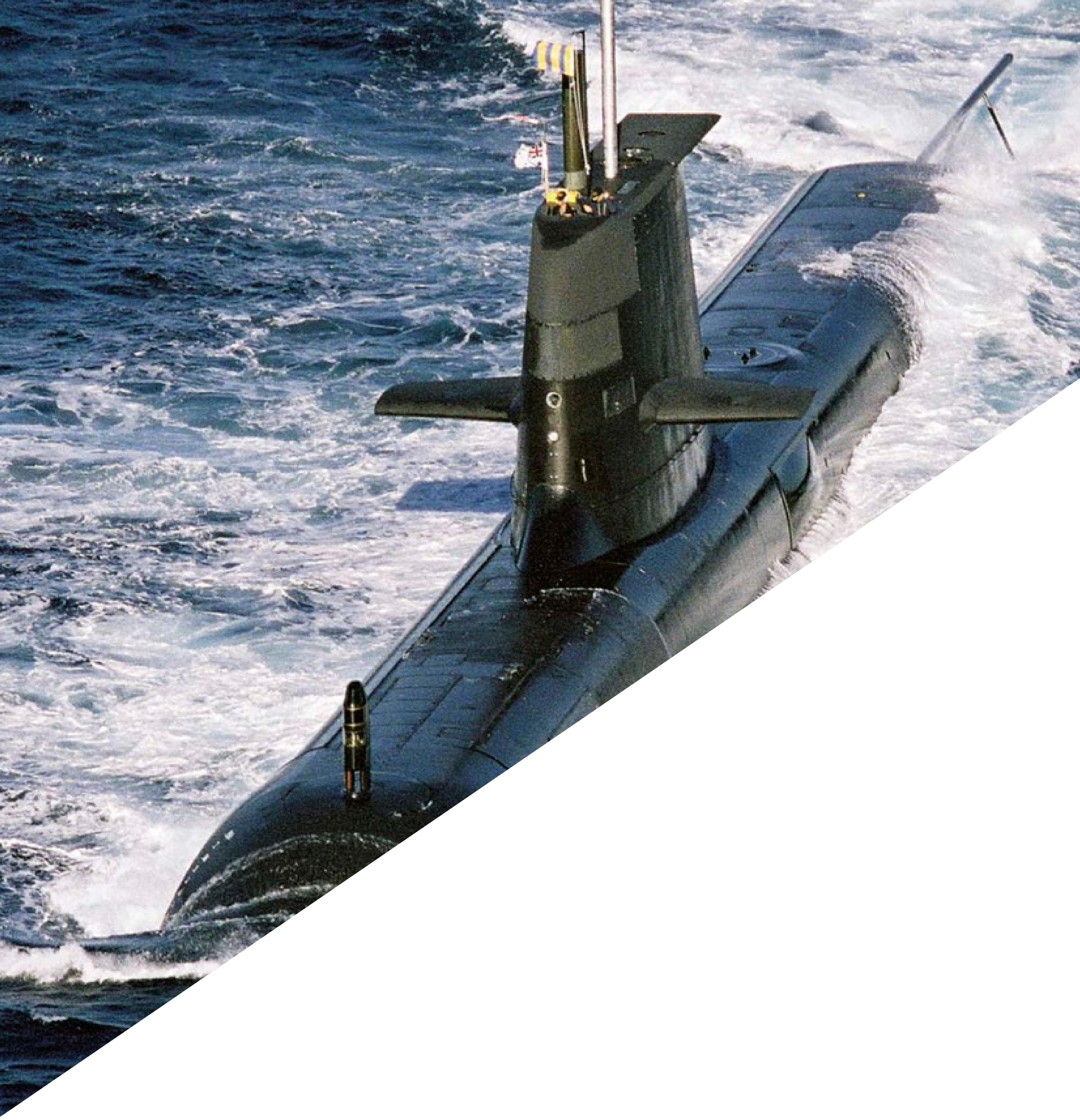

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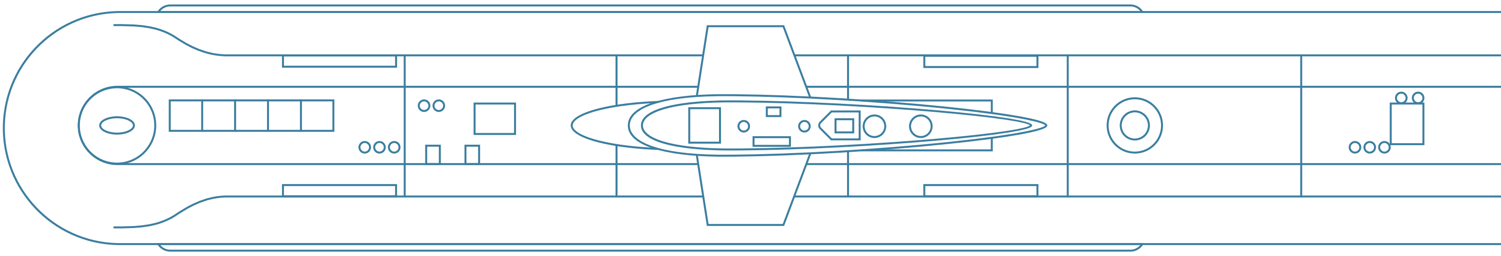
Defence Science and Technology Group
David Warren Building
24 Scherger Drive
Canberra Airport ACT 2609



FOREWORD

Over the past three decades, DST Group has helped deliver a highly effective submarine capability for Australia. It has provided extensive science and technology support for the Oberon and Collins class boats and has aided the development of concepts for the Future Submarine to replace the Collins class.

