AUSTRALIA'S SUBMARINE DESIGN CAPABILITIES AND CAPACITIES

Challenges and Options for the Future Submarine

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Summary

The Commonwealth of Australia will need a domestic workforce of roughly 1,000 skilled draftsmen and engineers in industry and Government to create and oversee the design of a new, conventionally powered submarine for the Royal Australian Navy. Although a workforce of this size and capabilities does not exist in Australia today, under the right circumstances one could be cultivated over the next 15 to 20 years. However, the Commonwealth could shorten the duration and lessen the costs of designing a new submarine if it were to collaborate with foreign design partners rather than rely exclusively on a domestic workforce to design the vessel.

So concludes our evaluation of Australia's capabilities and capacities to design conventionally powered submarines. In November 2009, the AUS DoD engaged RAND to independently evaluate and quantify issues connected with designing a new class of submarines that will replace Australia's six *Collins*-class submarines. The *Collins*-class vessels will begin to reach the end of their nominal 30-year service lives in the mid-2020s. At 3,000 tonnes, they are amongst the largest conventionally powered submarines in the world and have played a critical role for the RAN ever since the first vessel in the class, the HMAS *Collins*, was commissioned in 1996. As perhaps the most survivable elements of

Australia's military force, these diesel electric attack submarines collect intelligence, maintain an Australian presence in maritime areas, and dissuade adversaries from interfering with Australia's maritime trade or from taking other hostile actions against Australia or its allies.

Australia has committed itself to acquiring 12 new submarines to replace the *Collins* vessels, all of which face retirement by the mid- to late 2030s unless they undergo life extension programs. As detailed by the Australian Government in its *Defence White Paper 2009*,[5] this replacement submarine—known as the Future Submarine—will be designed to travel farther, stay on patrol longer, support more missions, and provide more capabilities than the *Collins* vessels.[6]

Acquiring these new submarines will be the largest and most complex defence procurement in Australia's history, and the Australian Government is considering an option of designing domestically and building in South Australia. However, because Australia has not designed a submarine in the modern era, the AUS DoD sought outside help to assess the domestic engineering and design skills that industry and Government will need to design the vessels, the skills that they currently possess, and ways to fill any gaps between the two. In November 2009, the AUS DoD engaged RAND to conduct such an evaluation of Australia's capabilities and capacities to design conventional submarines.

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5 *Defence White Paper 2009.*

6 At a minimum, the replacement will need to provide a range of warfare capabilities—anti-submarine; anti-surface; strike; intelligence, surveillance, and reconnaissance; electronic warfare; mine warfare—and to support special forces and advanced force operations. See *Defence White Paper 2009*, pp. 70–71, and *Defence Capability Plan*, Department of Defence, 2009, pp. 171–172.

RAND conducted this analysis between November 2009 and February 2010.[7] RAND's goal was to provide an independent, objective, and quantitative analysis that (1) describes the process of designing a modern, conventional powered submarine; (2) describes existing design resources in Australia that could support a future submarine design programme; (3) identifies and analyses gaps between design resources that Australia currently possesses and those that would be required by a new submarine design programme; and (4) identifies and evaluates options whereby Australian industry could achieve the desired submarine design capabilities.[8]

Overall Findings

Australia will need roughly 1,000 skilled draftsmen and engineers in industry and Government to create and oversee the design of a new, conventionally powered submarine for the RAN.

We found that Australian industry and Government possess a seedbed of personnel, software tools, and facilities that can grow to support the design of a new submarine. In Australian industry, numerous technical draftsmen and engineers exist who could contribute to

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7 In performing this study, RAND worked closely with Australian and U.S. consultants, including a former CEO of the Australian Defence Science and Technology Organisation, a former director of the U.S. Navy Nuclear Propulsion Program's Resource Management division, a former director of the U.S. Naval Sea Systems Command's Submarine/Submersible Design and System Engineering unit, a former technical director of the U.S. Navy's *Virginia*-class acquisition programme, a former director of naval architecture at Electric Boat Corporation, and a former commanding officer of a RAN submarine.

