SPECIAL REPORT

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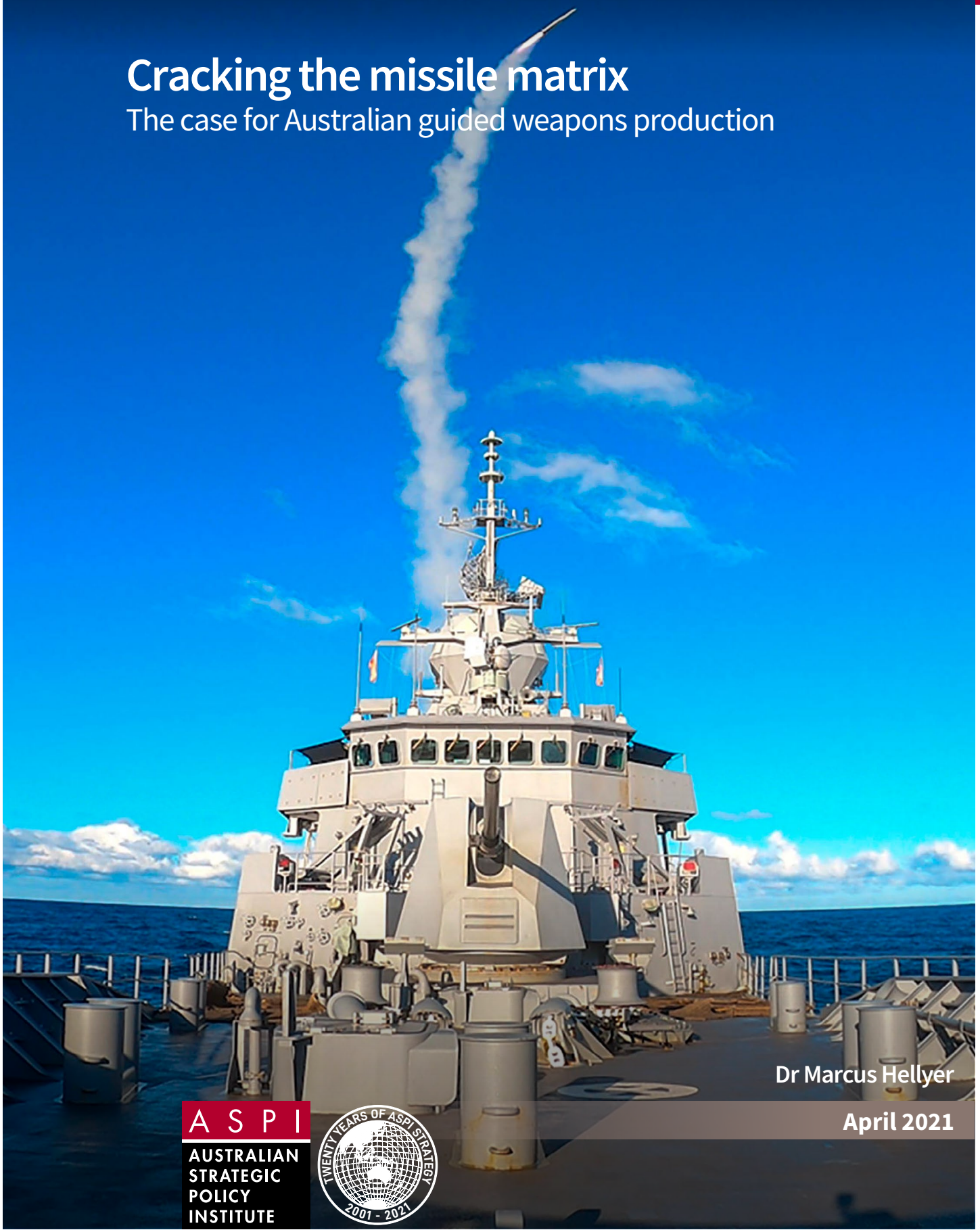
Cracking the missile matrix

The case for Australian guided weapons production



Dr Marcus Hellyer

April 2021

ASPI
AUSTRALIAN STRATEGIC POLICY INSTITUTE

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2001 - 2021

About the author

Dr Marcus Hellyer is a Senior Analyst at ASPI.

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Cover image: HMAS *Ballarat* conducts an Evolved Sea Sparrow Missile firing at sea, as part of the Anzac class frigate's sea qualification trials. Source: Defence image library, online.

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CONTENTS

We are witnessing the emergence of an era of missile warfare …

—General David H Berger, 38th Commandant of the US Marine Corps

There is no business as usual in the post-COVID-19 economy.
Tinkering at the edges on manufacturing policy is not an option. It hasn't worked in the past.

—Karen Andrews, Minister for Industry, Science and Technology
in *Make it happen: the Australian Government's modern manufacturing strategy*

EXECUTIVE SUMMARY

Last year's war between Azerbaijan and Armenia was short, sharp and decisive. By effectively employing precision guided weapons, the former rapidly forced the latter to capitulate and accede to its political demands. The conflict confirmed the centrality of guided weapons to modern war fighting and showed how small states can now master the technologies and techniques needed to use them.

Last year also witnessed the onset of the Covid-19 pandemic and the supply-chain crisis it triggered. That provoked much soul-searching from governments and companies about how to manage the risks presented by modern just-in-time supply chains that span the globe.

When we take those two events together, it's clear that the ADF will not only need many kinds of guided weapons across the spectrum of conflict, but also need to guarantee their availability in times of crisis when supply chains will be under pressure and threat. That will be difficult, since Australia currently manufactures virtually no guided weapons.

The Australian Government is also aware of both needs. Its 2020 Defence Strategic Update plans on investing tens of billions of dollars in guided weapons over the next two decades. It also directs Defence to explore the potential for new sovereign guided weapons production capability to mitigate supply risks. It appears that exploration has determined that the potential can be turned into reality: on 31 March, the government announced that it was 'accelerating' the development of a sovereign guided weapon manufacturing capability.

This report examines two fundamental questions. First, would the manufacture of guided weapons in Australia enhance ADF capability and provide greater self-reliance? Second, is it viable to manufacture guided weapons in Australia? The answer to both questions is 'yes'. The report also presents some key considerations about how the industry should be established.

No single measure is a panacea for supply-chain risks, but domestic guided weapons production, combined with greater stockpiling and cooperative development and production arrangements, would greatly reduce those risks.

Australia has the industrial capability to produce guided weapons here. In fact, we have a long and successful living history of doing that. We can also draw upon 'missile-adjacent' sectors such as space and autonomous systems as well as leverage the power of the fourth industrial revolution to accelerate the design and manufacture of weapons. We can also leverage our alliance with the US to establish production lines for US weapons here, to the benefit of both partners.

A multibillion-dollar investment in the local manufacture of guided weapons is also consistent with broader government policy; for example, it supports the government's modern manufacturing initiative, which is a key element in the effort to wean the Australian economy away from a dangerous over-reliance on the export of commodities and build on some other national strengths.

The government has announced that it's establishing a guided weapons 'enterprise', although it has released few details. What should that enterprise look like? To maximise the prospects for success, Defence needs to adopt a programmatic approach to its selection of guided weapons and actively manage the 'missile matrix'. That is, rather than allowing the number of types of weapons that it uses multiply by letting individual projects choose different weapons for different platforms, it needs to make decisions that take all relevant factors into account and choose weapons or families of weapons that will be used across multiple platforms.