The depth of expertise it has acquired through this work not only spans a wide range of technologies employed on submarines but also the ways that submarines can be operated to best effect. The organisation thus has a wealth of knowledge about a range of capability matters that impact the acquisition of a new submarine for Australia.

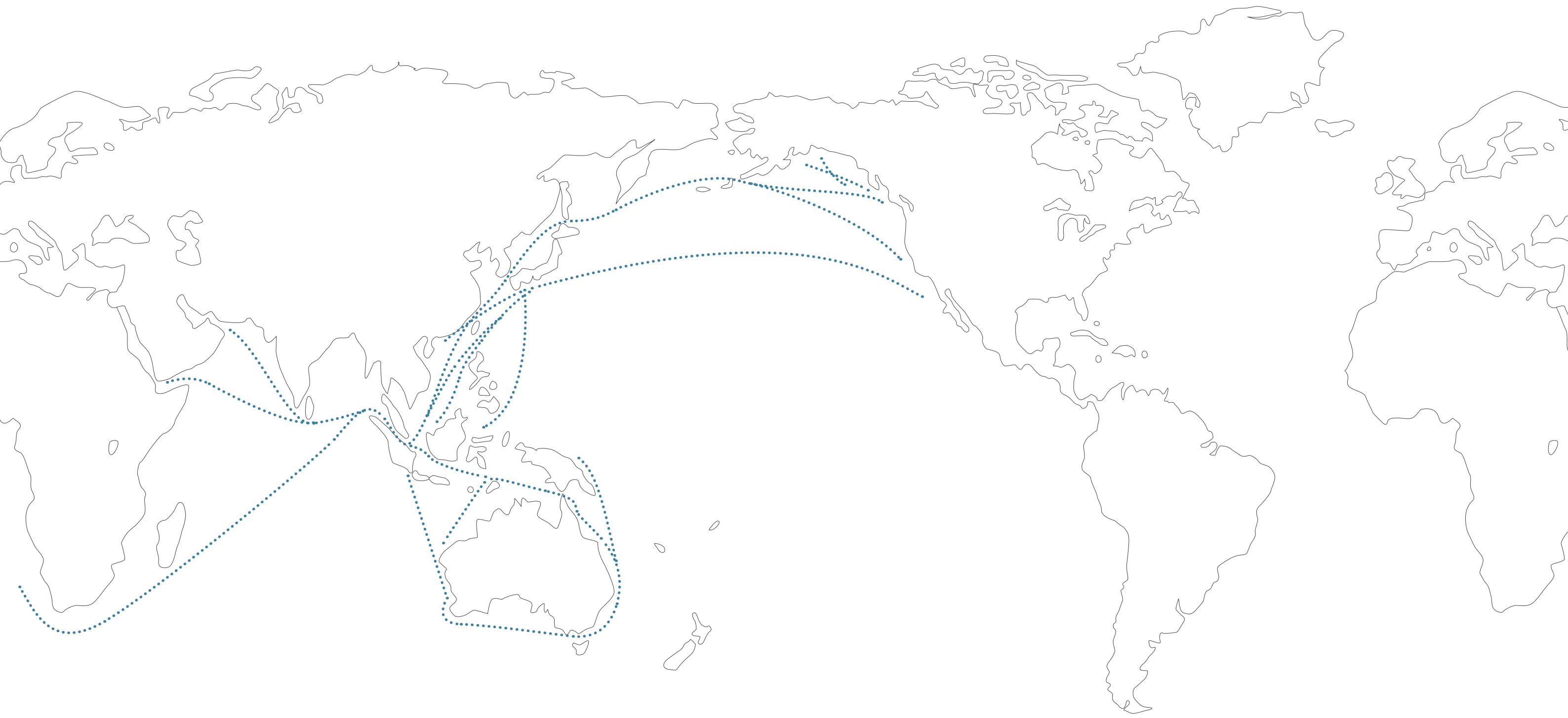
Dr Alex Zelinsky
Chief Defence Scientist

AUSTRALIA'S MARITIME STRATEGY

A fundamental question extant at the outset is, why acquire new submarines at all? To answer this requires an examination of Australia's strategic interests and how best to pursue them. One key determinant here is geographical in nature.

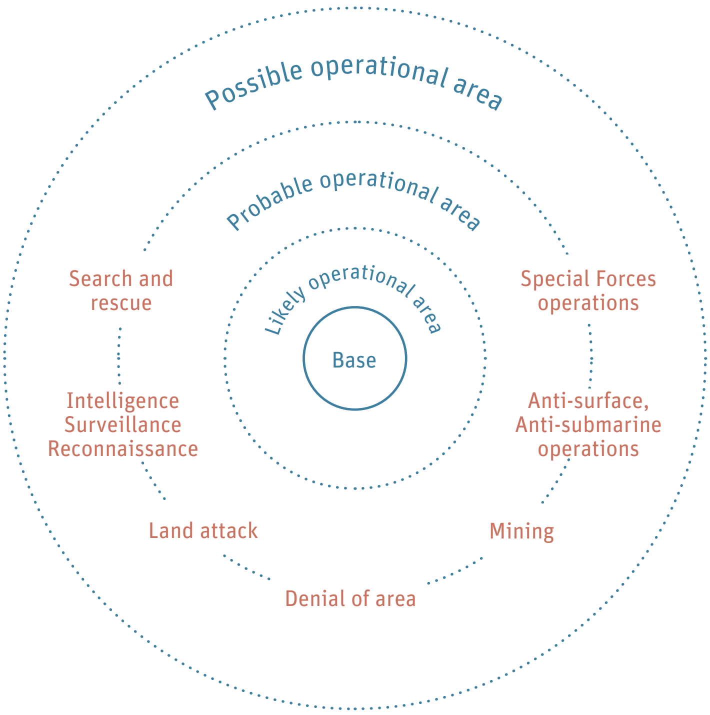
Because Australia is an island continent south of South-East Asia and somewhat remote to the rest of the world, its ability to trade with other nations – and hence its prosperity – depends on shipping being able to freely transit seaways in the region. The majority of Australia's trade is conducted with East Asian countries over seaways traversing the South-East Asian archipelago. Crucially for Australian maritime strategy, there are many straits and other maritime geographical features that form choke points through which all shipping is channelled. In the south of the archipelago, there are twelve navigable straits, while in the mid-north there are just five, and further north there are fewer still. These choke points could be used to great disruptive effect if controlled by an unfriendly power. Equally, they provide conditions that Australia can exploit to readily thwart any naval attacks approaching from north of the choke points. The capability to mount a sustained presence in these areas is thus of high strategic importance to Australia.