8 It should be noted that the design process we refer to here does not include the design of the combat system or of the propulsion system. At the direction of the Future Submarine Program Office, we did not address the designs of those systems in this research, since both are expected to be provided by vendors other than the submarine designer.

a new submarine design. Few of them have experience in submarine design, however, and their availability may be limited due to demands on their time from other commercial and naval programmes. This finding has three broad policy implications: First using this inexperienced domestic workforce instead of a fully experienced one to design the Future Submarine would lengthen the duration of time it would take to complete the design by three to four years and would increase the cost by about 20 percent. Second, adding submarine-experienced personnel from abroad would shorten the schedule and lessen the cost increase. And third, taking 20 years rather than 15 years to design the Future Submarine will reduce the peak demand for designers and draftsmen.

Focus of RAND's Research Effort

One strand of our research examined the processes that organisations use to design submarines. Another strand identified the resources—skilled personnel, software tools, and facilities—required by industry and Government to design a large, conventional submarine with the future capabilities outlined in the *Defence White Paper 2009*. This research strand also examined how different decisions about the conduct and content of the Future Submarine design programme can influence the magnitude and timing of demand for design resources. Based on several assumptions, we provided high and low estimates of personnel skill demand or requirements, plus a description of the facilities and software tools needed for a new submarine design.

Key Demand Caveat: Programme Decisions Have Yet to Be Made

Because the Future Submarine programme is in its infancy, nearly all key design decisions have yet to be made. Amongst the decisions facing

Australian defence decision-makers that will impact the design workload for both industry and Government are the following:

- setting the roles and responsibilities of industry and Government, which will impact the distribution of tasks
- setting the technical and operational requirements for the new submarine, which will impact the degree of technology advance needed
- selecting the specific design process (sequential, concurrent, or hybrid) to be employed
- specifying the level of detail in the design drawings that guide the production process, which can change the demand for draftsmen as well as the shape of the demand curve
- choosing to design or to buy major equipment and components[9]
- deciding when the first-of-class submarine will be required.

These uncertainties mean that it is quite challenging at this stage in the programme to make detailed projections of the total level of effort, the duration, or the design pace that the Future Submarine will require.

Demand for Industry Personnel

Our first step involved identifying skills that are required to design a submarine. All ship design programmes require the careful orchestra-

[9] Deciding to design or buy major equipment or components will be driven by other considerations. For example, selecting a foreign-designed combat system will limit the amount of other foreign participation in the programme. Intellectual property rights are another consideration. If Australia wants control over intellectual property, it will have to limit foreign involvement, which will affect the design effort. Decisions on either combat systems or intellectual property will drive how much technical transfer and assistance from abroad can be employed.

tion of a mix of skills and experience. The activities of draftsmen and engineers with basic marine engineering skills (such as naval architects, systems engineers, and marine engineers) and those skilled in specific systems (such as electrical and mechanical, or combat systems), as well as people experienced in project management, acquisition, contracting, and testing and commissioning—all must be choreographed.

Using a construct developed by the U.S. submarine designer General Dynamics Electric Boat Corporation,[10] we identified two broad skill competencies—draftsmen and engineers—made up of 17 discrete skill sets.

These skill sets became the foundation for how we estimated demand for industry design personnel brought about by the Future Submarine programme. To estimate the magnitude and timing of the demand for each skill, we employed a three-pronged analytical approach that entailed

- gathering and analysing historical design workload data on two conventional submarine programmes, the United Kingdom's (UK's) *Upholder* programme, which began in the 1960s and is now operated by Canada, and the *Collins* programme, which began in the 1980s and continues to the present[11]

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[10] Two shipyards build U.S. nuclear submarines—General Dynamics Electric Boat in Groton, Connecticut, and Northrop Grumman Shipbuilding in Newport News, Virginia. Since January 2008, Northrop Grumman Shipbuilding has been the name of the submarine shipbuilding facility at Newport News, Virginia. It was known as Northrop Grumman Newport News from 2001 until 2008, as Newport News Shipbuilding from 1996 until 2001, and as Newport News and Dry Dock Company before then. For simplicity's sake, throughout this document we refer to the General Dynamics facility as Electric Boat (or EB) and to the Virginia shipbuilding facility as Newport News.