That approach will have multiple benefits. Acquiring more weapons of fewer types will increase the economies of scale of local production. It will also help to contain the overheads of ownership, such as sustainment costs, the logistics chain and integration costs.

A programmatic approach will necessarily involve 'backing winners' up front. While some may have concerns about the potential loss of commercial leverage, Defence is already using such an approach with success, for example in the Navy's combat management system, for which the government has decided that all classes of ships must use Saab's combat system. This will involve seeing industry as long-term partners, rather than simply as suppliers—but that's already a fundamental tenet of the government's defence industry policy. Moreover, losing commercial leverage is a manageable issue, as Defence would be a more powerful, larger customer if it procured missiles using domestic co-production and the 'family of weapons' approach outlined in this report. And reduced commercial leverage is a different order of risk compared to losing a conflict owing to a lack of missile supplies.

A national guided weapons enterprise could adopt many of the measures in Australia's Naval Shipbuilding Plan, including enhanced funding for R&D, support for the establishment of precincts for the design and production of guided weapons, and coordinated training and education programs to develop the workforce. Making guided weapons one of Defence's 'sovereign industrial capability priorities', supported by an implementation plan, also makes sense as part of this broader plan.

But we can't wait until the perfect plan is developed. The urgency of our strategic circumstances means we need to start now. There are many mature weapons that the ADF is already using or has decided to buy that we can start producing here now with minimal risk. But the government should also make some 'big bets', investing in the development of emergent technologies such as hypersonic weapons that can be put into production here once mature, rather than waiting to see that maturity demonstrated elsewhere and then trying to retrofit Australia with a production capacity for these powerful new weapons.

The government has established a national enterprise to build ships, submarines and armoured vehicles in Australia, but, without guided weapons, those platforms will have limited utility. Put simply: a small number of military platforms without a large supply of advanced missiles is a force fitted for but not with combat power. The government's decision to establish a guided weapons enterprise, if implemented well, will be a key step in providing the ADF's platforms with the advanced missiles in the types and quantities they need to deliver lethal and survivable capability.

RECOMMENDATIONS

Recommendation 1

The Department of Defence should adopt an enterprise-level approach to guided weapons that:

- considers all relevant capability and industry factors in the selection of weapons
- minimises as far as possible the number of new weapon types
- seeks to maximise economies of scale
- identifies weapon types that should be manufactured in Australia
- makes guided weapons a sovereign industrial capability priority
- supports industry to establish local weapon production
- does not limit local production to one company's offerings.

Recommendation 2

Defence should seek the government's agreement to an initial portfolio of guided weapons that will be manufactured in Australia.

Production of those weapons should commence as soon as possible.

An indicative initial portfolio of high-priority weapons for local production would include:

- Spike LR2 missiles
- a family of tactical loitering drones
- air-delivered laser-guided bombs, JDAM-class weapons, or both
- the Evolved Sea Sparrow Missile
- hypersonics.

GUIDED WEAPONS: AN ESSENTIAL REQUIREMENT FOR THE ADF

In July 2020, the Australian Government released its Defence Strategic Update (DSU).[1] The document was refreshing for the frankness with which it assessed Australia's security environment, but its telling strategic assessments painted a very worrying picture. Faced with a more assertive and coercive rising great power, it concluded that the ADF's largely defensive capabilities didn't equip it to deter attacks on Australia or its interests.

The government stated that the ADF needs to grow its 'self-reliant ability to deliver deterrent effects'. This ADF requires a different set of capabilities to hold adversaries at risk further from Australia, such as longer range strike weapons. In short, the best defence is a good offence. The ADF also requires greater self-reliant ability 'to deploy and deliver combat power and reduce its dependencies on partners for critical capability'. Coming in the wake of the onset of the Covid-19 pandemic, the update also highlighted the vulnerabilities in global supply chains, including those critical for defence capability.

The DSU painted an alarming picture of the systemic capability gap between the ADF's current capabilities and those needed to meet Australia's strategic circumstances. Moreover, we don't have unlimited time to address that gap; the update also concluded that a 10-year strategic warning time for an attack on Australia or its interests 'is no longer an appropriate basis for defence planning'. In short, Australia needs more self-reliant military capability, and it needs to be delivered quickly.

The update and its supporting Force Structure Plan (FSP) present an acquisition plan to bridge that gap, but many of the lines of effort in that program will take many years to deliver—a factor that doesn't sit well with the update's conclusions about warning time.

In the light of the extremely long delivery times for manned platforms such as ships, submarines and aircraft, greater deterrent effects and self-reliant capability are likely to be delivered faster through investment in weapons, rather than new platform projects. Encouragingly, a key element of Defence's acquisition plan is a very substantial investment in guided weapons in the order of tens of billions of dollars. That includes acquiring new kinds of weapons as well as holding larger stocks of weapons.

But, to address supply-chain risks in guided weapons, the plan also raises the prospect of fundamental changes to the way Defence has done business by considering 'the potential for a new sovereign guided weapons and explosive ordnance production capability to mitigate supply risks, especially for those munitions with long lead-times'—which includes most advanced missiles.

More recently, on 31 March, the government announced that it was 'accelerating' the development of a sovereign guided weapon manufacturing capability and was establishing a guided weapons 'enterprise'.[2]

This report examines two broad questions. First, would the manufacture of guided weapons in Australia enhance ADF capability and provide greater self-reliance? Second, is it viable to manufacture guided weapons in Australia? The answer to both questions is 'yes'. The report also suggests ways to enhance the prospects for the success of a local guided weapons industry.

Our accelerating reliance on guided weapons

There are likely to be many facets to any future war beyond kinetic effects, such as cyber disruption and political warfare. Nevertheless, any examination of the history of the past 30 years of armed conflict and of contemporary military forces' current and planned capabilities would have to conclude that guided weapons are now central to modern military operations. Modern militaries' reliance on precision guided weapons has grown to the point where they would be largely ineffective in combat without those weapons. And they need them in large quantities, not just boutique numbers for exquisitely crafted precision strikes against small numbers of targets in discretionary deployments.

Their reliance on guided weapons continues to grow. In Operation Desert Storm in 1991, 'the proportion of PGMs delivered by US forces compared to nonprecision munitions was less than 10 percent.'[3] Eight years later, in 1999, during NATO's air campaign intended to persuade Yugoslavia to remove its forces from Kosovo, that proportion had risen to 29% (and that percentage had been pushed downwards by the old-fashioned use of carpet bombing by heavy bombers late in the conflict).[4] Four years later, in Operation Iraqi Freedom in 2003, the US and its allies expended 29,199 munitions, of which two-thirds were guided.[5] In Operation Okra (the campaign against ISIS in Iraq and Syria), the RAAF used only precision guided munitions. The F-35 uses only guided munitions, other than its 25-mm canon.

If that reliance on guided weapons was the case in conflicts in which the US and its allies had overwhelming air supremacy and technological superiority, it's likely to be even more so in fights with peer or near-peer adversaries. And, in a fight with a peer adversary, both offensive and defensive guided weapons will be necessary. For example, to have any chance of surviving China's lethal mix of supersonic anti-ship cruise missiles, anti-ship ballistic missiles (such as its DF-21D 'carrier killer') and emerging hypersonic missiles with ranges in the hundreds or even thousands of kilometres, Australian warships will require multiple advanced air-defence missiles. They'll also need offensive strike missiles of their own with hundreds or even thousands of kilometres range to shoot back. It's highly unlikely that an RAN frigate will ever engage an enemy ship with its 5-inch gun firing traditional 'dumb' rounds.

