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No Submarine Competition Winner:

Only a Preferred Contender who does Preview Test and Evaluation

Keith F. Joiner

18 April 2016

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Discussion Paper Series

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ABSTRACT

According to several Australian Government releases since December, three contenders are under detailed evaluation to design and build Australia's future submarine. Starting sometime this year this will be the major developmental Defence project for Australia over the next ten years. This paper reviews the possible developmental approach options that come next for Australia's future submarine using the U.S. Defense acquisition life cycles, and finds the best approach to be the U.S. acquisition model of Engineering Manufacture Development (EMD) before any production contract. Furthermore, the paper also reviews a major lesson learned in Australian acquisition regarding early preview test and evaluation (T&E), which has been the focus of serious reviews by the Senate, Australian National Audit Office (ANAO) and Defence since 2012. Such review includes public testimony by Defence only last month to the Joint Parliamentary Committee on Public Accounts and Audit, once again, regarding the absolute limits of paper-based down-selection from contender submissions even when the acquisitions are allegedly mature off-the-shelf acquisitions. As such, the paper recommends the preferred contender be put through a detailed series of preview evaluations even before an EMD contract is signed. Lessons learned from the Collins Class Submarine and example preview T&E activities are provided to help justify this caution for Australian Defence. Such preview T&E would practically and independently confirm for both the elated lead contender and Defence's hard-working project exactly what are the major technical and operational risks driving modification of Australia's submarine from its baseline German, French or Japanese design – and do so for the benefit of both the lead contender and Defence before they get locked into contract!

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Background

The SEA 1000 Project was established to develop Australia's future submarine and replace the current Collins Class Submarine. The project began in earnest with Australia's Defence Whitepaper in 2009 and was recently reiterated in Australia's 2016 Defence Whitepaper as being for 12 new submarines (p. 115). The project is approaching a significant milestone where the Government has committed to a decision in 2016 on the competitive evaluation process for the preferred partner to design and build this submarine.[1] One of the best overviews of this competitive evaluation process was an Engineers Australia magazine article in May 2015, because it covered the uniqueness of Australia's submarine requirement and the three reference designs being used by the two invited companies and one invited foreign government.[2] The unique challenge of Australia's operational requirement was illustrated with a tennis-racquet shape map, showing an outward transit from Australia of some 3500 nm, a loiter around the key maritime trade choke points of South-East Asia of some 35 days, followed by a return journey to Australia again of 3500 nm. The reference designs being used vary in size from displacements of 2950 tonnes up to 4700 tonnes, lengths of 84m to 99m, and ranges from 6100 nm to 18,000 nm. Each of the reference designs require some re-design to meet the Australian requirement; for example:

- the Japanese Soryu Class requires additional range and usable volume;
- the French Barracuda Class requires a diesel-electric propulsion to replace the current nuclear propulsion;
- the German Type 216 and the others all need to accommodate the U.S. AN/BYG-1 Combat System and MK 48 CBASS torpedo required by Australia;[3]
- likely remodeling of all interiors to accommodate Australia's unique anthropometrics and in some instances gender differences; [4,5]
- establishing within all re-designs adequate growth margins and modularity to enable spiral development and sustainment options as part of both continuous building and through-life docking;
- possibly establishing within all re-designs more robust developmental paths to:[6]
    - continue to reduce surface and sub-surface signatures,
    - enable torpedo counter-measures,
    - exploit electronic support measures,
    - improve the stealth, range and autonomy of deployment systems;
    - improve the stealth, security, frequency and bandwidth of all communications to and from the submarine; and
    - improve the safety and autonomy of the submarine platform management.

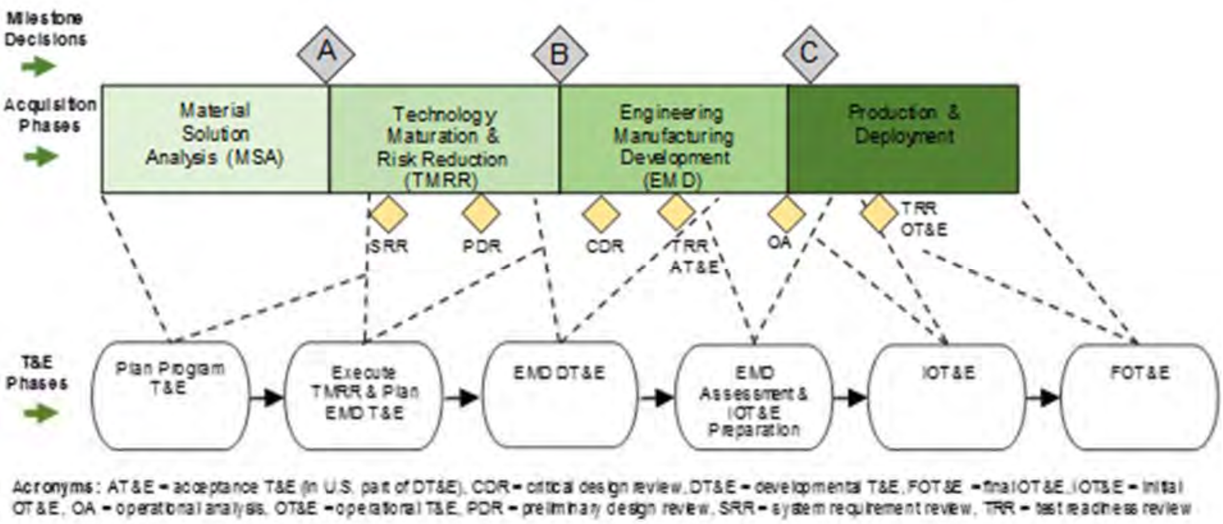
Clearly the design strategy of SEA 1000 is to leverage mature international submarine, combat system and torpedo designs within the context of a redesign set around an overall unique set of operational requirements. The greatest technical risks of this strategy are first the integrations of the combat system and weapons and second establishing the multi-dimensional spiral development pathway. The greatest operational risk, at least initially, is that the preferred tenderer and Australia's project staff will not fully appreciate all modifications and design challenges of an Australian crew in the preferred reference design class. Carefully structured and timely preview test and evaluation can certainly target these early technical and operational risks in order to fully inform Australia's next decision on whether to commit to a design development contract.