[11] The historical data on the *Collins* and the *Upholder* submarine design programmes were instructive. However, both programmes involved circumstances that are unlikely to be repeated in the Future Submarine effort (e.g., with the *Collins*, where the Commonwealth

- drawing on experienced submarine designers and programme managers to generate point estimates of workload levels and skill mixes that they expected would be required to design a large, conventional submarine with the future submarine capabilities outlined in the *Defence White Paper 2009*
- generating an independent set of estimates of the workload that will be required to design the Future Submarine, drawing from the RAND team's experience analysing submarine, maritime, and industrial design matters over many decades. We did so by constructing workload profiles for each skill that we had identified as being necessary for designing a submarine and summing those profiles over the roughly 15-year duration of the design effort.

This approach produced a range estimate of demand: The total workload to design a conventional submarine will require 8 to 12 million man-hours (MMH) of fully proficient, experienced industry design personnel.[12] This prediction is based on the Future Submarine's having

assumed that the original Kockums 471 design would be more useful than it actually turned out to be). Moreover, our reconstruction of the data from those programmes might not have identified all of the man-hours required to design the respective vessels. Because the Future Submarine is likely to be larger, more technically complex, and have more stringent safety requirements, we took these data into consideration as only one element in the mix of data and expert opinions that we ultimately used.

12 Decisions that could drive the total workload to the lower end of 8 million man-hours include less-challenging operational performance and capabilities and less-detailed drawings and other documents produced for construction. On the other hand, more-challenging operational performance and capabilities and more detail in the construction drawings could result in a total workload approaching the upper bound of 12 million man-hours. Different views exist as to whether concurrent design requires fewer design hours than the traditional design process during the design phase. However, most agree that savings will be captured during the production phase because fewer problems will be encountered during production. The man-hours shown here assume that major systems and components—power/energy, combat, etc.—will be bought and the only cost will be their integration into the submarine.

a design duration of 15 years and a design workload distribution that follows historical patterns. The peak demand at the total workload level would occur around year 7 of the design. At its peak, the workforce would number between 600 and 900 submarine-proficient technical personnel, comprising 300–450 draftsmen and 300–500 engineers.

Demand for Government Personnel

To oversee the submarine process, the Government is responsible for developing requirements and ensuring that the design efficiently meets those requirements. It does this by exercising technical authority, establishing safety criteria (supported by a thorough safety testing programme), engaging in programme management and oversight, and maintaining capabilities not supported by industry (such as specialised component design or research and development [R&D] programmes).

We also estimated the total number of engineering and project management personnel that the Government would need to oversee a submarine design effort. Based on historical U.S., *Upholder*, and *Collins* submarine design experience data, we estimated that the Government would require a workforce on the order of 15–20 percent of the total industry level of effort, a proportion depending largely on the level of involvement the Government chooses to have in the design. This translated into a dedicated Government effort of 80–175 personnel.

Demand for Facilities and Software Tools

The engineering facilities and software tools required for a submarine design depend on a variety of factors. These factors include the complexity of the submarine, the amount of design reuse from the previous generation of submarines, and the Government's acceptance of

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If major systems or components need to be designed and tested, those costs are in addition to those estimated here.

risk—both technical and operational. These choices, as yet unmade in the case of the Future Submarine, affect which facilities and tools are required.

Three categories of sophisticated modern design tools emerged in our analysis:

- Category 1: Tools that must be developed domestically and that, if absent, carry substantial risk to the design
- Category 2: Tools that need not be developed and that, if absent, carry moderate risk to the design
- Category 3: Tools that can be substituted with little or no attendant risk.

In all, we identified 20 distinct design areas that require facilities and software tools. And, although no one area is overly demanding, combining those 20 interrelated areas to design a vessel with a restricted internal volume that operates in a hostile operating environment is particularly difficult.

The engineering facilities required to support a submarine design can be grouped into three broad areas: combat systems; hull form design; and hull, mechanical, and electrical (HM&E) systems. For example, hull form design would require tow tanks, cavitation chambers, and acoustic measurement facilities. Facilities required to support submarine design can be located with industry, government, or academia. However, designers and engineers must have the level of access to the facilities required to support a submarine design.