Indo-Pacific major shipping lanes



WHY SUBMARINES?

The capability options available – in addition to submarines – include the major battle order assets of ships and aircraft along with unmanned aerial vehicles and satellites. In high-threat conditions, surface vessel operations are mounted in task force groups, which, however, have endurances of just a few months, and no more than two task forces can be mounted by Australia at a time. Australia's fighter aircraft, meanwhile, can strike surface shipping, but only over relatively short distances unless supported by tanker aircraft, which themselves require fighter escorts. Due to the relatively limited flight times of fighters, keeping enough aloft to sustain an effective operation will quickly exhaust aircrew and the availability of airworthy aircraft. Moreover, both ships and aircraft are readily detectable at considerable range, allowing an adversary time to respond.



By comparison, once a submarine leaves port and dives, it essentially becomes invisible, detectable only at relatively short range by sonar through the application of a large and complex search effort. The element of uncertainty this introduces has a multiplier effect in terms of deterrent capability – simply knowing that a type of boat has the range and endurance to operate in a given area will inspire fear that one could be lurking anywhere at any time. An adversary's options then are to cease operating in that area or to contest control of it by mounting anti-submarine operations. The great advantage submarines have over anti-submarine warfare forces is expected to exist for many years to come.

Another difference between surface vessels and submarines is that the latter are generally tasked as sole assets for the achievement of a required military outcome. If the range and endurance capabilities of a boat are sufficiently extensive, a fleet of them may thus be able to sustain a continuous presence in a given area of interest, with one arriving on station as another departs for home. A further advantage is that submarines can operate in forward areas where more readily detectable assets, such as ships and

aircraft, would be denied access. They are therefore highly suited to intelligence, reconnaissance and surveillance data gathering as well as Special Forces missions. In addition, their stealth combined with the highly sensitive suites of sonar arrays they carry uniquely enable them to gather vital data for anti-submarine warfare on the whereabouts of other submarines.

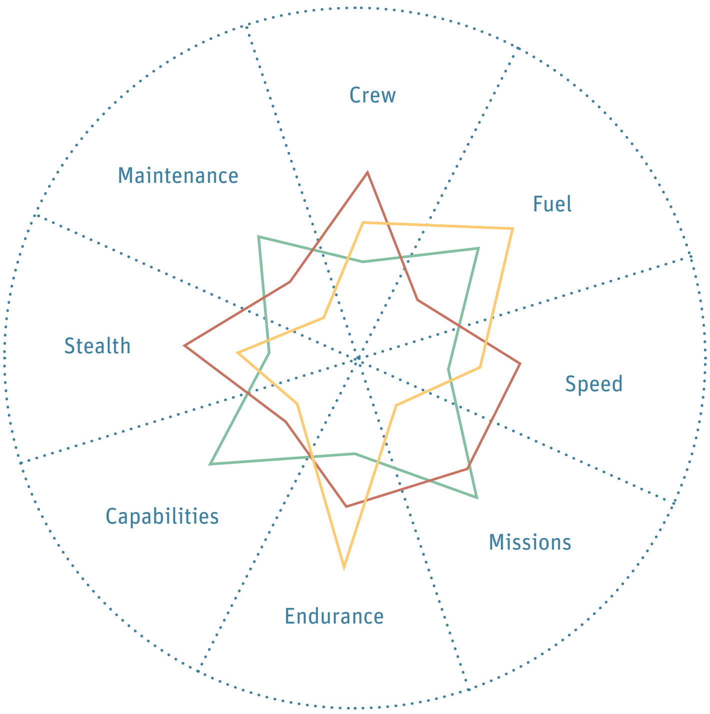
Hence, although submarines are costly to acquire and run, they deliver a disproportionately large military effect. According to the *2016 Defence White Paper*, “Submarines are powerful instruments for deterring conflict and a potent weapon should conflict occur.” They offer what Vice Admiral Ray Griggs, former Chief of Navy and current Vice Chief of the Defence Force, describes as ‘strategic weight’ – a property that can shape or change the behaviour of other nations and their decision-making, which no other Australian Defence Force asset or combination of assets can do. With the waters of South-East Asia becoming increasingly militarised, the strategic weight submarines can bring to bear for Australia thus seems increasingly cost-effective.

The next questions to consider then are the type and number of boats to acquire.

WHAT KIND OF SUBMARINE?

One determinant here is the missions the boats will be required to undertake. These will include anti-submarine warfare; anti-surface warfare; intelligence, surveillance and reconnaissance; mining and support to special operations.