Where is Australia's Submarine in an Exemplary U.S. Defense Life-Cycle?

Australian Defence has done some large-scale developmental projects, such as the Jindalee Over-The-Horizon Radar Network, the Collins Class Submarine and the Airborne Early Warning and Control aircraft, however, these were all birthed during the Defence single-service acquisition periods prior to an amalgamated material organisation which was formed in 2001. The only large-scale developmental project birthed within Australia since 2001 has been the Air Warfare Destroyer which appears to be successful, pending its current test and evaluation, but with some significant cost and schedule overruns. Australia's frequency of large-scale developmental projects is not only low, but the proportion of developmental projects in Defence, irrespective of size, is in decline. This decline is primarily to avoid technical risk and the flow-on effects in cost overruns and capability delays. For example, analysis across three Major Project Reports to Government has found [7] '*that, generally, MOTS projects are more likely to be delivered on time while AMOTS* [Australianised MOTS] *and Developmental acquisitions are more prone to underestimating technical complexity and systems integration effort.*' The findings and concerns are not unique to Australia, with an Australian Senate report[8] citing similar observations in several U.S. Congressional reports. The infrequency and decline of Australia's developmental projects creates a risk that it may be losing some of its developmental expertise and the supporting policy and practices, especially in system engineering and test and evaluation. As such, developmental projects like SEA 1000 need to be baselined against U.S. Defense policies wherever possible.

The U.S. Defense acquisition lifecycles, milestones and major design reviews are shown in Figure 1 and are particularly useful to envisage where the future submarine project is, and where it should go. Such benchmarking is particularly useful this year in Australia during the uncertainty caused by the implementation of the First Principles Review of Defence, where the Australian Defence acquisition lifecycle is being revised and so too are the Defence governance structures that provide contestability at the project, program and portfolio levels.[9]

FIGURE 1: U.S. DEFENSE ACQUISITION LIFECYCLE WITH T&E PHASES[10]



The U.S. acquisition lifecycle begins with a material solution analysis that then ends with the U.S. '*Milestone A Approval*,' which broadly equates to the Australian project scoping phase that concludes in Australia as Government '*First Pass Approval*'. Both are approvals-to-solicit, but in the U.S. the solicitation cannot yet include production or through-life support. The *Milestone A* or *First Pass* effectively ended for SEA 1000 with Government approval last year to enter into restricted solicitation.

From a systems engineering perspective it means there are top-level requirements and an operational concept, while from a T&E perspective there is a test concept document or early T&E master plan.

What is of most interest to SEA 1000 is the next phase in the U.S. lifecycle known as technology maturation and risk reduction (TMRR), which some would broadly equate to the Australian Defence process from *First to Second Government Pass*, where the activities are mainly sorting through the solicitation proposals and coming to an agreed basis with the preferred contender to contract development and, in some cases, production and support. The U.S. TMRR phase envisages practical activities with the market place, sometimes in Government facilities, that will mature the necessary technology and reduce technical risks before a contract with one or more developers to do the engineering manufacture and development. An example is the U.S. Joint Light Tactical Vehicle project which during the TMRR phase developed several prototypes vehicles and did some limited operational and developmental testing with those vehicles in Australia, mainly to inform the requirements specifications. This project then entered a competitive EMD phase, where three contenders where funded to each produce a final competitive design for an operational analysis.

The Australian solicitation phase has had some success in conducting innovative risk reduction activities as part of the solicitation phase through what is termed in Australia as preview T&E and/or Offer Definition Activities, where these activities help determine the technical and operational risks far better than purely paper-based selections and analyses.[11] In 2012, the Australian Government sought to prescribe greater use of preview T&E[12] and the amendments to Defence policy formally came into effect from 2014[13] and were audited as being successfully implemented in 2015.[14] An example of the use of preview T&E to inform an EMD developmental contract is the testing of a prototype Hawkei light tactical vehicle to confirm it had the maturity and risk profile suitable for a final development phase: more on preview T&E later.

The U.S. EMD phase ends with both design acceptance and an operational analysis by one of the U.S. operational test agencies, all focused on informing *Milestone C* approval for production. U.S. Defense has had a difficult history with large-scale developmental projects and the tendency to go into production too early. The book *Pentagon Wars* by Colonel Burton, and the movie that followed,[15] are an illustration as to why *Milestone C* is under-pinned by Congressional Law, Title 10.[16] These laws dictate who can test and when before any production may commence. Contractors are inherently motivated by jobs and profit to get to production and the project offices are equally motivated to complete the expensive and time-consuming development phase as early as possible. In the U.S. the T&E organisations are a fundamental check, by law, on progressing beyond *Milestone C*. By comparison, the Australian *Second Pass* approval is usually for both development and production in one approval; in essence, both a *Milestone B* and *C* and the T&E organisations (without preview T&E) are often not involved until operational T&E, which is usually too late to inform design or acquisition. Independent elements of the U.S. central test and evaluation model have been recommended to Australian Defence by the Australian National Audit Office as early as 2001 but rejected by Defence at the time.[17] More recently there has again been cogent arguments for the current first principles reform of Defence to create a stronger independent central test and evaluation office.[14,18]

In the case of complex systems and platforms, the Australian system is also known to seek long periods of contracted support and do so again in the same *Second Pass* Government approval. Within such a context in Australia, it is not surprising then that a number of leaders and experts in Australia are expressing concern about the acquisition process being used initially for the future submarine, lest it be a precipitous and long one-way journey. For example the Opposition Defence spokesman has stated:[19]

> '*The CEP is really about choosing our submarine marriage partner for the next half century (some would argue that we did that when we chose Sweden and the Collins-class last century). If we down select to one partner nation at the end of what's a very short competitive evaluation process, a process that won't deliver all that much in the way of verifiable performance, then competitive tension thereafter won't be possible.*'

An academic assessment goes into greater detail about the likely contractual risks:[20]