Much of the public discussion about defence acquisitions and defence industry in Australia and other nations focuses on the platforms that carry and launch those weapons, rather than on the weapons themselves, but, without them, the platforms are useless. In one sense, the $89 billion submarines, $45 billion frigates and $17 billion F-35s that the Department of Defence is buying are just delivery systems for the guided weapons they carry. And, since modern military operations consume large numbers of those weapons, we run the risk of having useless platforms if we don't properly plan to be able to maintain the flow of those weapons to frontline forces.

And it's not just large platforms exchanging guided missiles at long ranges. With the merging of guided weapons and drones and the miniaturisation of both, even infantrymen can now launch small, loitering precise munitions simply by throwing them into the air.

The 'democratisation' of guided weapons

At the time of the 1991 Gulf War, the US's precision strike capabilities, the result of massive investment under its Second Offset Strategy, were virtually unique. That's no longer the case. As noted above, China has developed a vast range of long-range precision guided weapons that have already forced the US to reconsider its force structure and approach to operations in the Western Pacific.[6]

But it's not just great powers that can produce these capabilities. A range of middle and smaller powers have developed precision guided weapons, including Israel, Turkey, Sweden and Iran. Some of those producers have also made them available for export. This means that the number of states that qualify as peer or near-peer adversaries by being equipped with precision guided weapons is growing.

Even small states with limited defence budgets can acquire such systems on the global market and develop a level of proficiency that only two decades ago was the province solely of a very small number of advanced militaries. The recent conflict between Azerbaijan and Armenia was telling. The latter rapidly capitulated as its army collapsed in the face of precise air strikes delivered by drones employing guided weapons provided by Turkey and Israel (Figure 1). The same capabilities used by Azerbaijan are being exported to our region.[7] The boundary between the haves and the have nots is evaporating.

Figure 1: Azerbaijani drone footage of a strike on Armenian forces; a country with a GDP that's only 3.1% of Australia's and a defence budget that's only 7.2% of Australia's successfully employed drones and guided weapons, causing its adversary to collapse militarily and capitulate politically

Source: Azerbaijani Ministry of Defence, online.

And it's not only states that are employing guided weapons. Quasi-state and non-state actors do, too. Hezbollah has long had access to anti-tank guided missiles provided by Iran, using them to destroy Israeli armoured vehicles, significantly raising the cost and risk of Israel deploying 'boots on the ground'.[8] Hezbollah has also severely damaged an Israeli warship with a land-based anti-ship cruise missile, most likely a Chinese C-802. The Yemeni Houthis have also used anti-ship cruise missiles to destroy a United Arab Emirates vessel and forced US Navy ships to deploy sophisticated countermeasures to protect themselves.

Even terrorist groups with a limited technological support base have been able to use off-the-shelf consumer goods to produce weapons that can deliver effects similar to guided weapons. ISIS used commercial drones to drop grenades down the hatches of Iraqi army tanks.

The merging of weapons and drones

Another development is that the roles of guided weapons and drones are becoming increasingly merged. There are well-established synergies between drones and guided weapons; drones can themselves launch weapons, and they can provide targeting for weapons launched by manned aircraft, as well as providing targeting for weapons launched by other drones.

However, drones and weapons have also essentially merged in the form of loitering munitions, commonly known as suicide drones. Such systems have long endurance, allowing them to loiter over the battlefield and giving them the ability to prosecute targets of opportunity. One well-known example is the Israeli Harpy, which was probably used operationally by Azerbaijan in its recent conflict with Armenia. It's also being exported to our region.

Such weapons are relatively small. That reduces the infrastructure needed to support the employment of precision guided weapons. While armed drones are generally smaller than manned aircraft, they still need a runway, ground crew, refuelling and rearming support, and so on. Loitering munitions don't. They can essentially be launched from containers on the backs of trucks or ship decks.

The outcome of the ongoing processes of democratisation, miniaturisation and merging of unmanned aerial vehicles (UAVs), weapons and sensors are systems such as the Australian-designed Defendtex Drone 40 (Figure 2). This is a hovering UAV in the format of a 40-mm grenade that can be launched from a soldier's underslung grenade launcher, or just thrown into the air. Individual rounds can be fitted with a range of payloads, including kinetic warheads as well as sensors. This step in the democratisation of guided weapons means that even an infantry section will have the organic capability to deploy smart, persistent swarms of guided weapons. British soldiers are already employing them on operations.[9] But democratisation also means that Australia's adversaries will have them, too.

Figure 2: UK troops trained with the Defendtex Drone 40 before their deployment to Mali in October 2020

Source: UK Ministry of Defence, online.

Numbers matter

In sum, in any likely future conflict, the ADF will both face and itself employ a full spectrum of guided weapons, from long-range strike weapons down to individual soldier systems. The ADF will need a full range of countermeasures that disrupt the adversary's kill chain—but some of the most effective are themselves sophisticated weapons that can, for example, either destroy hostile platforms before they launch their weapons, destroy the weapon in flight or, like the Nulka, act as decoys.[10]

The outcome of a conflict between the ADF and adversaries operating these weapons will be determined by many factors, including the technical capabilities of the individual guided weapons used and the enabling systems, such as targeting and intelligence, that make them effective. But victory may also go to the side that can replenish these new 'consumables' of conflict fastest. Whichever side is unable to sustain the supply of them to its frontline forces will be at a severe disadvantage. This means success will come to those who recognise that advanced missiles and loitering munitions need to be thought of and procured as flows, not stocks.

The ADF has traditionally relied on small numbers of technologically superior systems in both platforms and weapons. It has historically done 'one-off' buys of relatively small numbers of guided weapons that are meant to last for decades from international suppliers. However, the democratisation of these technologies means that mass is increasingly important. In this regard, the Australian Defence organisation has a long way to go to ensure that it can sustain the flow of consumable weapons. A fundamental shift is required in its approach to acquiring guided weapons.

AUSTRALIA'S INVESTMENT IN GUIDED WEAPONS

Previous investment

Guided weapons are nothing new for the ADF. Australia has been in the fortunate position of being able to pick the best systems available on the global market. While Australia has a long history of guided weapons design and production (which we review later), nearly all of them have been acquired overseas. According to data published by the Stockholm International Peace Research Institute, Australia has been the fourth largest importer of arms over the previous decade; one major driver of this has been our acquisitions of guided weapons.[11]

Over that period, according to reporting on the AusTender database, Defence has signed contracts worth $3,302 million in the general category of 'missiles'. AusTender provides few details; most of the entries are payments to the US Foreign Military Sales program for unspecified missiles, including a $610 million payment in 2016. In some cases, AusTender states what the missiles were, such as a $216.1 million contribution to the Evolved Sea Sparrow Missile (ESSM) program in 2014 and another for $153 million in 2017.