An associated determinant is that of distance to be covered. If Australia had access to a forward base in a friendly country closer to the operational area, this could be significantly reduced. However, a maritime strategy that assumed continued access to a foreign base is highly risky, and making use of this access, moreover, would greatly diminish the submarines' stealth advantage since their whereabouts will be known. Australia has a port relatively close to the operations area – Darwin. The shallowness of the surrounding sea near Darwin that leaves submarines vulnerable to attack, the location of the city on Australia's northern frontier closest to potential adversaries and the relative lack of industrial infrastructure make Darwin less than idea as a submarine base. Since Fleet Base West at Fremantle is the chosen port for Australia's fleet, these submarines thus need to have long range, high transit speed and long endurance performance. The larger the submarine, the greater its range, transit speed, endurance, crew size and military capabilities, but larger size, however, also entails larger cost of construction and maintenance.



PROPULSION SYSTEMS

Another determinant for consideration is the desired propulsion system. Nuclear power offers several advantages here. This technology harnesses the heat generated in a reactor by nuclear fission to produce high-pressure steam that turns steam turbines connected to the propeller shafts or powers an electric propulsion system indirectly by turning generators. The fuel supply of a nuclear submarine can last for many years and even the lifetime of the boat in some cases. Hence, the range and endurance of such boats are only limited by food supplies and crew endurance. Moreover, a nuclear reactor generates high amounts of power that can propel submarines at speeds as fast as or faster than ships, allowing for very rapid transit times. The ability to sustain high speeds also offers a much greater capability to successfully position the submarine for attacks on other vessels.

The Australian Government has ruled out the nuclear option since Australia lacks the appropriate infrastructure, regulation guidelines and procedures to successfully build and operate nuclear submarines, and the time required to amass such support systems and skilled people would extend beyond the timeframe for replacement of the Collins class fleet.

DIESEL-ELECTRIC BOATS

The alternative propulsion option is diesel-electric. These types of submarines are fitted with large diesel engines that turn generators to charge a bank of batteries. Electric motors draw power from the batteries to turn the submarine's propeller. With few moving parts in the electric motor, the submarine can operate very stealthily when running on battery power. However, it needs to periodically rise to periscope depth to run its diesel engines so that the batteries can be recharged, an operation known as 'snorting'. At this time, the boat's masts are detectable by radar, and the wake they create may be spotted visually. In addition, engine noise may be detectable by sonar systems some distance away, and this noise will also impair the ability of the boat's sonar to detect other vessels. The captain can choose when to snort to minimise the likelihood of detection, with the optimal times being after dark, during bad weather, in waters away from operational areas and when merchant vessels are nearby to mask the boat's engine noise. The proportion of time taken running the diesel engines to recharge the batteries compared with the amount of time spent submerged is called the indiscretion ratio.

The diesel-electric propulsion system offers more limited submarine performance than the nuclear option. The faster a submarine travels underwater, the greater the amount of power it requires to overcome the resistance, or drag, of moving through the water. While a submarine may be able to stay submerged for several days if it is moving slowly, it might use the available power in the batteries in a few hours if it is travelling at high speeds.


Lead acid battery test facility.

Thus the faster diesel-electric submarines travel, the more often they have to snort (which diminishes their stealth advantage), the quicker they use up their diesel fuel supply and the less distance they can cover. This impacts on their ability to sink ships that are capable of sustaining speeds in excess of 20 knots. While submarines have the advantage of stealth over ships, they generally need to be prepositioned ahead of a ship to successfully attack it.

One way of improving the performance of diesel-electric submarines may be provided through use of lithium-ion batteries, which can store higher amounts of energy in a given volume of battery. Another way is by the addition of a system called air independent propulsion (AIP) involving the use of oxygen, carried onboard in liquid form in high-pressure tanks, along with other fuel. Some kinds of AIP technologies, such as steam turbines and Stirling engines, make use of the heat energy liberated by combustion, while fuel cells combine oxygen with hydrogen to produce electrical energy and water. For larger submarines that transit large distances, however, AIP is likely to only ever be useful as a supplementary system that offers additional capability for silent running when required by exceptional circumstances.

BIGGER BATTERIES MEAN BIGGER BOATS

Battery powered propulsion endurance can, of course, be improved by increasing battery size. However, this then would require bigger engines to avoid lengthy snorting times to keep the indiscretion ratio low. Bigger fuel tanks would also be required – all of which adds to the size and buoyancy of boat needed for the additional volume and weight.

However, the larger the submarine, the greater the drag generated as it pushes through water, which then requires more power to propel it. As the size and power of a submarine increase, eventually the gains made in range, speed and endurance diminish. By studying the interplay of these factors, Department of Defence analysts have established that in order to sustain presence a long way from Australian waters, a diesel-electric powered submarine of at least 3,500 tonnes displacement weight will be required. This is bigger than the size of the Collins class. As Vice Admiral Griggs, noted, “Submarines of this size are an effective balance between propulsion capacity, the internal volume required to fit equipment, fuel, weapons and people, and the logistics to sustain them for long endurance missions.”

CAPABILITY EDGE

Equally important to the abilities to reach a distant operational area in a timely fashion and sustain a presence are those of being able to carry out missions and bring force to bear when necessary. Staying safe and operating effectively depends on detecting the presence and movements of adversaries before they detect those of the boat. Submarines therefore need to be equipped with sonar arrays that are as large as possible for high sensitivity signal detection, along with sensors deployable on the surface to gather optical and electromagnetic types of data. The tasks of processing and interpreting the data captured by these different kinds of sensors require skilled operators. Crew engaged in demanding work such as this need to be rostered on and off watches with sufficient recovery time to avoid burn-out over the course of a deployment. The more crew required, the greater the allowance that needs to be made for crew quarters, provisioning and habitability support systems.