> *'Australia's hairy chested handling of the CEP to date stands to compromise its ability to make an informed selection of an international partner for our future submarines. That's partly due to asymmetries in the information available to, on one hand, the Australian defence customer and to, on the other, those candidate suppliers the customer has invited to participate in the CEP. Looking further downstream, those information asymmetries are exacerbated by the developmental nature of our future submarines. Neither defence customer nor selected supplier can anticipate every development in the future submarine project and negotiate, ex ante, contingent provisions in the contracts that will satisfactorily cover unexpected design and production challenges that occur ex post.'*

I think much of the caution in such commentary comes from a lack of detail about what comes next in the acquisition process, caused by the myriad of factors outlined earlier, such as: the track record of Australian Defence, the somewhat one-stop approval of Australian *Second Passes*, the infrequency of large-scale developmental projects, and the current changing of the Australian Defence lifecycles. In particular, there is a lack of detail about the risk-reduction activities that will inform that next decision to contract the EMD. I think leaders and commentators would be more comfortable if Australia were operating in the U.S. lifecycle of TMRR, with the oversight of their rigorous T&E laws and personnel, since there are significant checks and balances. The Australian Defence Minister sought to reassure the public and gave something of insight into a cautious '*TMRR-like*' approach when she stated:[21]

> '*For a program of this nature, we need to work closely with the selected international partner to fully develop the Future Submarine. This is going to be very resource-intensive for both Defence and the selected international partner. Once the partner is selected, there will be about three years of further development work before we finalise the Future Submarine's capability and cost. Indeed, lessons from the Collins Class submarine program and other international submarine acquisition programs clearly indicate the need for such collaboration to arrive at the best understanding of capability, cost and schedule.*'

I interpret the Minister's comments as a three-year period of EMD design and land-based systems prototyping before beginning a first-of-class submarine. By the nature of first-of-class submarines, that submarine will still be prototype and its building and testing will effectively be a second EMD phase. True production of a block of submarines, should only commence once the first-of-class is in initial operational T&E. Development of large complex platforms like the F35 aircraft and Australia's future submarine inevitably challenge any country's capability to maintain competitive tension, especially if you have only a small number of platforms to buy. This competitive concern was expressed by Bergmann (2015) as follows:[22]

> *'If Defence plans to sign a production contract three years after selecting a preferred designer, they leave themselves open to enormous risks. Put simply, without commercial leverage the Commonwealth will either have to pay whatever the designer wants—or start the entire process again. …The only way to protect against those sorts of possibilities is to have at least two bidders to choose from and maintain competitive pressure for as long as possible.'*

Eventually, like the countries where the submarine developers come from, Australia must choose and thereafter the commercial pressure has to come from the evolution of the submarine through continuous spiral development by both the parent country and Australia, hopefully operating in unison. Such industry partnering is a hallmark of the major Defence powers and Australia will only grow such Defence capacity in line with its economy, if it masters such complexity in its contracting – a point alluded to by the Minister in the full transcript of the earlier cited argument. Australia need not run that competition overly long if the parent countries are open and honest, although there are some major Australian acquisitions where the opportunity to do so was not properly exploited.

In summary, the U.S. Defense acquisition lifecycle is similar to Australia's until the point of approval-to-solicit (*Milestone A, First Pass*), but the next two phases in the U.S. are far more deliberate in their risk-reduction than Australia has hitherto applied in the solicitation phase (*Second Pass, Milestone B*) and the final decision for production (*Milestone C*). Australia's future submarine appears to now be following a more U.S. acquisition approach, which is apropos for its developmental nature and should, so long as the Government does not depart from the associated checks and balances, lead to better project management. It would help all concerned though, if the new Australian Defence lifecycle and governance structures (contestability & T&E) were published, especially if it has a tailored version for major developmental projects like SEA 1000.

Australian Lessons on Preview Test and Evaluation before Contract

Early preview test and evaluation of capabilities before an acquisition contract has been best-practice for many years, centered around the common-sense appreciation by project managers and system engineers on setting up such contracts for success through the earliest possible appreciation of technical risks. The very structure of the U.S. acquisition life-cycle covered earlier, shows this general appreciation. So it was a surprise to some acquisition managers when the Australian Senate found in 2012, that for at least a decade prior to that, there had been insufficient use of preview T&E on many major acquisitions, mainly under the often false premise of acquisitions being off-the-shelf.[12] The Senate sought, and Government agreed, that Defence prescribe a policy of offering preview T&E on all Government acquisition approvals. The resulting Defence planning process began use in 2013[11] and was formally released in 2015.[13] The process is based on developing the earliest possible test and evaluation prior to contract and preferably as part of solicitation, using systematic evaluation of the technical and operational risks likely on a proposed acquisition.[11,13] The process was recently endorsed by the Australian National Audit Office (ANAO) as having been successfully implemented by Defence: a final check rarely achieved in most Defence reform areas.[14] That audit was reviewed publically by the Joint Committee for Parliamentary Accounts and Audit (JCPAA) earlier this year, principally because of yet another ANAO report that was released last year and which came from this decade-long period in Australian Defence acquisition.[23] The latest ANAO example is yet another multi-billion dollar Defence project that had been delayed by 3-4 years when paper-based down-selection of an allegedly off-the-shelf acquisition proved inadequate and preview testing had to be arranged at short-notice so the tendering and selection could be recalibrated.[24] Defence officials at the JCPAA hearing testified that the lesson on preview T&E had been learnt, that the new policy would ensure a repeat was unlikely, and that the current restructure of Defence (First Principles Review Implementation) would only strengthen use of this preview policy.[23] The two large projects currently undergoing serious down-selection for the future submarine and light-armoured vehicle (SEA 1000 & LAND 400), both possibly announced before the Australian election, will test the commitment of both Defence and Government to this policy and practice of preview test and evaluation.