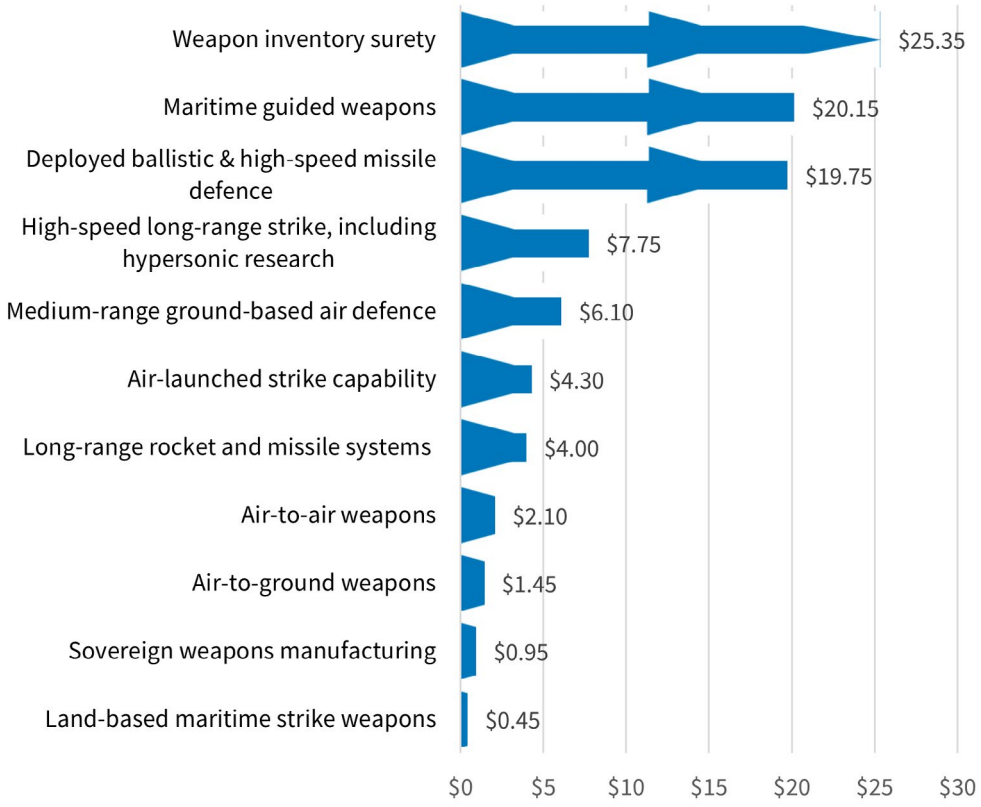
Australia's weapons acquisitions have been primarily, but not exclusively, from the US (a table of Defence's guided weapons projects and purchases is in Appendix 1). We've also bought European weapons that have been successfully integrated (such as the ASRAAM missile on the Hornet) and not so successfully integrated (such as the MU90 lightweight torpedo onto any ADF aircraft).

The fundamental question is whether it makes sense to continue to be so reliant on imported weapons.

Planned investment

Defence's investment in guided weapons is set to increase dramatically. The government's defence planning documents make it clear that the ADF has entered the 'age of missiles'.[12] Broadly speaking, the 2020 FSP outlines around $100 billion in investment in guided weapons over the coming two decades (Figure 3).

Figure 3: Planned investments in missiles and other guided weapon systems (median point of FSP bands, $ billion)



Source: 2020 Force Structure Plan, online.

New capabilities, both offensive and defensive

Several factors are driving this. The first is that the government is seeking new kinds of capabilities. Second, larger stocks of the types of weapons already in service will be required. And, finally, guided weapons will increasingly permeate the ADF so that more platforms will employ them.

The first reason arises from a fundamental change of direction in the government's understanding of the kinds of military capability Australia needs. The DSU assessed that 'Australia has a highly effective, deployable and integrated military force. But maintaining what is a capable, but largely defensive, force in the medium to long term will not best equip the ADF to deter attacks against Australia or its interests in the challenging environment this document sets out.' Therefore, the government is seeking to acquire 'more potent capabilities to hold adversary forces and infrastructure at risk further from Australia, including longer range strike weapons, cyber capabilities and area-denial systems.'

The FSP that accompanied the DSU broadly described the new capabilities. Ones that can be described as longer range strike weapons or area-denial systems that employ guided weapons include hypersonic missiles and long-range land-based rocket and missile systems.[13] Indeed, in some regards, the nature of the Army will fundamentally change as it moves to become a missile force with new, long-range missile capabilities.

The ADF will also acquire new kinds of defensive capabilities. For the first time, the investment plan includes funds to acquire a ballistic missile defence capability. While the FSP provides little detail on what type of system is required, the funding envelope suggests something like the US Patriot or even the THAAD system. There are also substantial funds for a medium-range ground-based air defence system. Again, this is a new kind of capability for the ADF.

Defence will need a lot of missiles

The second reason for the steeply growing investment in guided weapons is that the ADF is going to need a lot more missiles, even of the ones it already has in its inventory. This is in part because platforms are increasingly reliant on missiles, but another key driver for the growth in missile numbers is that the ADF's platforms are getting bigger.

Take the Navy's surface fleet. Each of the RAN's eight Anzac-class frigates has eight vertical launch cells, each capable of holding a quad pack of four ESSM short-range air-defence missiles. That's a maximum load-out of 32 per vessel (Figure 4). The Anzacs can't operate the longer-range SM-2 missile currently in the ADF inventory, let alone the even more capable SM-6 that's in Defence's acquisition plans. So that's a total of 256 for a full load-out for the class. At around $2.4 million per missile, that's a cost of $614.4 million, even before we get to replenishing weapons expended in combat.

Figure 4: HMAS *Ballarat* conducts an Evolved Sea Sparrow Missile firing at sea, as part of the Anzac-class frigate's sea qualification trials

Source: Defence image library, online.

But the fleet is going to require even more missiles at greater cost. The nine Hunter-class frigates that will replace the Anzacs each have 32 vertical launch system cells. Theoretically, that could mean 128 ESSMs per ship, but it's likely that some of their cells will hold the SM-2 and potentially even the SM-6, both of which require one cell per missile. The SM-2 and SM-6 missiles cost around $3.2 million and $6 million, respectively. A full load-out for the Hunters could require more than 600 missiles at a cost of over $1.6 billion.[14] And those numbers will need to be replenished.

When we add in the three Hobart-class destroyers, which have 48 cells each, a single load-out for the surface fleet could require more than 850 missiles at a cost of nearly $2.5 billion. That's before we consider war stocks, other guided weapons that don't require vertical launch cells, such as some anti-ship missiles or lightweight torpedos, or expendable passive defensive systems, such as the Nulka hovering decoy.

Guided weapons will increasingly permeate the force

More ADF platforms and units will incorporate guided weapons. They'll have to, if they're to have any chance of surviving on the modern battlefield. No current Army vehicle mounts a missile. However, both types of vehicles being acquired by Project LAND 400 (the Boxer combat reconnaissance vehicle and the yet-to-be-chosen infantry fighting vehicle) will have launchers for the Israeli Spike missile in addition to their main guns. That's potentially around 500 missile-equipped vehicles.[15] In future, missiles may also be mounted on protected vehicles, such as the Hawkei.

The ADF currently uses unarmed surveillance UAVs but doesn't have armed drones. Defence is planning to acquire the Sky Guardian, a variant of the Reaper, which is likely to be armed with laser- and GPS-guided bombs and Hellfire missiles. But, with the miniaturisation of both drones and weapons, the use of weaponised drones is likely to saturate downwards so that even infantry units will have organic air-launched guided weapon capabilities. As we've seen, the Drone 40 is already a blend of drone, sensor and guided weapon. Australia's adversaries will acquire them even if the ADF doesn't.

Maintaining the flow of increasing numbers of increasing types of weapon mounted on increasing types of platforms in conflict will be a challenge that Defence isn't currently equipped to meet.