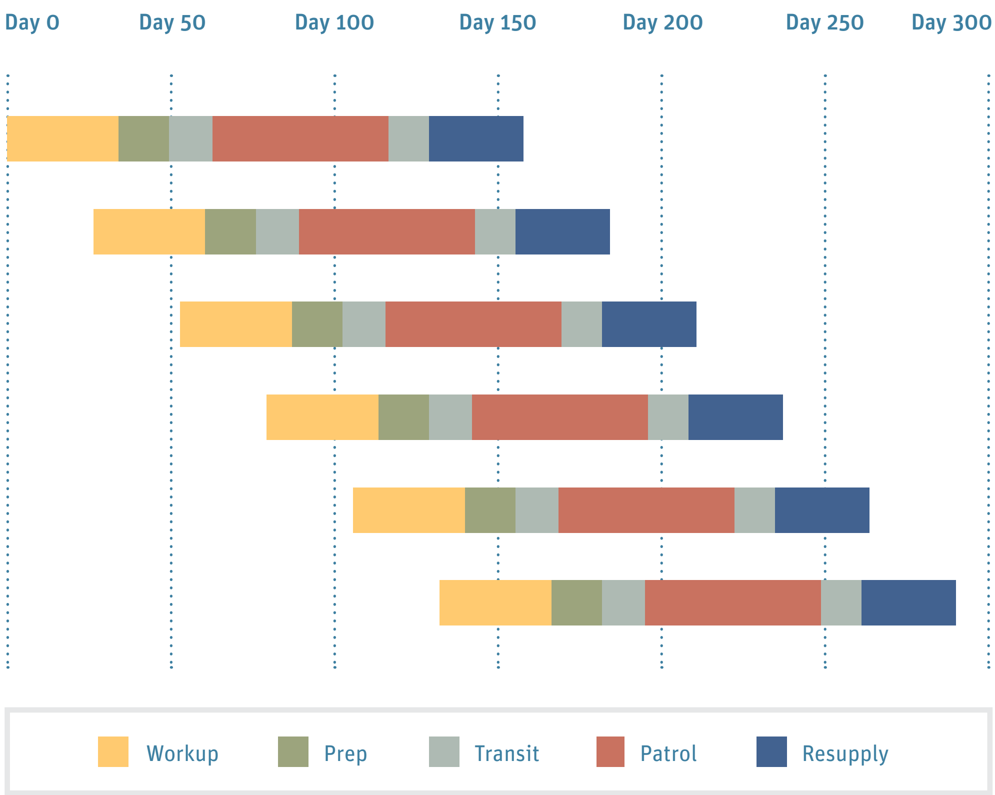
A capability edge also depends on remaining as invisible as possible. One way of achieving this is to develop designs for the hull, propeller and onboard machinery that keep the amount of noise emitted extremely low. Other noise minimisation measures include the use of vibration dampening mountings and noise cancellation systems. These make the boat less detectible to passive sonar systems listening for such signals. Another way to enhance the boat’s invisibility is to clad it in tiles that absorb or deflect away the pulses of sound emitted by active sonar systems, thus rendering the boat less detectible to active sonar systems. Many of the measures taken to give the boat a stealth advantage will thus impact on the weight and buoyancy of the boat and its performance.

Boats also need a large array of communications systems to enable communications and data exchanges with their home port and to facilitate interoperability with allies such as the US Navy.

HOW MANY SUBMARINES?

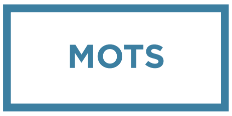
Once the range and transit speed of a type of submarine have been established, this data can be fed into calculations to establish the time taken to transit from port to a given operational area and the time that can then be spent on station before needing to return to port. With this being known, and also the time required for submarine maintenance and crew R&R, the number of submarines needed to deliver a given level of presence can be calculated.

Defence analysts have established that a fleet of twelve submarines would be needed to maintain the level of presence required to fulfil Australia's strategic needs. With each boat to be capable of the same range, speed and endurance performances as Collins class boats but being much stealthier and more militarily capable, and the new fleet being twice the size, Australia is expected to have ownership of a highly effective submarine capability for many years to come.

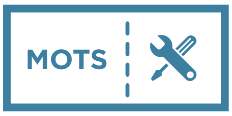


ACQUISITION OPTIONS

There are several ways that a new diesel-electric submarine could be acquired. The options below are discussed in order of increasing level of risk.



One is to buy what is termed a military off-the-shelf (MOTS) design built for another navy but made available for purchase. While such a design will have been proven and is therefore a low-risk option, the particular uses for which it was built may not match Australia's needs. Any attempts to push the range, speed and endurance of such boats may incur high maintenance costs and reduce boat reliability and availability. Moreover, the ownership of this model by other navies may increase the difficulty of developing a capability edge.



Another option is buy a MOTS design and modify it, which could involve increasing its size to enhance capabilities such as range, endurance or crew capacity. This will incur the time and cost penalty of extra design work, and will only deliver the required improvements in capability if the design can be successfully up-scaled. If difficulties are encountered, a wholly new design may be the better option.

A third option is a new design that can take one of two forms; it may involve the integration of proven MOTS components, thus offering a lower risk development path, or it may require the development of new ones to attain desired capabilities.