If the preview test and evaluation planning is done properly it proposes the earliest exposure of qualified operational test and evaluation specialists and developmental engineers or scientists to any alleged mature aspects of the design, with test activities as independent of the company(s) being considered as possible. Where aspects of designs are truly developmental, the process proposes funded prototype demonstrations around key risks like the maturity of new technologies or integration risks. An early example of the application of this new prescribed preview process is in the currently underway down-selection of new light armoured vehicles for the Australian Army under Project Land

400. The approval-to-solicit (*First Pass*) by Government for Land 400 included provision for user trials on lethality, threat survivability and mobility, as well as an engineering demonstration of the integration of the Australian Army's battle-management and communication systems to a vehicle.[25] Such activities require up to three prototypes, two of which are likely to be destructively tested against representative threats. The purpose of such tests and demonstrations, before a major development and acquisition contract, are to:

- confirm the maturity of the most critical of claimed capabilities (i.e., blast & penetration),
- ensure the operating concepts and likely limitations are appreciated by both parties (i.e., user trials in hot-wet climate rather than European ranges);
- there is a real ability to rapid-prototype the necessary high-risk technical integrations to confirm technical risks; and
- engineering skills, commercial partnering and the necessary data and equipment release (i.e., the integration demonstration).

In the case of the LAND 400 project, as with the SEA 1000 project, it is not essential to do such preview test and evaluation on all contenders, rather it can be done on just the lead or preferred contender if necessary. The decision on how many contenders to take through to preview test and evaluation should be based on the need for that discrimination, that is, how close the contenders are and the cost of the testing. What is critical, is that:

- such preview test and evaluation is enabled (i.e., envisaged clearly) by the solicitation documents,
- it is done while genuine commercial pressure still exists (i.e. other contenders are only set aside) as independently and as professionally as possible, and
- it genuinely informs the contract negotiations of both parties.

If for example, a technical or operational risk is found from such preview, both the preferred contender and the Government should sensibly revise affected requirements, and the price and schedule margins before the contract is signed. The next section of this paper will look at what the preview test and evaluation should look like for SEA 1000.

What would Preview Test and Evaluation look like for the Preferred Contender

The Australian Defence process for determining preview test and evaluation starts with cataloguing the technical and operational risks and reviewing them with scientists, developmental testers and operational testers in a series of structured workshops.[13] To develop these risks, Defence has had access to its own Collins Class Submariners and maritime Defence scientists, as well as access to engineers and testers from the U.K. Astute Class and U.S. Virginia Class submarine developments.[26] Most of the technical and operational risks for SEA 1000 are likely to be in the re-design to achieve the Australian unique requirements and mandatory system fits covered earlier. An article by the Australian Naval Institute[27] and three articles by the Australian Strategic Policy Institute[28] are good general background on these technical and operational risks for the three contenders. Using only this publically available material, Table One below provides an indicative summary of the key factors likely to be driving the decision between the contenders. The format shown is a Pugh Decision Matrix method used in the modern U.S. test and evaluation methods,[29] which ascribes a value to each contender against a baseline; in this case the baseline is the current Collins Class.

TABLE 1: INDICATIVE PUGH DECISION MATRIX ON SUBMARINE CONTENDERS

Requirements	weight ▼	Japan Option	German Option	French Option
Strategic Alliance advantages	1	2	0	0
Design & Export Experience	1	1	3	2
Non-Proliferation Advantages	1	-1	-3	-3
Extent of Redesign - Endurance Submerged	1	1	3	2
Extent of Redesign - Range	1	1	2	3
Extent of Redesign - AN/BYG (power, space weight etc)	1	-3	-1	-2
Extent of Redesign - Weapons (Capacity, Type etc)	1	1	3	2
Extent of Redesign - Autonomous Vehicle & Operations	1	1	2	3
Extent of Redesign - Crew	1	1	3	2
	# Winners	**2**	**5**	**2**
	Sum of Values	**4**	**12**	**9**

Scoring - Detailed Pugh:

-3 = far worse than baseline
-2 = much worse than baseline
-1 = worse than baseline
0 = same as baseline
+3 = far better than baseline
+2 = much better than baseline
+1 = better than baseline

Please do not take the ratings shown here too seriously, as it is almost heretical to reduce some of the complexities of the strategic advantages to such a number scale. For example an excellent article by Davies and Scheer of ASPI proffers that there is fundamental non-linearity in the likely strategic benefits of the Japanese option.[30] Furthermore, the re-design risks shown here are without any access to the Contender's bids or Defence's key experts. The point of the table is merely to illustrate the likely factors and to deliberately provoke the following two important thoughts in readers:

- The decision ultimately comes down to weighting strategic advantages with technical and operational risk. There is an excellent discussion of this by Davies and Thomson of ASPI that ends with the conclusion: [31]

  '*So when the government sits down to contemplate the CEP submissions, it needs to decide what's more important: the fidelity of technical information, or making a decision about Australia's strategic relations with Asia. Do we want an industrial partner or a strategic partner? If it's the latter we should just get on with it.*'

  If readers are uncomfortable with the idea of taking either strategic or technical approaches, then you will need to weight the factors. For example, using the Pugh Matrix below, if you weight strategic effects as three times as important as technical ones, perhaps on the basis of these being in effect for longer, such as 30 years rather than ten years, then the rankings change from those shown where the German option leads the French and Japanese Options 12-9-4 respectively, to the Japanese option equaling the German option 6-6-3.

- That the decision-maker, until they do some actual test and evaluation, is always taking someone else's assurances and assessments (as I've done) and reducing them to ever diminishing levels of granularity and overlaying their preferences. If you conclude, like most, that such an approach is tenuous, you are hopefully convinced of the key point that before you contract using tax payer's dollars in an increasingly irreversible project, you need to check those assurances and assumptions with some practical testing; that is, do not sign a vehicle purchase without a test drive.

The exercise above was deliberately done to show that if the down-selection is based on technical and operational risk factors, then the current policies of Defence, as strongly pushed by Government, means the important preview test and evaluation (offer definition activity) has to occur while the down-selection is still in play (i.e., the others are only set aside), so that if additional risks are disclosed, schedules and costs adjusted, then the deciders can re-run their selection numbers and see if it would affect the rankings. If it would have affected rankings, then preview test and evaluation can be extended to include the next-ranked candidate. If however, the decision is based on purely strategic grounds, then the other contenders can be stood down, but regardless, no contract should be signed for full development until a preview is complete.