MANAGING THE OVERHEADS OF THE MISSILE MATRIX

The missile matrix

The ADF's rapidly growing reliance on guided weapons presents risks. The first major risk is that, as the number of guided weapons in ADF service grows, the challenge of acquiring, integrating, sustaining and operating them all will become less and less manageable. Guided weapons require many supporting elements in order to function effectively. It's not simply a matter of buying them and storing them in a warehouse until it's time to use them. The more different weapons Defence acquires, the more those overheads multiply, and a deployed ADF will be burdened with more and more complex logistical challenges to support multiple different missile types.

We can illustrate the potential proliferation of weapon types in a matrix (see Appendix 2). ADF platforms are listed on the vertical axis: fast jets, patrol aircraft, armoured vehicles, infantry, helicopters, surface vessels, submarines and so on. Across the top there are types of targets: aircraft, armoured vehicles, bunkers, warships, speedboats and so on. The matrix shows the weapons that the platform could use to prosecute the target.

Over the coming decade, it's very likely, and indeed unavoidable, that Defence will acquire many more kinds of guided weapons. The risk is that each of Defence's platform projects selects a different weapon to prosecute each target, resulting in each box in the matrix having a different weapon. That would massively multiply the number of different kinds of weapons in the inventory, increasing the overheads while potentially decreasing the war stock of each kind.

We've seen that occur already; the Army's infantry use the Javelin against vehicles and bunkers, its Tiger armed reconnaissance helicopter uses the Hellfire against those targets, and the Spike has been selected for the Boxer combat reconnaissance vehicle for that role. The Navy's frigates and destroyers carry two types of antisubmarine torpedo—a European one launched by the ships themselves and an American one that the ships' helicopters carry. There's a long back story to that involving the failed Super Seasprite project and Defence's tendency to underestimate the cost and risk involved in integrating new weapons into old platforms.

There are potentially other areas in which the number of weapons could proliferate in the ADF. One is anti-ship missiles. The ADF's surface ships, submarines, fast jets (both Super Hornets and F-35As) and maritime patrol aircraft all require a new long-range anti-ship missile, plus there's a new land-based anti-ship missile capability in Defence's investment plan. The AGM-158C long-range anti-ship missile (LRASM) has been selected for the Super Hornet and P-8A maritime patrol aircraft to replace the Harpoon, but there are other possible options still open for other platforms.

As hypersonic weapons mature, it's also possible that the number of hypersonic weapon types in the ADF's inventory could rapidly multiply, should the Army, Navy and Air Force all choose different weapons.

Defence will need to balance the capability benefits of narrowly choosing the optimal missile for each platform and application against broader benefits offered by choosing missiles that can be used across a range of platforms and applications—and produced at volume, partly because of the economies of scale from an approach to weapon selection that thinks of families of weapons, and that selects the same missile for closely related tasks.

Costs and risks of fundamental inputs to capability

The sustainment cost of Defence's weapons is substantial. In 2020–21, it's $215 million for the Army and $134 million for the Navy.[16] Additional weapon types come with additional overheads. Defence refers to the enablers necessary to employ a capability effectively as 'fundamental inputs to capability' (FICs). There are nine.[17] In essence, these are the overheads of effective ownership. With every new weapon in inventory, the FICs increase.

This is most obvious in the case of the 'support' FIC. Every new weapon introduces additional support requirements: its sustainment supply chain, new support and test equipment, new training for maintenance personnel, and new technical data. While modern guided weapons have long shelf lives, they still need skilled maintenance staff to ensure that software is up to date, to check that batteries and energetic components such as warheads and propellants haven't degraded and to replace them if they have.

Those sustainment supply chains can be fragile; currently, some components need to be returned to the original manufacturer overseas for repairs or upgrades, with lengthy turnaround times. The cost of transporting 'energetic' components such as warheads and motors with propellant fuels can be extreme due to the need to use military or other certified aircraft. The more sustainment that can be done locally, the better.

But there are other, less visible requirements. New weapons need to be integrated into platform simulators to support training. As weapons become increasingly software reliant, they'll require frequent software upgrades. They may require intelligence mission data, tailored to a specific threat set or environment, that requires threat libraries and updates.

All businesses seek to minimise overheads through standardisation as much as possible. Defence, too, will need to minimise overheads by minimising the number of different guided weapons it employs.

Managing integration costs and risks

As the number of weapons increases, so too do the cost and risk associated with integrating them onto our platforms. Integrating weapons is a non-trivial task taking several years of effort and tens of millions of dollars to address both software and physical integration. Defence has a very mixed record of success in its efforts to integrate new weapons into old platforms. Project JP 2070 was to acquire the MU90 torpedo and integrate it into the Adelaide- and Anzac-class frigates as well as three aircraft: the Super Seasprite and S-70B-2 Seahawk helicopters and the AP-3C maritime patrol aircraft. Defence eventually abandoned efforts to integrate the torpedo into any of the aircraft.[18]

Australia did successfully integrate the AGM-158 joint air-to-surface standoff missile onto the F/A-18 A/B 'classic' Hornet fleet (Figure 5), but even there the planned integration on the AP-3C was not completed. Moreover, integration onto the classic Hornets doesn't mean that the weapon is also integrated onto the Super Hornet. That means that, as the classic Hornets are progressively withdrawn from service, the ADF doesn't have a platform that can carry its longest range strike weapon.

Figure 5: Australia successfully integrated the AGM-158 joint air-to-surface standoff missile onto the classic Hornet; with the impending retirement of that fleet, the weapons' future employment in the ADF is unclear

Source: Defence image library, online.

Even when Defence has successfully integrated weapons, as in the integration of the US Hellfire missile onto its European Tiger armed reconnaissance helicopter, it's had to bear the entire cost and risk itself to deliver a unique, orphan solution.[19]

Because of experiences such as those, Defence has turned to off-the-shelf solutions, particularly for its air systems. The RAAF acquired the same version of the Super Hornet as the US Navy along with the weapons suite already integrated into it. The RAN did the same with the Seahawk Romeo maritime combat helicopter that replaced the Seahawk S-70B-2.

But relying on others to manage all weapons integration comes with risks, too. Australia is still waiting for the Joint Strike Fighter (JSF) consortium to integrate a long-range maritime strike weapon onto the F-35, despite Australia being a JSF partner nation and long-range maritime strike being Australia's highest priority for the program—that's one reason Defence had to resort to the fallback option of acquiring the LRASM for its Super Hornets.[20] So, being able to leverage off friends' and allies' integration efforts is an important factor—it's just not always possible for a force that uses a mix of Australian, US, European and Israeli systems. Retaining the ability to integrate our choice of weapon onto our choice of platform is a key element of sovereign capability.

How does this support the case for domestic manufacture?

We can draw some conclusions from these observations. Most importantly, Defence needs to actively manage the missile matrix to rationalise the number of kinds of weapons or families of weapons. This will generate the following benefits:

- It will reduce the overheads of sustainment.
- It's likely to result in the ADF being able to acquire larger numbers of each kind of weapon.

- Generating scale will also make local production more economically viable.
- If Australia can design and build components for missiles and assemble them, it's likely that we can also sustain them in country, eliminating the need to return them to overseas manufacturers.
- Creating commonality reduces integration risk, as lessons learned from integrating a weapon onto one platform can be applied when that same weapon is integrated onto other platforms.
- Local manufacture will also reduce integration risks if it's accompanied by the transfer of technology and access to software, allowing Defence and Australian industry to develop a deeper understanding of the weapons.