Existing Design Resources in Australia That Could Support a Future Submarine Design Programme

To evaluate the current level of submarine-design resources in Australia, we sent detailed surveys to 46 industry firms, seven Government organisations, and three academic institutions. The survey posed various questions about the number and experience levels of skilled draftsmen and engineers, the ability to expand the workforce, and estimates of the future demand for the organisations' draftsmen and engineers. The survey also asked about facilities and software tools. We received responses from 28 industry firms, four Government organisations, and two academic institutions.[13] All the primary companies and organisations with submarine experience responded.

In many cases, companies did not, or could not, respond to all the survey questions. Follow-up interviews helped fill in our understanding of the data provided and some of the gaps, but we were forced to estimate some survey responses. This was a particular problem in the case of estimating future demand for personnel, both for personnel in general and for those with submarine-specific skills.

Our Estimate of Current Levels of Industry Personnel

Although thousands of draftsmen and engineers are employed in Australia, many work outside the defence sector, and few have relevant submarine-design experience. Table S.1 shows our estimate[14] of the

[13] Follow-up interviews were conducted with many of the organisations that responded to the survey and with others that had not yet responded. We conducted interviews with additional Government organisations and with nine universities.

[14] To make the estimate, we assumed that an existing combat system or a modification of an existing system would be used in the new submarine and that the majority of the combat-system design work would be accomplished by firms similar to those in our combat-systems group. Those firms have significant submarine experience and are typically offices of major

Table S.1
Summary Level Draftsmen and Engineers from Survey

	Total Number		Number with Submarine Experience	
Group	Draftsmen	Engineers	Draftsmen	Engineers
Platform design	374	1,215	196	262
Technical expertise	66	260		
Total[a]	462	1,548	206	275

[a] Includes a 5-percent factor for submarine-experienced personnel from the companies that did not respond to the survey

total number of draftsmen and engineers in the platform and technical groups that have submarine experience.[15]

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international corporations that could provide resources for combat-system design. The main firm that designs the *Collins* class successor will require draftsmen and engineers who are experienced in integrating the combat systems with HM&E. We made a similar assumption for other major components of the new submarine. These components could be developed by the firms in our component group or procured from an international company. The design effort associated with these major components is not included in our demand estimates. However, we did include demands for the integration of these components into the HM&E of the new submarine.

15 These draftsmen and engineers currently support other projects, and the precise future demand for the existing personnel is not clear from the survey responses. However, companies that employ submarine-experienced draftsmen and engineers stated in our follow-up interviews that their submarine workforces are engaged in through-life-support activities for the *Collins* class or are supporting the Air Warfare Destroyer programme. These companies' expectations of future revenue indicated that the future demand for these personnel is expected to stay steady or increase. There may be no idle submarine-experienced personnel to apply to a new submarine-design programme. As a result, submarine-experienced support personnel will need to be drawn from existing programmes to support the new submarine-design effort.

We estimated that 20–40 percent of the approximately 480 submarine-experienced draftsmen and engineers could be transferred from their existing programmes to help form the new design team. This would result in approximately 100–200 personnel who could serve as the base of the new submarine design team. Note that these people would be drawn from existing programmes and that they would therefore need to be replaced by new hires. Note also that some skills may be more difficult to build because there are so few personnel currently available to mentor new recruits. For example, there are minimal numbers of draftsmen with submarine heating, ventilation, and air conditioning system (HVAC) or piping skills and of engineers with communications, fluids, HVAC, propulsion, or testing skills.

Current Levels of Government Personnel: Our Survey and Estimate

We assessed the available Government submarine-design resources by surveying and/or interviewing a range of organisations involved in submarine design and sustainment and in other non-submarine maritime programmes.[16]

Table S.2 shows the number of Government engineers, scientists, and technical personnel that are presently dedicated to design or

[16] The submarine organisations included the Defence Materiel Organisation (DMO) Directorate of Submarine Engineering (DSME), the Defence Science and Technology Organisation (DSTO) Marine Platforms Division (MPD), the Maritime Operations Division (MOD), and the Submarine Combat System Program Office (SMCSPO). We sent a survey to but did not receive a response from the Collins Program Office (COLSPO), the Office of Director General Submarines, the DMO Maritime Systems Division (MSD), and the RAN Commander of Submarine Force. However, we subsequently learned that the COLSPO has been reorganized and now has three submarine-experienced personnel. This reorganisation is not reflected in Table S.2. With respect to non-submarine maritime programmes, we interviewed government representatives from the Air Warfare Destroyer (AWD) Alliance and gathered data about non-submarine maritime-engineering personnel within DMO and the Office of the Chief Naval Engineer (CNE).