So if the technical and operational risks are those shown around re-design for submerged endurance, range, combat system, weapons, autonomous vehicle and operations and crew, then what would the preview testing involve, at least prior to a developmental contract? I would propose the following preview activities be conducted by Defence and the preferred Contender to confirm claims and assumptions and collectively determine technical and operational risks in the expected re-design:

- **Range and Submerged Endurance.** An Australian operational test team to conduct a trial of the reference submarine's range and submerged endurance in the submarine or representative land-based test site. A scientific team conduct some veracity checks on simulation modelling underpinning predicted improvements in range and endurance at the preferred contender's submarine development facility.

- **Combat System Integration.** A funded rapid bench-level integration of the combat system with the extant submarine non-combat systems at a land-based test site, employing where necessary interface emulators, rapid-prototype software interfacing and live, virtual or constructive technologies. This demonstration would need to involve both the combat system developers and submarine developers and may need to occur in a submarine land-based development site, the combat system development site, or a neutral site for both.

- **Weapons Integration.** A funded rapid bench-level integration of the weapons with the extant submarine weapons control and launch systems at a land-based test site, where necessary employing interface emulators, rapid-prototype software interfacing and live, virtual or constructive technologies. This demonstration would need to involve both the weapon developers and submarine developers and may need to occur in a submarine land-based development site, the weapon developers' sites, or a neutral site for all concerned.

- **Autonomous Vehicle and Operations.** An Australian operational test team with mine-counter measure (MCM), rapid environmental assessment (REA) and Special Forces staff to conduct a trial of the current submarine's autonomous vehicle and autonomous personnel operations in either the reference submarine or the most analogous representation available for such autonomous system and personnel deployment.

- **Crew.** An Australian operational test team of representative users to trial all example user interfaces in all land-based test sites for the reference submarine design, supplemented by scientific staff doing computer-based anthropometric evaluation. Such evaluations will examine the extent of re-design necessary for such workspaces and living areas.

There are three broad areas where common objections to such preview activities can be categorised: (1) already done, (2) too costly and time-consuming, and (3) not representative of the final design. Each of these are worth examining somewhat as they may be used in SEA 1000 to reject this best-practice.

First, project managers will often claim to have already undertaken these activities, however, when you check the claims it usually turns out to be poor evidence. For example, a sea-ride might have been undertaken by an Australian submariner, yet they were not qualified operational testers with an agreed test plan and no test report was written. Another hypothetical example is that an Australian scientist may have undertaken a visit to a research facility, however, no actual combined research was agreed and conducted with a scientific report – it was at best a visit and discussions. Also, these activities are likely to have been done without the direct information, and thus focus, of the contender's submission (i.e., for SEA 1000 the CEP) and the imprimatur of the announced preference and the focus of informing contract negotiations for both parties. In other words, professionalism and timing is key to frank, credible and constructive preview.

Second, project managers will often object to preview activities on the basis of the cost and time involved. Given priority and resources from both the preferred contender and Defence, preview activities like those listed above need only take three to six months. When six months is compared to the number of Defence projects experiencing serious delay and cost overruns later in the process, usually due to unanticipated technical or operational risks, then such early time is well spent. Just one re-negotiation of a major contract often takes longer than the preview activities would have taken.

Third, project managers will often object that such preview activities are not on representative designs. Here the fear is often that a test team will so heavily criticise the reference design, that it will threaten the viability of the re-design. Put another way, the fear is that the test team will take the task out of the context of shaping the re-design and use the opportunity to push for alternatives not available to their testing. Qualified and experienced test and evaluation professionals are trained to focus such evaluations on re-design rather than rejection. Furthermore, project managers and contending companies must guard here against hypocrisy because often their acquisition strategies, submissions and risk assessments are liberally laced with how mature the reference designs are, how mature new technologies are, and how low-risk are necessary modifications, yet they fear a test team cannot see through to a viable solution in a preview? Key to all preview activities being credible and contextual is the need to establish functional and physical configurations under test and contrast that with what has been tendered or submitted.

Finally, a useful breakdown for justifying preview activities is to think in terms of known and unknown risks as follows:

- There are risks a <u>Contender knows</u> but Defence does not. These risks are often assumptions about the maturity of technologies, skill-levels of Australian workers and crews, the veracity of modelling, the availability of experienced software engineers and the read-across of technical standards and operating manuals between countries and across languages. Preview activities are particularly good at disclosing such unknowns.

- There are risks <u>Defence knows</u> but the contender does not. These risks are often in the areas of inter-related Defence projects that must network or inter-operate with the capability and which if delayed in Defence approvals or funding, will force multiple configurations and testing on the Contender's designs. Another particular problem area is Australian ranges, test infrastructure and processes for operational acceptance, where the Contender can be surprised by the lack of test infrastructure, difficulties in accessing necessary operating personnel, technical cases to expend weapons, and so on. Preview activities are not as good as disclosing such difficulties as the earlier unknowns, however, ensuring the test team doing the preview activities includes the most experienced in fielding recent operational capabilities (i.e., not necessarily the last submarine, but the last ship) can ensure the contender is partnered while having some degree of common appreciation in this area.

- Finally, there are risks neither the Contender nor Defence knows. These risks are usually in areas like system interfacing where interface control documents have incorrect or insufficient detail, human factors in both software usability testing and anthropometrics, electromagnetic interference, cybersecurity vulnerabilities, environmental weaknesses, maintainability difficulties, or supply chain defects. Preview testing can be effective in disclosing interface difficulties through bench-level demonstrations and human factors issues, however the other risks listed are not usually resolved until proper developmental test and evaluation.