ADDRESSING SUPPLY-CHAIN SECURITY

The supply-chain risk

Another major risk associated with the ADF's increasing reliance on guided weapons is one that Covid-19 has brought into sharp relief: supply-chain security. The Covid-19 crisis, combined with a more overtly economically coercive China, exposed the fragility of global supply chains, even in peacetime. Guided weapons have all the hallmarks of a supply-chain crisis waiting to happen. They're highly complex systems built overseas consisting of numerous subsystems supplied by diverse manufacturers around the world. They take a long time to manufacture. And, in wartime, an adversary will be actively seeking to interdict those supply chains.

Moreover, in a contingency when we might want a lot of them in a hurry, the countries that manufacture them probably will too and will prioritise their own militaries' requirements. We've seen this phenomenon already in the health sector with 'vaccine nationalism', even between close political and economic partners.

The 2020 FSP clearly articulates the supply-chain risk:

> One of the most consistent and important lessons from previous conflicts around the world has been how quickly supplies of precision munitions can come under stress, especially for those nations that possess little domestic capacity to manufacture them. In a world that is becoming more contested and where supply chains have been shown to be fragile in moments of crisis, it is important for Defence to re-evaluate its capacity to sustain the ADF on operations.[21]

To address this, the DSU states that the government's plans include 'more durable supply chain arrangements and strengthened sovereign industrial capabilities to enhance the ADF's self-reliance, including in the context of high-intensity operations'.[22]

What are the options to address supply-chain risks? Broadly speaking, there are four main approaches: diversifying suppliers, holding larger stockpiles, burden sharing, and domestic manufacture. All of those are non-trivial tasks in the case of guided weapons. None will be sufficient alone, and all of them are likely play a role in addressing the challenges Defence faces.

Diversifying suppliers

Diversifying suppliers makes sense, particularly if a key or indeed monopoly supplier is someone you can't rely upon in a crisis, but it's hard to diversify suppliers once the shooting starts. If it's hard to do with something like medical ventilators, it's even harder with even more complex systems such as guided weapons. We've seen already that the integration of new weapons is difficult and takes time and lots of money. New weapons aren't simply 'plug and play', so it's not just a matter of placing an order for weapons with a new supplier.

There are other challenges to diversification. As the number of players in the Western arms industry has consolidated in the past few decades, there are fewer options for weapons. For example, in the US, there's no direct competitor for the ESSM maritime air defence missile. If the ESSM were unavailable, Australia could try to get a less

capable missile such as the SeaRAM or a more capable missile such as the SM-2, but all three are Raytheon products, so if the supply chain for the ESSM were interrupted, it's likely that it would be too for Raytheon's other products. Moreover, the SeaRAM hasn't been integrated into the Navy's combat system, and the SM-2 can't be used by the Navy's Anzac frigates.

Australia could seek a European alternative to the ESSM, but integrating European weapons into the largely American combat systems used by Australia's platforms has historically been challenging. It's not impossible, but it's not something that can be done on the spur of the moment. So, while drawing on non-US weapons could help mitigate some risks in some types of weapons, it would have to be done well before a conflict starts.

Stockpiling

Stockpiling is Defence's traditional approach to managing the guided weapons supply chain. It generally buys a stock of a particular type of weapon it can afford within the given project budget (sometimes deeply constrained by how much money a project that procures platforms has left once it gets around to weapons to go on them) and stores them, occasionally topping up its holdings as small numbers are consumed in practice firings or certification activities.

The challenge has always been knowing how many weapons to hold. Because many weapons cost millions of dollars each, stockpiling is expensive, so there's always pressure to hold the absolute minimum. In the post–Cold War era of US unipolar hegemony, the risk of holding only small war stocks of high-end weapons was probably acceptable. That's no longer the case in an era in which the government has acknowledged the possibility of conflict with a major power. In high-end war fighting against a major power, even if we fight alongside the US, war stocks will be consumed very rapidly. As noted above, the US coalition used around 20,000 guided weapons of all kinds against Iraq in 2003—a state that was far from being a major power and indeed had virtually no air force or navy to speak of.

It's clear that the government has recognised this risk. The 2020 FSP states that the government has directed Defence to develop options for 'an increase in weapon inventory across the ADF to ensure weapons stock holdings are adequate to sustain combat operations if global supply chains are at risk or disrupted'.[23] It's devoting $20.3–30.4 billion over the next two decades to 'weapons inventory surety'. That suggests it's going to spend a lot to maintain larger war stocks as well as to allow the ADF to expend more munitions in realistic training.

Larger stockpiles go a long way to making the ADF's war-fighting capability more robust, but it's a limited form of sovereign capability costing a lot of money. Stockpiling by itself has disadvantages:

- It gives the ADF some self-reliance in wartime, but only if it were able to accurately gauge in advance how many weapons it needs to have on hand for all potential contingencies—which is essentially impossible to do.
- It doesn't solve supply-chain problems if Defence is still reliant on long supply chains for the repair or replacement of components, particularly if the weapon needs to be returned to the original manufacturer overseas.
- As a consumer of off-the-shelf weapons acquired overseas, Defence will have very limited ability to enhance or modify those weapons as the nature of conflict evolves.
- It assumes that weapons with the attributes that Defence needs are available to be acquired and stockpiled in the first place.

Burden sharing

Defence has historically sought to meet some of its guided weapons needs through a form of burden sharing in the form of cooperative weapons programs. In those programs, usually with the US, it contributes to the cost of developing the weapons. They have included the Mk-48 heavyweight torpedo and the ESSM (the latter with several international partners). The government recently decided to enter into similar programs to evolve the SM-6 long-range air-defence missile and the Mk-54 lightweight torpedo.

Such programs can have advantages. The cost of development is shared, and theoretically Australia has a voice in setting the requirements for the program. Australian industry generally has opportunities to introduce components into the program's global supply chain.[24] This has resulted in the development of greater industrial capability here. Australia also gets more assured access to production slots under these arrangements—at least in peacetime.

But such programs also have disadvantages as they are now structured. The development schedule is driven by the major partner. And, as the JSF program's delayed integration of a maritime strike weapon has shown, being a member of a cooperative program doesn't guarantee that Australia's requirements are met when we need them. The more partners, arguably the greater the supply-chain risk. This was graphically illustrated when Turkey was ejected from the JSF program, forcing the consortium to find alternative suppliers for key components.

But perhaps the biggest risk from a supply-chain perspective is that there's still only one production line and that's in the major partner's country. Even in peacetime, it can take several years for orders of weapons to be delivered. While it's unlikely the US would turn off the supply to punish Australia, in time of crisis both countries (and any other additional partners) will all be clamouring for weapons from the single production line. That exposes all the partners to strategic risk. That can be mitigated by establishing multiple production lines in several partner countries, ideally with duplication of the production of components providing redundancy in time of crisis.

Growing the workshare of Australian small and medium-sized enterprises that contribute items to existing offshore missile production chains—as in the JSF industry approach—has brought export success and developed local industry capability, but it won't meet the strategic need to have a reliable flow of missiles available during conflict. Only production—or co-production with existing international suppliers—here in Australia can achieve that. So far, this hasn't been done with weapons that Australia has acquired through cooperative arrangements with the US, but there are precedents for companies establishing production lines in other countries, such as the Israeli company Rafael's production of the Spike missile overseas. So, in principle, it can be done.

That brings us to the fourth approach to mitigating supply-chain risk: local manufacture.