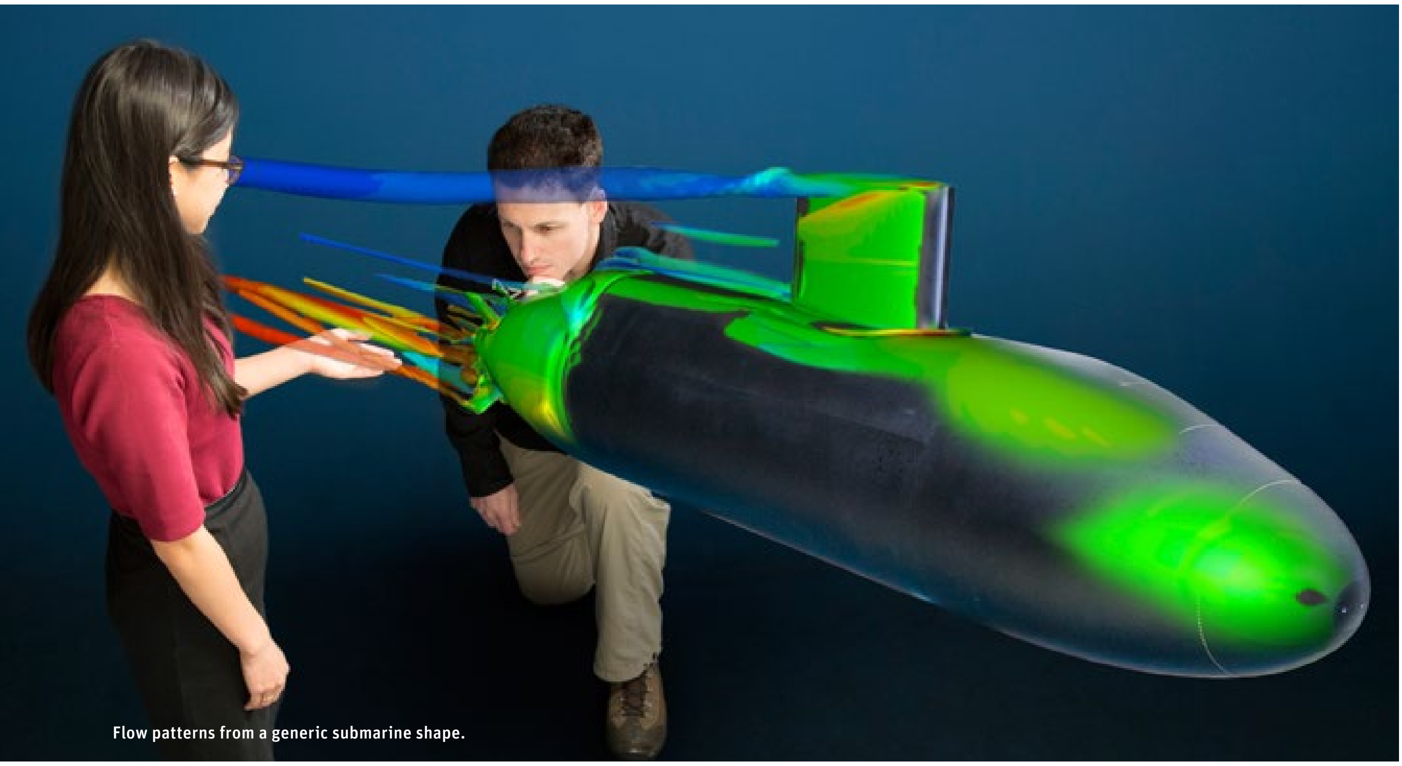
Sitting somewhere between these two latter options is one termed 'upgraded Collins' which involves capability enhancements to the Collins class design with proven MOTS components. Since the Collins class boat is not now in production, some design work inherent in a new design would have to be undertaken to ensure the new components could be successfully integrated.

Out of all these design options, the Defence analysts found that only a new design would meet Australia's requirements – the most risky option and also the most costly. The question then arises, where and by whom should this new type of boat be designed and built?

MAKING AUSTRALIA'S NEW SUBMARINES

Submarine construction is one of the most complex and difficult ventures advanced industrial nations undertake. The Collins class boat is made of about half a million parts, about five times that of a large commercial airliner and about three times that of a frigate.

The design process is the most demanding phase of all. One factor making it so is the need to ensure that the selection of everything fitted and carried on board – provisions, fuel, weapons, equipment and the crew's size and skill sets – will be optimal for fulfilment of the boat's operational requirements over its lifetime. This configuration cannot be much altered later because the boat's ballast tanks are designed to be just big enough for effective buoyancy control, kept minimal in size to maximise boat operational efficiency and thus its endurance on battery power. The addition of weight later on could compromise buoyancy control, which must be precise particularly when travelling at periscope depth to avoid inadvertently exposing large parts of the boat above water. Also, since a submerged boat essentially flies through the water as an aircraft does through air, the distribution of weight throughout the boat must be uniform so that it transits and manoeuvres with optimal hydrodynamic efficiency. The weight distribution must also ensure that the boat sits upright both above and below water. Even relatively small additions in weight will significantly affect the boat's trim if placed far from its centre of gravity.



Flow patterns from a generic submarine shape.

Experimental setup to investigate shock loading.

One very challenging aspect of submarine construction is production of the steel alloy for the hull structure. This material has to be capable of withstanding the stresses bearing on it as a result of submarine manoeuvres and underwater explosions. It and the welds used to join sections must have strength under tension and compression at all relevant thicknesses of plate, and it must exhibit high fracture toughness. The material also needs to be corrosion resistant to withstand constant immersion in salt water, and have low-level magnetic properties to ensure low likelihood of detection by electro-magnetic sensors.

A further challenge is that of sourcing some specialised technologies. Because of the restrictions placed by allied countries on the release of anechoic and reflective tiles for use on Australia's Collins class submarines, these had to be designed and made in Australia. The sovereign ownership of some such technologies means that domestic design and production capabilities are essential.

The Australian Government has stated that one aim of the Future Submarine project is to maximise the involvement of Australian defence industry. With some highly specialised design and construction techniques required, the question then arises, what types and levels of experience with submarines can Australia draw on?