Lessons in Test and Evaluation from Collins Class Submarine

The Collins Class Submarine had serious difficulties in its test and evaluation, because the majority of the testing occurred much too late in the program. For example an overview of the Collins testing by the ANAO in 2001-2002, when five of the six boats had been built and operational still not achieved, found test plans were not updated, resourced or enforced, that test coordination meetings were not being held and critically, that Defence lacked the resources or methodologies to verify and validate safety-critical software.[32] The inadequate testing had been advised to the Defence Minister in a special report two years earlier, which stated:[33]

> *'To our surprise, deficiencies have occurred in items that should have been relatively straightforward, had testing, even along the lines of that routinely applied to merchant ships, been undertaken. … More seriously, the structure of the contract … has been a factor in the difficulties with, amongst others, the combat system, propeller, and periscopes. It was aggravated by the lack of insistence on all the testing required to reduce risk, notably full tank testing of hull models and early checking of more routine equipment to avoid unnecessary problems.'* (p. 6, p. 16)

Presciently to the case for preview test activities on SEA 1000 today, the authors of the 1999 report to the Minister stated the following, almost in frustration of '*how did it come to this*': [33]

> *'What is required are terms which compel the contractor to demonstrate his capacity to deliver in advance of the execution of the contract itself. This might variously be through an established track record of building the same thing for similar applications (if not, something similar or a derivative for a different application), or a series of tests or trials.'* (p. 16)

The poor test and evaluation on the Collins Class submarine development did not occur due to any lack of Navy policy on such test and evaluation, quite the contrary; the policy (known as ABR 6205) was, if anything, more rigorous at that time prior to the amalgamation of the materiel divisions of the three services. For example, the ANAO audit in 2001-2002 covered 23 maritime projects of the time and found some, like the Minehunter Coastal ship project, to be exemplary, and recommended that Defence needed to better enforce its test and evaluation policy for greater consistency, especially the release of equipment into service with inadequate testing. (para 4.75-76 & recommendation 3). Defence rejected this recommendation, preferring instead to front-load better planning and resourcing of test and evaluation in the acquisition life-cycle. At last, 14 years later SEA 1000 will be an opportunity to see if in the submarine domain, Defence policies will be true to this solution.

A summary of lessons learned from Collins Class was commissioned in 2011 by Defence with the RAND Corporation to inform the SEA 1000 program[34] and this report drives at least one recent influential article on SEA 1000 to reinforce testing.[27] Unsurprisingly, developing '*a thorough and adequate testing program during the design and build portion of a new program*' is a summary RAND finding with the following specific concerns from that report for SEA 1000:[34]

- '*Technologies that advance the current state of the art should* also *be adequately prototyped and tested prior to being incorporated into a new design. This prototyping and testing was not always followed during the Collins requirements process. For example, type-testing was not done to the extent that it should have been for the Hedemora engines on the Collins class*.' (p. 12).

  Technological advances are part of every contender's bids (relative to the Collins) but just two Japanese examples are their impending use of:

  - Lithium-Ion batteries to substantially improve the power density and extend the submerged endurance without air- independent propulsion, and
  - a permanent magnet synchronous electric motor with high torque at low revolutions that minimises propeller noise and removes gearbox noise.

  Such developments must first be rigorously tested in near-real land-based test sites; in this case, for the submarine propulsion system.

- '*Although multiple tests were done on the Hedemora diesel engine, the team failed to test it in salt water. … Collins had a complex fuel system that allowed water to enter the engine … When a similar design was used in the salty, open water in which Australian submarines operate, water was sucked into the engine. … it has affected the ships' endurance, because the crew now must leave 30 percent of the fuel in the tank to prevent water contamination. … Noise levels also proved to be a problem. First, the requirements for noise were not well laid out in the contract, perhaps because of a lack of technical understanding of noise issues. Adding to the problem was the lack of tools to measure submarine noise. …The noise problems came from several factors—the flow of water over the hull, the shape of the casing, and cavitation from the propeller. … In 1998, the propellers started to develop fatigue cracks. Sonaston, the material used for the propellers, proved to be too brittle for boats operating in an open-ocean environment. …Other serious problems the Collins experienced were vibration on the periscopes, unreliable communication masts, and a poor propeller shaft seal'* (pp. 24-26).

  While this is a long quote, it goes to the consistent lack of representative testing of components in land-based test infrastructure that can do accelerated-life testing using Australian conditions. Australian submarine conditions are in many respects, like water temperature, salinity, sea-states, turbidity and marine-life, fundamentally different to European conventional submarine waters. In the case of the noise measurements, Australia built the necessary instrumented ranges well after first-of-class testing and these ranges have since not been kept to the standard necessary to support the submarine design or development proposed under SEA 1000.[36]

- '*Program managers must understand that when they specify an operational requirement they must also specify how to test for the achievement of that requirement. … This typically involves test procedures, including who will do the testing, how the test will be conducted, and how success or failure will be measured*' (p. 41).

  This finding reinforces that a program must set test measures and the necessary test infrastructure before assembling prototype equipment.

- '*Specifying performance requirements is not sufficient; how to test that the design meets those requirements must also be outlined in the contract. Unfortunately, adequate testing procedures were not developed or enforced for the Collins program. … Understanding and specifying adequate test procedures is an area where the involvement of the technical community is especially important'* (p. 44).

> This finding goes to the competence of the project office in test and evaluation and the adequacy of independent project governance to ensure adequate testing. If Australian Defence does not believe the bulk of its projects warrant the independent test and evaluation oversight of the U.S. system, then it will need special test governance oversights for the few major development programs like SEA 1000 where these checks are necessary. The recent ANAO audit of Defence T&E found there are 12 separate test organisations, not one of which is devoted to developmental testing in the maritime domain.[14] Australian Defence has independent test agencies for development of land and aerospace equipments but in maritime this critical skill and governance is left to individual maritime projects to assemble with the associated loss of independence and disparity inherent in such a solution.[37] Given the proportion of investment in maritime capabilities recently announced by the Australian Government,[38] reform of the test organisations and test governance has to address this maritime development area or the disparity and lack of adherence to test policy observed by the ANAO in maritime projects in 2002[17] and 2011[39] is doomed to continue into the life of SEA 1000 and other ship projects.