THE VIABILITY OF LOCAL PRODUCTION

The government's 31 March media release announcing the acceleration of the guided weapons enterprise states that 'Australia's defence industry already has tremendous capability in the area of weapons technology … The Government is confident that this represents the necessary industry capability that will be transferrable to areas like guided weapons.' Is that an accurate assessment? It most likely is, particularly when we take into consideration 'missile-adjacent' industry sectors that the enterprise can draw upon.

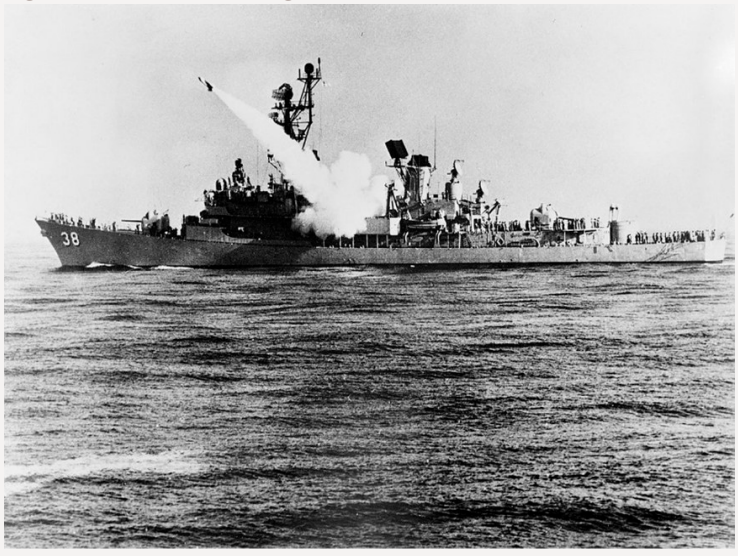
Australia's heritage of missile design and production

The local manufacture of guided weapons is a possibility raised in the DSU. In addition to increasing the weapons inventory, it states that the government has directed Defence to develop options to 'Explore the potential for a new sovereign guided weapons and explosive ordnance production capability to mitigate supply risks, especially for those munitions with long lead-times.' The FSP also contains a funding line of $0.8–1.1 billion titled 'Sovereign weapons manufacturing'.

The fundamental question is whether local production of guided weapons is viable. There's a perception that Australia hasn't produced guided weapons and has limited ability to do so. That's not the case. Australia has a long history of developing guided weapons, which have entered production and service. They've included:

- the Malkara anti-tank missile
- the Ikara anti-submarine missile, which carried a torpedo (Figure 6)
- JDAM-ER, an extended-range version of the JDAM GPS-guided glide bomb.[25]

Figure 6: HMAS *Perth* firing an Ikara antisubmarine missile



Source: Defence image library, online.

In addition, Australia has produced key missile-adjacent technologies such as air vehicles and sensors, including the Jindivik, which is a subsonic unmanned jet-propelled target plane.

Many of those weapons and systems were the result of extended research programs; the development of the JDAM-ER drew on glide bomb research stretching back to the 1970s, for example. Also, work in one program fed into subsequent programs. For example, the development of the Malkara informed that of the Ikara. Many of those technologies were exported and entered into service with other militaries.

Australia's current industrial capability

During the development of this report, several industry experts assessed that Australia currently has the ability to design and produce all components of missiles, with the exception of some kinds of seeker heads (i.e., the sensor in the tip of the missile that tracks the target).

Perhaps the most successful program is the ongoing Nulka project. This revolutionary decoy that protects ships against anti-ship missiles is essentially a hovering missile with an electronic warfare payload rather than a kinetic warhead (Figure 7). It's used extensively on Australian, US and Canadian warships.

Figure 7: The Nulka decoy

Source: BAE Systems, online.

The Nulka was developed by the Defence Science and Technology Group in cooperation with the US; Australia focused on the vehicle, while the US largely developed the payload.[26] The industry prime on Nulka is BAE Systems, although much of the early development was conducted in house by the Defence Science and Technology Organisation. The Nulka round is assembled and maintained at BAE's facility at Orchard Hills.

According to BAE Systems, 'Nulka is now Australia's largest defence export, having generated more than $1 billion in export revenue for our economy.' Its medium-term future has been secured through the government's recent announcement of a further five-year contract for production and in-service support.[27]

Another significant illustration of Australian industry capability is the ESSM program, which is being delivered through an international consortium. Australia participated in the first stage, Block 1, which is in service, and is also a key contributor to Block 2, which is nearing production. According to Defence:

> The ESSM Block 1 program commenced production in 2000 and has delivered more than 3000 missiles to the NATO SEASPARROW Consortium and third-party nations. The program has injected more than $400 million into Australia's Defence industry, with BAE Systems Australia leading the Australian industry contribution. The thrust vector controller, aerodynamic control fins, dorsal fins, guidance section units, as well as guidance and control algorithms were all delivered by Australian industry.

> The ESSM Block 2 program commenced initial production in 2019, and has already resulted in contracts valuing more than $100 million for Australian suppliers in development and early production work. Australian industry's contribution is expected to increase as the program progresses through full-rate production and support phases, and Defence will continue to negotiate to maximise Australian industry's involvement. Australian suppliers to the ESSM Block 2 program include BAE Systems Australia (thrust vector controller, missile fuselage, guidance section internal structure, and telemetry transmitter), L3Harris Micreo (Intermediate Frequency Receiver), Varley (complete missile and missile section containers), and Raytheon Australia (supplier management).[28]

While Australia didn't design or build the complete missile, many of the components listed above were designed by Australian companies and not simply manufactured under licence.

BAE has also designed a passive radio frequency (RF) sensor that's being integrated into the Norwegian Joint Strike Missile manufactured by Kongsberg. The sensor guides the missile onto an RF signature being emitted by the target. The sensor has entered full rate production for export.[29]

In August 2018, the government announced that it had selected the Rafael Spike LR2 missile for the LAND 400 armoured vehicles, and that the missiles would be assembled in Australia by Varley Rafael Australia (Figure 8).[30] In February 2020, Defence confirmed that the missile would also be acquired for dismounted troops under Project LAND 159.[31] Rafael, an Israeli company, has considerable experience in establishing the production of its weapons in other countries, such as Germany and India, involving the transfer of technology. Despite Defence's enthusiasm for the weapon, Varley Rafael Australia hasn't yet received a contract to produce missiles, so it's been unable to establish a local production line.

Figure 8: Rafael has established production lines for the Spike family of missiles overseas

Source: Euro Spike, online.

Other areas of Australian defence industry have latent capabilities to support the production of guided weapons in Australia. For example, Thales, which manages the Australian Government's munition facilities at Mulwala and Benalla through its Australian Munitions business, has considerable ability to manage energetics for missiles (that is, explosives and propellants).

The fourth industrial revolution and 'missile adjacent' technologies

Overall, Australia can produce most of the components for guided weapons, but that isn't the sum of our industrial capability. There are many other sectors that are relevant for missiles. I've noted that we're seeing a merging of guided weapons and drones. This means there are also clear synergies in the design and production of guided weapons and autonomous systems such as drones—the subsystems needed for drones are the same as those needed for guided weapons. They include guidance, autonomy and artificial intelligence, propulsion, sensors, and so on. An industrial ecosystem that can manufacture drones has many of the capabilities needed for guided weapons.