Table S.2
Number of Government Engineers, Scientists, and Technical Personnel Presently Dedicated to Submarine or Other Maritime Design or Sustainment Activities

Organisation	Submarine Personnel	Other Maritime Personnel
DMO	87	391
DSTO	86	0
Navy	0	63
Total	173	454

sustainment or to other maritime programmes.[17] There are 173 full-time equivalent engineers, scientists, and technical staff members who are dedicated specifically to submarine design or sustainment in the organisations that responded to our survey. Another 454 engineers assigned to the DMO or the CNE on non-submarine maritime programmes may have expertise that is generally if not specifically relevant to submarine design work.

Broadly speaking, our surveys and interviews suggested that experienced submarine-design personnel are available. Across skill categories relevant to submarine design, the most significant capability resides in installation and testing of combat systems rather than in design, no doubt reflecting the ongoing Collins-class combat-system programme. In contrast, in the area of HM&E, the Government appears to have significant breadth but less depth.[18]

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17 Table S.2 does not reflect DSTO personnel who are dedicated to non-submarine maritime science or technology; this information was not available at the time of writing.

18 For example, there are few (if any) Government personnel specializing in propulsion, fluids, electrical systems, cost estimation, testing, and planning and production.

As described in the *Defence White Paper 2009*, several modernisation programmes compete for personnel required by the Future Submarine programme. On the one hand, these programmes may provide points of leverage to the extent that certain naval-engineering skills are transferrable between surface-ship and submarine programmes. On the other hand, these programmes may compete for the most-experienced technical personnel supporting Government work. In all cases, any assessment of capability gaps must account for these competing demands and reflect the fact that existing personnel are fully employed.

Our Estimate of Current Academic Capabilities

For reasons of scope, this study did not assess the capability or the capacity of the Australian educational system, broadly conceived. Rather, we focused more narrowly on a subset of universities and colleges that have programmes or departments in maritime- or defence-related science and engineering. In this regard, the Australian Maritime College (AMC) appears unique, offering both undergraduate and graduate-level courses in naval architecture, marine and offshore systems, and ocean engineering. AMC offers significant expertise and facilities that both industry and the Government could leverage in designing a future submarine.

Other generally relevant expertise may be more dispersed across universities and academic departments. The Future Submarine may be able to leverage these centres of expertise, but the challenge may lie in engaging and managing the distributed resources. The emerging Defence Systems Innovation Centre venture between the University of

Adelaide and the University of South Australia provides another model for such interaction between Government and academia.[19]

Our Survey of Existing Industry and Government Software Tools

Our surveys of, and interviews with, industry and Government organisations suggested that numerous software tools are utilised within the submarine and maritime communities today.[20] These tools range from computational programs for such areas as acoustics, structures, and hydrodynamics to complex, three-dimensional modelling software, many of which are available within Australian industry or in the United States.[21]

Our Survey and Estimates of Existing Design and Test Facilities in Industry, Government, and Academia

Industry, Government, and academia reported that they can access significant facilities either on-site or off-site. The Government facilities—located at DSTO, SMCSPO, and the Maritime Ranges System Program Office (MRSPO)—are heavily weighted towards combat systems and shock or acoustic testing. The majority of naval architecture facili-

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[19] Discussions with AMC, the University of Adelaide, the University of Melbourne, the University of South Australia, Flinders University, Monash University, Deakin University, the Royal Melbourne Institute of Technology, Swinburne University, and the University of Melbourne suggest that Australia has strong educational institutions. AMC once again appears to be unique.

[20] Access to certain tools may be restricted if foreign design partners are involved in the programme.

[21] In general, Government organisations involved in *Collins*-class in-service support report using similar software tools in an effort to maximize efficiency. The DSTO and AMC report co-development of software tools used in complex hydrodynamic and naval-architecture research.

ties, including tow tanks and cavitation channels, are located at AMC but are primarily funded by DSTO.