AUSTRALIA'S INVOLVEMENT WITH SUBMARINES

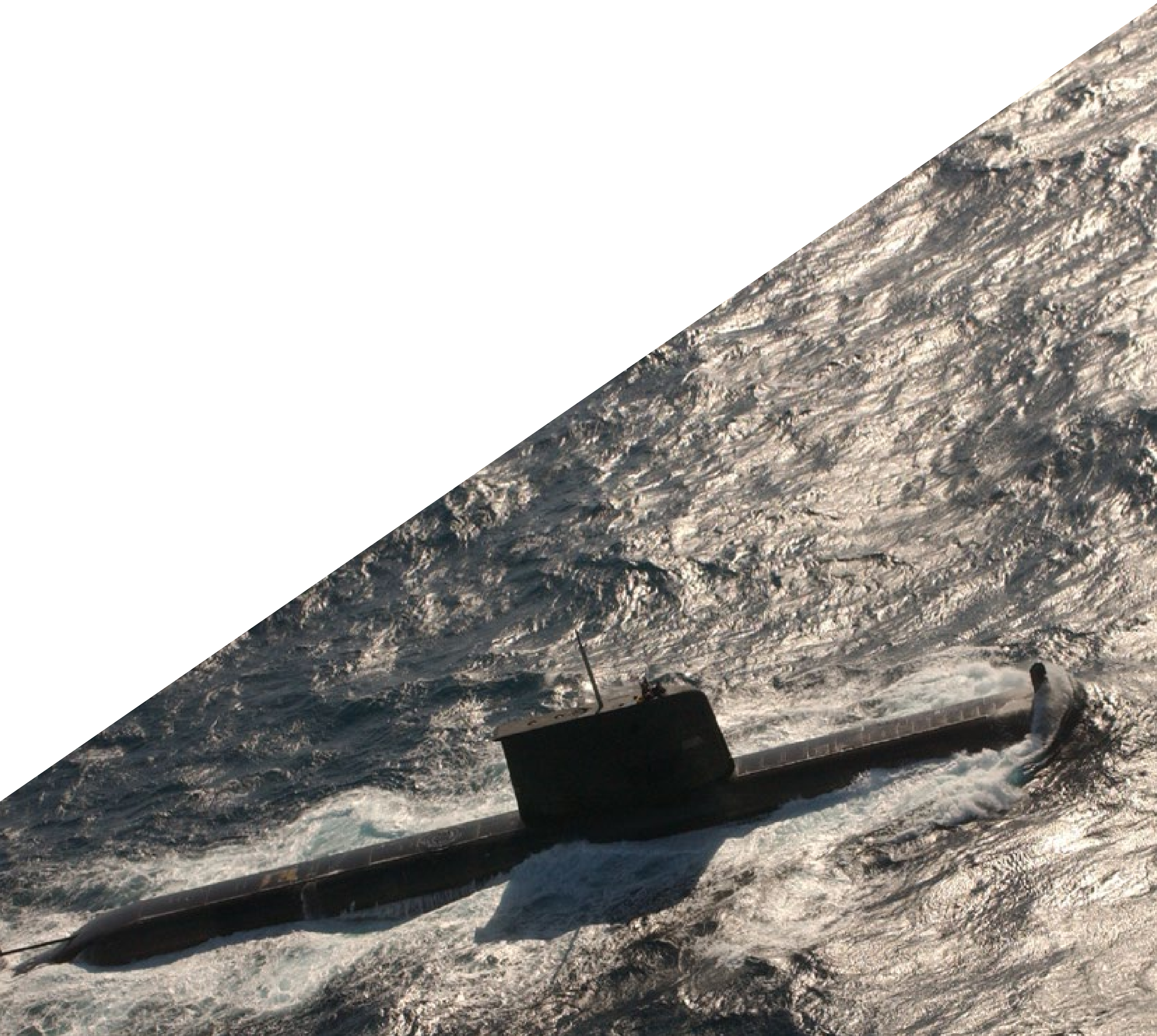
Australia began an operational involvement with submarines at the beginning of last century when two E class submarines were acquired from the United Kingdom, named *AE1* and *AE2*. Following the outbreak of WWI, these were sent into action against the German Pacific Fleet near New Guinea, with *AE1* being lost for unknown reasons at this time. *AE2* significantly assisted the ANZAC landings at Gallipoli by penetrating the Dardanelles and wreaking havoc on Turkish navy ships before being damaged by gunfire and then scuttled. By the 1920s, submarines had fallen out of favour with the RAN for a variety of reasons, and after briefly operating two British-made O class boats, Australia gave priority to developing its surface vessel capabilities, continuing on this path throughout WWII.

By 1963, however, many in Australian government circles now saw the value of submarines for strategic strike operations and intelligence gathering, and six of the new British O class boats were acquired. One outcome was the valuable experience gained in combat system technology and engineering as a result of Australia's submarine weapon system upgrade program. Another outcome, still little known to the Australian public, was the expertise acquired through missions to detect, track, locate and identify Soviet nuclear submarines and other advanced warships in the Southern Ocean during the height of the Cold War. According to one report, these top-secret ventures "... won the Australian submarine service the admiration of US and British naval intelligence agencies ... ."

With a decision to replace the O-class boats being taken in the early 1980s, and no MOTS designs found to be available that met Australia's requirements, the Australian government launched a tender process to select a company to build its new boats. Kockums of Sweden was contracted to design and build an enlarged version of its Västergötland class submarine – to be known as the Collins class – with the majority of the build being undertaken in Australia by the Australian Submarine Corporation in Adelaide. Work was also subcontracted out to many other Australian defence industry suppliers as well as some overseas. The combat system was procured separately, with Rockwell selected as the supplier. Although problems were encountered with excessive boat noise at higher speeds and an underperforming combat system, both problems were rectified to produce what is now recognised to be one of the most highly capable diesel-electric submarines in the world.