There is one other area of the Collins Class experience that impacts on the test and evaluation of the new submarine. There have been many reports into the difficulties sustaining the Collins Class that found the Collins program focused on building the submarine and not the support and test infrastructure to sustain it.[40,41] Modern land-based test sites not only act as a clearing house for hardware and software build of the first-of-class, but they provide the means to support the design through-life by spirally-developing parts of the design as they become obsolete, or as a result of later testing for the first-of-class or operational service. Such test facilities also link to training facilities to ensure configurations are constantly managed for the crews who shift between boats. Australia's maritime testing policy (ABR 6205) has maintained a very mature developmental test structure of categorising maritime testing from environmental compliance and factory acceptance tests of components (CAT 2), testing in representative land test sites (CAT 3), before finally a first-of-class harbor acceptance test program (CAT 4), sea acceptance program (CAT 5) and operational testing (CAT 6). Maritime programs of course elect to invest in the test policy and associated infrastructure to more or less extents and clearly Collins under-invested. Such investment can be short-term, just to support the build, or long-term to support through-life. The recent building in Australia of two Landing Helicopter Dock ships, now the Canberra Class, is an example of the short-term, because it chose to build a temporary land-based test site which then became the bridge of the second ship. The future submarine is expected to be an evolutionary design process; that is, a first-of-class followed by blocks of subsequent submarines which are continuously in build. Taken to the extreme, SEA 1000 can, and should, be a continuous build, so it can support a submarine life as short as say about 18 years, such that the first of class decommissions as the 13th boat is operational, or if Australia's strategic circumstances change and more submarines are required, or some combination thereof. Such an evolutionary and continuous build approach avoids block obsolescence and the enormous cost and risk of '*clean sheet*' designs and projects. Within the context of this paper, such an approach warrants '*state-of-the-art'* land-based test sites that do the full suite of research, development, test, evaluation and through-life supply and training support. Moreover, all submarine systems must be represented in one of many land-based test sites, and the sites must also link to provide full submarine performance replication and direction. An example breakdown of necessary land-based test sites is: power and propulsion, command and weapons, sonar systems and noise measurement, other signature measurement and replication, submarine platform management (including life-support, maneuvering), communication (on & off platform), rescue, and autonomous vehicle and personnel.

Applying the Collins Class Testing Lessons to the New Submarine

This article will not repeat the obvious lesson on preview activities outlined earlier, rather this section will focus on the contracted developmental test and evaluation of the future submarine. Here the recent work by the Australian Naval Institute[27] provides an insight into the importance of testing as a means to control the highly iterative submarine design process, as well as the need to carefully work-package the submarine systems so as to ensure testing drives build without excessively stopping or starting that build. These lessons can be taken as applying to each land-based test site, then the first-of-class submarine and then blocks of follow-on submarines.

Probably the simplest way to outline how the contracted development test program for SEA 1000 should proceed, based on the lessons-learned from Collins, is to outline proposed goals for the SEA 1000 submarine test program, each with a short justification:

(1) *Land-based test sites will be designed and built that collectively connect 100 percent of all real safety-critical systems for the submarine, 90 percent of all real mission-critical systems for the submarine and 70 percent of all real other systems: the remainder of systems can be emulated or simulated. These targets must be achieved <u>at the commencement of category three</u> land-based test site testing and be maintained and re-tested prior to category four, five and six test readiness review. The percentage is to apply to hardware and software configuration items. These percentages of real submarine systems are to undergo accelerated-life testing in representative Australian conditions prior to the operational testing of the first-of- class submarine.*

The need to re-confirm these targets prior to each test readiness review is to ensure deficiencies found in each phase of testing are corrected and re-tested before the next phase of testing commences, mainly those safety-critical and mission-critical functions.

(2) *Land-based test sites are to undergo cybersecurity vulnerability and penetration testing as part of their category three testing. The first-of-class submarine is to undergo cybersecurity vulnerability and penetration testing as part of its harbour acceptance testing. All cybersecurity testing is to be to a plan agreed as U.S.-standard by the U.S. Directorate of Operational T&E.*

The need for such cybersecurity testing with U.S. assistance is covered by a recent academic article[42] and is given some impetus by the Australian 2016 Defence Whitepaper and associated investment plan.[38]

(3) *All land-based test sites and the in-water instrumented range sites are to connect real-time in a whole-submarine high-fidelity capability modelling, which for when the submarine is present on the tracking or noise ranges, can mix live with virtual events real-time.*

The need to connect the live ranges with the whole-submarine capability model is to enable exercises to include events that are realistically simulated in real-time where it is not always cost-effective to do so for real (i.e., weapon launches, autonomous vehicle deployment etc.).

(5) *Facilities proposals are approved and funded for all land-based test sites of the future submarine, their interconnecting infrastructure, and the two key in-water instrumented ranges within two years of the initial contract of the preferred Contender, whether those facilities are in Australia or overseas and whether the facilities constitutes a modification, upgrade or new facility.*

Major facilities, whether in-water or land-based, typically require a minimum of seven years to be ready, allowing for design, survey, commission, public consultation, parliamentary works approval, build and commission. Complex test instrumentation can often take a further two years after it is installed to have competent staff and reliable use, ideally refining their skills testing the current Collins systems. While there are some interdependencies between the submarine system design and the test-site facilities, sufficient margin can be put in to cover all possibilities. An example here might be to put the protections into the propulsion and power test site to cope with Lithium-Ion batteries.

(6) *All land-based test systems sited overseas, perhaps leveraging existing test sites for the reference design, must have secure links for a live, virtual and constructive node in Australia that enables whole-submarine high-fidelity capability modelling.*

(7) *Bench-level hardware and software integrations are to be established for all submarine systems <u>prior to critical design</u> <u>review</u>, that confirm the feasibility of all interconnections where necessary using rapid software prototyping and the emulation of up to 50 percent of non-safety-critical systems.*

(8) *All land-based test sites must achieve 90 percent confident replication of the agreed output responses based on actual first-of-class submarine testing before operational release of the submarine using U.S. design-of-experiment test methodology verified by U.S. Directorate of Operational Test and Evaluation.*

(9) *A test and evaluation master plan is to be developed between the development contractor and all affected Services and test organisations as part of the contract approval and include, at this stage, test measures for each of the output responses of every land-based test site using the methodology employed in U.S. test and evaluation master plans at Milestone B as agreed by U.S. Director of Operational Test and Evaluation.*

(10) *The test and evaluation master plan is to be updated every year and re-approved by all concerned with what has been achieved on the test program and the detail of the test program in the coming years, including fully integrated schedule and cost information for the test program. The Developmental Contractor is to agree, with exception as necessary, the master plan at every revision.*

Development and constructive maintenance of a test and evaluation master plan as the current plan is an excellent metric of a resourced and likely-to-succeed test program.