It is important to point out that many of the facilities identified as available to industry are located at DSTO and AMC. When viewed as a pooled resource, Government and academia provide facilities for hull form development, hull form design, and combat system development and testing. Facilities located in industry tend to support the development of the hull, mechanical, and electrical design of the submarine.

Gaps Between Design Resources That Australia Currently Possesses and Design Resources That Would Be Required by a New Submarine Programme

Gaps exist in both industry and Government between the number of experienced design personnel who are available to work on a new submarine programme today and the number that a new submarine design programme would require. Fewer gaps exist with respect to the software tools and design/testing facilities that a new submarine will require.

Industry Personnel Gap

The number of experienced submarine design personnel employed by Australian industry today falls below the number that would be required to meet peak demands to design a new submarine. This shortfall is displayed in Table S.3, which shows the total number of skilled draftsmen and engineers available in Australia with submarine experi-

Table S.3
Submarine-Experienced Draftsmen and Engineers Available in Australia and Peak Demands, by Skill Category

	Skill Category	Number Available	Maximum Demand	
			8 MMH	12 MMH
Draftsmen	Electrical	12	64	96
	Mechanical	45	39	58
	Piping/HVAC	5	58	86
	Structural/arrangements	47	89	134
	Other	96	39	58
Engineers	Signature analysis	4	20	29
	Combat systems and ship control	7	51	77
	Electrical	16	39	58
	Fluids	1	26	39
	Mechanical	37	26	39
	Naval architecture	19	64	96
	Planning and production	2	13	20
	Structural/arrangements[a]	—	—	—
	Testing	1	7	10
	Management	1	13	20
	Engineering support	160	26	39
	Other engineering	22	39	58
Total		475[b]	613	917

[a]Grouped with naval architecture.
[b]Demands from other programmes may result in few (if any) personnel being available to support a new submarine design.

ence and the peak demand estimated for those skills at the 8 MMH and 12 MMH demand levels.[22]

Government Personnel Gap

At first glance, our analysis of the supply of Government personnel resources suggests that the total number of personnel is sufficient to meet the estimated demand of 85 to 175 personnel. Across DMO and DSTO, our surveys indicated that there are more than 173 engineers currently associated with submarine design. The Government's existing submarine design workforce has a significant amount of experience from the *Collins*-class programme and has special capability in combat systems due to the design responsibilities assumed by SMCSPO. Moreover, there are about 450 engineers working within DMO and the CNE on non-submarine maritime programmes who may have expertise that is generally, if not specifically, relevant to submarine design.

However, this broad look ignores two important gaps. First, existing personnel are fully employed supporting the *Collins*-class or other RAN programmes and cannot contribute to a new submarine design without risk to ongoing RAN programmes. Second, our surveys indicated that there are too few personnel with skills anticipated to be important in the design of a future submarine. In particular, there are few if any resources in the discipline of large complex programme

[22] As noted above, the number of people with submarine experience in Australia does not imply these personnel are available to support the new submarine programme. Demands of other programmes will require the services of most, if not all, of these personnel. In all but the Other Engineering and Professional Support skill categories the number of individuals who are currently available is below the peak demand level. The Electrical and Piping drafting trades have less than one-third of the peak design requirement. Less than one-third of the peak design requirement is available in the Fluid Engineers, Naval Architects, Planning and Production, and Signature Engineers skill categories.

management and in specific areas related to propulsion, fluids, electrical systems, cost estimation, testing, and planning and production.

Tools and Facilities Gap

We found that Australian industry currently supports many software tools that would be required for a new submarine design programme and that the majority of the required facilities are available between Government, industry, and academia. The one critical gap that Australia will need to address entails a facility to test integrated propulsion and energy alternatives. While other facilities that do not currently exist in Australia can be "borrowed" from the United States or United Kingdom, we concluded that a new integrated propulsion/energy test facility should be built in Australia.