This achievement was particularly remarkable given that the Collins class was effectively a new type of submarine evolved from a Swedish design of half the displacement. Furthermore, the Collins class have to travel much further through rougher waters at higher speeds than other diesel-electric submarines and they incorporated a large amount of new technology. The success of this experience has inspired many in Australian defence and government circles to seek the acquisition of a bigger fleet of more capable submarines as replacements for the Collins class. Aligned with this is a national aspiration to further develop Australian boat building and maintenance industries.

So what is the state of Australia's submarine construction skill base now?



AUSTRALIA'S SUBMARINE CONSTRUCTION CAPABILITIES

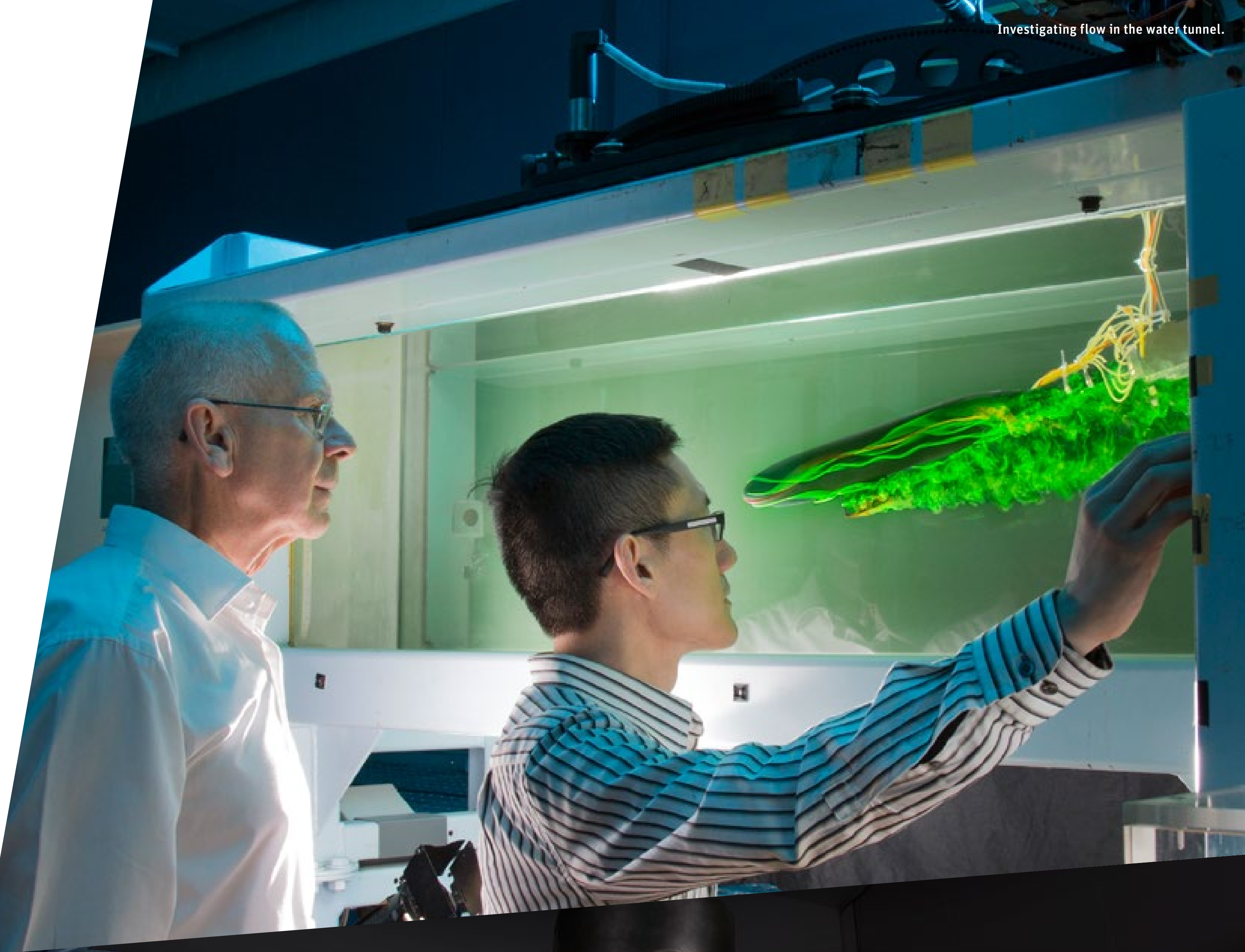
In 2009, the Future Submarine project commissioned the RAND Corporation to study Australia's ability to design a submarine. While a good skill base for management and technical support was found in industry and the government sector, skill gaps and insufficient initial capacity were identified in some areas. The required software design tools were found to be available in Australia and most of the testing facilities either existed in Australia or could be accessed in allied countries. To address the skill capacity shortage, RAND proposed the options of building a team of Australian designers, hiring designers from overseas or collaborating with an international design company. The first option made the biggest addition to cost and delivery time but also provided the best prospects for establishing a long-term design capability in Australia.

When making its decision about the builder of Australia's new submarines, the third option was the one taken up by the Australian government. In April 2016, Prime Minister Malcolm Turnbull announced that the French company, DCNS, had won a competitive evaluation process with its conventionally powered Shortfin Barracuda design.
The submarines will be built in Adelaide, Australia.

FURTHER INFORMATION

Chief Maritime Division
(08) 7389 7619

Research Leader Maritime
(03) 9626 8577



Investigating flow in the water tunnel.

Testing radar absorbing material for submarine periscope.

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