(11) *An independent annual report on the SEA1000 test program is to be compiled by a central Defence test organisation and made available to the Australian Parliament's JCPAA as part of the annual major project reports.*

(12) *There is to be a funded and documented meeting of a SEA 1000 test and evaluation planning group with representatives from all affected Services, Defence test organisations and Developmental Contractor test areas every quarter from the period*

of preliminary design review through to the completion of initial operational test and evaluation. If any testing is performed by a foreign military or foreign contractor test agency, their representatives are also to attend.

Open and regular test planning and consultation between all affected organisations, especially between Defence and the Developmental Contractor, has been shown to be critical to success in test programs.

The structure of these goals tries to avoid excuses which see designs and production proceed regardless of good test practices usually because of a lack of available funding and the readiness of time-consuming new test facilities. Further, it actively seeks to de-risk design review milestones through developmental test activities like bench-level software and hardware integrations to inform outstanding risks. By focusing on land-based test sites, significant percentages of critical componentry will be vetted in realistic interdependent systems-of-systems before being released for build, and will undergo cybersecurity and accelerated-life testing before seeing operational test in any submarine. The importance of constructive regular test planning, consultation and independent reporting is reinforced, so as to set up all concerned for a successful and readily adaptable test program. Coupled with the preview test activities outlined earlier for pre-contract, these contract test goals would implement most of the lessons learned from Collins, leverage the key U.S. test processes and checks, and take onboard the key concerns of ANAO reports into Defence test and evaluation.

Conclusions and Recommendations

Australia's future submarine project is a large developmental project because it has to redesign a submarine from Germany, France or Japan to meet a unique Australian mission and do so in such a way as to shape an evolving design and sustainment framework for Australia's submarine for at least the next 50 years. As such the project is more akin to U.S. Defense projects than the limited acquisition policies, competencies and governance frameworks currently available in Australian Defence. A comparison of the U.S. Defense and Australian Defence acquisition lifecycles shows Australia's future submarine is at about *Milestone A* for the U.S. process and at *First Pass* for the Australian process. The comparison shows the U.S. lifecycles that would come next for Australia's submarine are foundationally more structured towards technological maturation, risk reduction and iterative development than Australia's usual path to its next stage of *Second Pass*. Moreover, the U.S. test and evaluation system has far greater authority and independence, by law and precedence, to govern development of such a complex platform than what exists in Australia; acting as a brake to the natural inclination of contractors and project managers to rush to production too early. That said, all the indications so far are that Australia's submarine project is about to enter a risk reduction activity phase with the preferred contender and such an activity is entirely consistent with the more appropriate U.S. lifecycle approach.

Australia does however have some valuable local policy and experience in test and evaluation that it needs to apply to the future submarine project. Analysis of Australian acquisition projects over the last 15 years by the Australian Senate, National Audit Office and the Joint Parliamentary Committee for Accounts and Audit, have pressured Defence to formalise as policy its hitherto best-practice of preview test and evaluation before contracts. This recently reinforced preview policy is focused on revealing technical and operational risks through practical demonstrations and testing that either the contender, Defence, or both, may not have known. The intent of such activities is to compliment paper-based down-selection methods in such a way as to balance their inherent weighting towards contender-supplied technical assessments. Such policy is now mature in Defence. Further, based on recent testimony by Defence, such preview test policy is expected to be reinforced in the current Defence restructure of acquisition and its governance. Based on public literature concerning the submarine contenders this paper has, at least superficially, examined the likely technical and operational risk categories for the future submarine. These risks were then used to propose a series of five hopefully incisive preview activities that Defence can use with the preferred contender over the next few months before the first development contract. Activities proposed include structured user trials of the reference design land-based test sites and bench-level rapid-prototyping integration activities — all aiming to confirm the necessary modification areas (Australianisation) and look for undisclosed or unknown risks.

This paper also examined the available literature on the lessons-learned from the test and evaluation of the Collins Class submarine. At the peak of operational difficulties with the Collins in 1999, a Ministerial report expressed considerable frustration at the inadequacy of test and evaluation not to have screened for technical risks earlier, including a prescient call for preview testing as part of any future selection. The ANAO confirmed the inadequacy of the Collins testing in a more detailed review published in 2002 and they ascribed the difficulty to project governance not enforcing the necessary test policy. Unfortunately, Defence at the time rejected the ANAO recommendations to improve along U.S. lines the independence and governance of such project testing, ironically arguing it did not do projects that warrant such rigorous oversight! In 2011 Defence commissioned a RAND report on the lessons-learned from Collins for the future submarine, which this paper has now used as a basis to recommend appropriately focusing the future submarine's development around the current maritime test policy of the ABR 6205.

Principally the new project needs to structure its design and build around a series of about five major land-based test sites and two in-water instrumented ranges for noise signature, surface signatures and tracking. Such complex test facilities are notoriously time-consuming to build and commission to competency (up to nine years) and while most major developmental projects like Collins did, aim to deliver such infrastructure, inevitably the submarine production becomes the focus if this infrastructure is not given first approval and funding priority. Eleven high-level test and evaluation goals are provided in this paper to focus the submarine project and contender on a serious qualification of each and every system through the proposed representative land-based test sites of every necessary type, including cybersecurity and accelerated-life testing. The goals include checks to ensure deficiencies are rectified in the land-based test sites before each test readiness review for harbour acceptance, sea acceptance and operational testing of the first-of-class submarine, so as to prevent the operational testing problems of Collins and mimic the best of U.S. checks on the testing of such projects.

The proposed five preview activities (before contract) and eleven test goals (in contract) are commended to Australia's future submarine project and the successful contender, irrespective of whether they are French, Japanese or German.

Notes

1 Australian Defence Whitepaper 2016, para. 4.121, p. 114.

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3 Ibid; SEA 1000 Project, Competitive Evaluation Process, online http://sea1000.gov.au/current -activities/competitive-evaluation- process; & SEA 1000 Project, Expert Advisory Panel, online http://sea1000.gov.au/current -activities/expert-advisory-panel.

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5 Australian Strategic Policy Institute, September 2014, "*STRATEGY The submarine choice:*

Perspectives on Australia's most complex defence project", p. 26.

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