Options Whereby Australian Industry and Government Could Achieve the Desired Submarine Design Capabilities

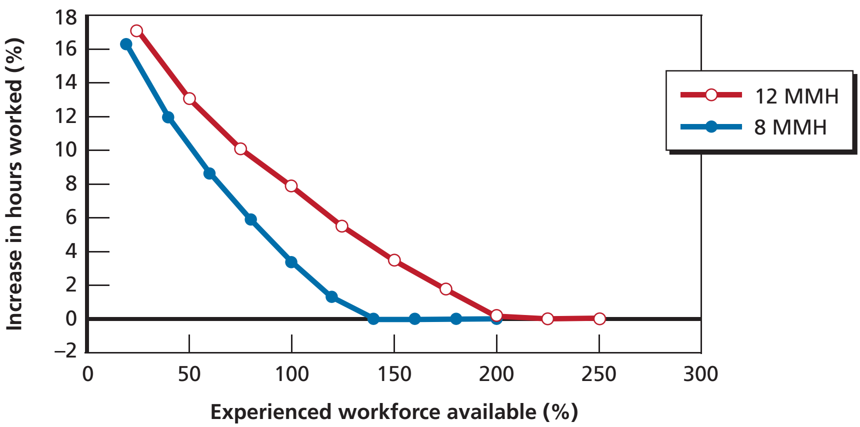
We evaluated two options that industry could pursue to cultivate submarine design expertise: (1) recruit new personnel solely from within Australia, and (2) infuse submarine-experienced personnel from other countries.

To evaluate these options, we constructed a simulation model to test how changes to the size and proficiency levels of the available design workforce would affect the man-hours and schedule required to design a new submarine.[23]

[23] The model starts with the annual demand for skilled personnel over the course of the design programme and a pool of submarine-experienced personnel to meet that demand. When the pool of experienced people is exhausted, a second pool of people with some distribution of general proficiency (but not submarine proficiency) is used to meet demand. These less-experienced personnel require training and mentoring, which result in less work

Sample outputs of the model are shown in Figures S.1 and S.2. Figure S.1 shows the relationship between total engineering man-hours and the percentage of Australia's current workforce submarine-experienced engineers who would be available to support the Future Submarine design programme.[24] Separate lines show the 8 MMH and 12 MMH design estimates. The figure shows that if 20 percent of today's 275-engineer workforce were available, total man-hours would increase by approximately 17 percent. If 150 percent of today's workforce were available (equal to some 400 engineers with submarine experience),

Figure S.1
Increased Engineering Hours Versus Skilled Workforce Available, 15-Year Design Profile



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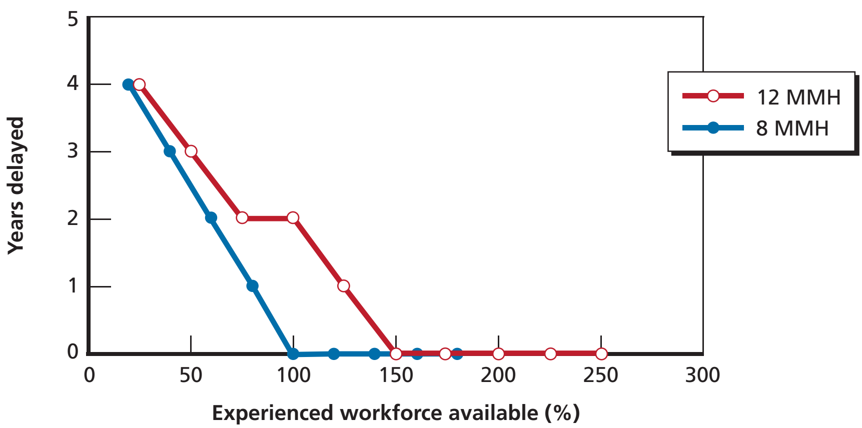
being performed than fully proficient workers can accomplish. Unaccomplished work in one period is pushed to the next time period.

[24] Separate analyses for draftsmen and total technical resources showed similar results.

total man-hours would not rise at the 8 MMH demand level. But to have the same effect at the 12 MMH demand level, approximately 550 submarine-experienced engineers would be necessary (or about twice as many as currently exist in Australia).

Figure S.2 shows the schedule impact as a function of the number of submarine-experienced engineers available to support the new submarine design programme. If 20 percent of the submarine-experienced engineers in Australia were available, the schedule would increase by approximately four years. That increase drops to three years if 40 percent of the skilled workforce were available. If all 275 submarine-experienced engineers were available, there would be no schedule delay for the 8 MMH demand; an additional 135 submarine-experienced engineers would be needed if the total demand is 12 MMHs.

Figure S.2
Schedule Delay Versus Skilled Engineering Workforce Available, 15-Year Design Profile



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The figures suggest two potential implications for recruiting:

- Building the design workforce solely with Australian resources could increase the total man-hours to accomplish the design by as much as 20 percent and delay its completion by three or four years. However, Australia would end up with a fully capable submarine design workforce that could work on both future submarine efforts and other naval programmes.
- Adding experienced submarine personnel from other countries could reduce or eliminate the additional man-hours and schedule delays. In addition, such a move would reduce the burden associated with drawing down the design team as the programme nears completion, because international workers could return to their home countries. However, collaboration may result in specialised skills or capabilities missing from the Australian workforce.

Evaluating Options for Closing the Gap in Government

At first glance, our analysis of the supply of Government personnel resources suggests that the total number of personnel is sufficient to meet the estimated demand of 85 to 175 personnel. However, this broad conclusion ignores the two important gaps in existing resources mentioned previously: (1) Existing personnel are fully employed on other RAN projects and (2) surveys indicate that there are too few personnel with experience in important skill categories. Although the Government appears to have ample expertise in areas related to combat systems, less experience in areas related to hull form and HM&E design may introduce risks to the Future Submarine programme.

To close the Government personnel gap, we recommend drawing a core of technical personnel from the support of the *Collins* class and other maritime programmes and hiring additional personnel both as replacements for core personnel and to fill out the Future Submarine programme. This would leverage the *Collins*-class experience, reduce the risk of under-resourcing the support to the *Collins* class and other programmes, and keep training costs reasonable.

Evaluating Options for Closing Tools and Facilities Gap

To close the skill and technology gap, we recommend leveraging existing relationships with allied nations to "reach back" for capability in the areas of combat systems and hull form design. Access to propulsion and energy system technology from allied partners may be limited. Therefore, long-term investments in land-based test facilities and expertise will be required to close the HM&E gap.

Policy Considerations

We found that a core of technical resources, including personnel, software tools, and facilities, exists in Australian industry and Government that can evolve to support the design of a new submarine. There are numerous technical draftsmen and engineers in Australian industry who could contribute to a new submarine design. However, few of those technical personnel have experience in submarine design. Furthermore, the demands of other commercial and naval programmes, including the support for the *Collins* class, may limit the availability of the technical workforce, especially people skilled in submarine or naval systems.

These findings lead to several policy considerations:

- Forming the design team for the new submarine from in-country resources could increase the total man-hours to accomplish the design by approximately 20 percent and cause the schedule to lengthen by three to four years. Nevertheless, this is an investment in developing technical and managerial expertise that the Commonwealth's senior leaders may choose to make.

- Adding submarine-experienced personnel from other countries could result in a smaller increase in man-hours and a shorter schedule. These personnel could be recruited by the platform design firm, come from international offices of Australian companies, or result from collaboration with an international submarine design and construction company.
- Lengthening the time to design the Future Submarine from 15 to 20 years while not changing the required fully proficient man-hours could reduce the peak requirements for skilled personnel and, as a result, could reduce the total man-hours needed to accomplish the design and could allow needed technologies to mature.
- Although extending the design period could reduce the increase in man-hours from an inexperienced workforce, designing the Future Submarine in flights would not necessarily have the same impact.[25] The design of the first flight would be basically a "new" submarine; subsequent flights would have smaller peak demands and could help in sustaining future submarine design capability.
- Programme management skills are important in both industry and Government. Those possessing such skills are the leaders who must guide the Future Submarine programme to a successful conclusion.
- Building up an in-country design capability and then letting that capability wane after the completion of the design effort might be counter-productive. Technology advances by regional countries or

[25] The concept of flights applies to subsequent submarines of a class and has *no* effect on the numbers of people required to design the first of the class or the duration of the design.

a change in mission priorities will require the Australian defence forces to sustain a capability advantage in the region. This capability edge requires a sustained submarine technical capability. Continued employment of the first-of-class design workforce to build updated models or flights of the initial submarine would help maintain the design workforce over a longer period of time. Also, technical personnel in both industry and Government are needed to conduct and oversee the initial production programme and could also provide in-service support to the new submarine.