But there are synergies with other sectors beyond autonomous systems. The space sector uses the term 'space-adjacent' to refer to areas of technology that might not have been developed specifically for space applications but are relevant to and can be applied in the sector.[32] This is one of major enabling factors in Space 2.0 (that is, the sharply decreasing cost of space technologies), which is allowing new players to develop and market space capabilities.[33]

According to the Australian Space Agency, 'the 10 most common capabilities of space-adjacent firms are: precision machining and design; remote operation and automation; machinery and component manufacturing; R&D and manufacturing; advanced manufacturing and design; systems design and engineering; electronics manufacturing; network operation; engineering design, manufacturing and support; and major infrastructure delivery.'[34] The agency further notes that 'overlapping or transferable capabilities can lower barriers for organisations using their existing workforce to pivot into new opportunities in adjacent industries as they arise.'

The capabilities listed above are fundamental elements of the 'fourth industrial revolution'.[35] They provide Australia with an emerging 'ecosystem' of advanced modern manufacturing capability that provides not just 'space adjacent' but also many 'missile adjacent' technologies. Those technologies can be found in sectors that at first sight seem to have little in common with missiles. An example is the advanced technology used in the mining sector and provided by Australian companies—the requirement for robust, remote operations in difficult conditions is a key driver, along with the mining sector's rapid adoption of autonomy- and data-led operations.

The potential of these 'adjacent' sectors and the broader fourth industrial revolution for Australian industry is highlighted by Boeing Australia and its industry partners' success in the rapid design and test flight of Boeing's Airpower Teaming System (ATS), aka Loyal Wingman. While the development of manned combat aircraft has taken decades, the ATS has gone from the start of detailed design to successful flight in three years. The rapid progress of the ATS shows how the ecosystem of technologies that make up the fourth industrial revolution is bringing its transformative potential to the defence sector. Key elements of this are advanced digital design technologies that make use of 'digital twins' to test and fly a virtual version of the aircraft thousands of times, allowing problems to be identified and addressed well before it takes physical flight.

When we consider Australia's living history of guided weapons design and production and combine it with the broad ecosystem of missile-adjacent technologies, it's clear that we have many of the preconditions in place to embark upon a more robust, sovereign missile enterprise.

GUIDED WEAPONS AND THE GOVERNMENT'S DEFENCE INDUSTRY POLICY

There's significant local industry capability for the design and production of the systems necessary for guided weapons. However, that's not necessarily the result of deliberate government policy. In contrast to many areas of government where there are policy aspirations but a lack of resources to implement them, in the case of guided weapons we have the opposite problem: the government is willing to spend tens of billions on weapons, but there's been a lack of policy on whether it should be done in Australia and how to do it here most effectively.

The fundamental issue is that, while the government's broader industry policy theoretically supports the manufacture of guided weapons, it hasn't been an explicit policy. That's looking like it's changing, between the statements in the 2020 DSU and the government's recent announcement about accelerating the establishment of a sovereign guided weapons enterprise. So far, details are few, but the right explicit, directed policy and leadership from the government can orchestrate the tens of billions of dollars in Defence's current investment plan for weapons in ways that result in Australian production and co-production of at least some of the advanced missiles that the ADF requires. This would reduce strategic risk for Australia in a darkening regional environment, as well as being a positive contributor to our alliance with the US by providing alternative and more dispersed supply sources for our partners in times of crisis.

Supportive industry policy

Developing Australia's advanced manufacturing capability has taken on renewed urgency in government policy since the onset of the Covid-19 pandemic. On 1 October 2020, the government released *Make it happen: the Australian Government's modern manufacturing strategy.*[36] The strategy's vision is for Australia to be recognised as a high-quality and sustainable manufacturing nation that helps to deliver a strong, modern and resilient economy for all Australians. It has six priorities; one is defence and another is the adjacent sector of space.[37] One of the goals of the strategy is to develop greater resilience through:

- making supply chains more resilient to external shocks, including through a 'supply chain resilience initiative'
- supporting global market diversification.

As we've seen, domestic manufacture of guided weapons would support both of those measures.

In addition to its media release about accelerating a guided weapons enterprise, the government also released on 31 March the road map for the modern manufacturing strategy's defence sector. The simultaneous release suggests the two initiatives are closely related. While guided weapons aren't a priority per se, the road map highlights the range of existing cross-sector technologies that can be applied to defence manufacturing. It also highlights the need to 'scale up' defence manufacturing, which is something that the government's multidecade, multibillion-dollar acquisition plans for guided weapons have the potential to achieve, if properly implemented.[38]

While defence is one of the six priority areas in the modern manufacturing strategy, the defence sector effectively has a five-year head start due to the release of the government's Defence Industry Policy Statement as part of the 2016 Defence White Paper. Its policies and measures have been further articulated and developed in subsequent policy documents, including the 2018 Defence Export Strategy and the 2018 Defence Industry Capability Plan.[39]

Those later documents have reinforced the fundamental objective of the government's defence industry policy, which 'is to deliver the Defence capability necessary to achieve the strategy set out in the Defence White Paper, supported by an internationally competitive and innovative Australian defence industrial base'. Again, domestic manufacture of guided weapons would directly support that objective.

We've noted that the 2020 DSU and FSP direct Defence to remediate supply-chain risks for guided weapons, including by 'exploring the potential for a new sovereign guided weapons and explosive ordnance production capability to mitigate supply risks, especially for those munitions with long lead-times'.

There's further in-principle policy support for the domestic manufacture of guided weapons. In late 2020, the government made an important amendment to the value-for-money guidelines that govern public-sector purchasing. The guidelines, published by the Department of Finance, state that domestic economic benefit should be taken into account when assessing value for money. This includes 'developing Australian industry capabilities or industrial capacity'. One example of this provided in the guidelines is 'enhancing key industry sectors through the Department of Defence's Sovereign Industrial Capability Priorities'.[40]

The policy gap

There's certainly industry policy 'top cover' to support the production of guided weapons in Australia, but so far that hasn't translated into a more focused public policy describing how it will be done.

More details on the government's guided weapons enterprise will no doubt be forthcoming, but one policy gap should be remediated as soon as possible: despite the key role a flow of guided weapons plays in modern war fighting, domestic manufacture of guided weapons isn't one of 10 sovereign industrial capability priorities (SICPs), even the munitions and small arms SICP (Figure 9).[41] That SICP states that 'Australian industry must be able to manufacture propellants, munitions, ammunition and small arms.' Those aren't the kinds of guided weapons we've been discussing, and they're far from the new kinds of longer range strike weapons required by the government's 2020 DSU.[42]

Figure 9: The then Minister for Defence Industry, Christopher Pyne, launching the Defence Industrial Capability Plan at ASPI in April 2018; the plan's 10 SICPs didn't include guided weapons—a policy omission that should be rectified

Source: Defence image library, online.

Defence has been progressively releasing industry and implementation plans for the 10 SICPs. These are detailed, robust pieces of work that state what industry capabilities are required, set timelines to achieve them, and provide measures to realise those goals. An implementation plan for guided weapons could mobilise and direct tens of billions of dollars to grow Australia's advanced manufacturing capacity as well as to deliver essential military capability.

During the development of this report, Defence informed ASPI that it's 'reassessing the Sovereign Industrial Capability Priorities and considering additional Priorities with regard to capabilities identified in the 2020 FSP, including guided weapons'.[43] That would be a good thing.

THE NEED FOR AN ENTERPRISE-LEVEL APPROACH TO GUIDED WEAPONS

Good outcomes won't happen by themselves

The government has announced that it will establish a guided weapons enterprise. It's not yet clear what that will look like, but it does need to be fundamentally different from what has come before in Defence's approach to guided weapons.

Despite the unprecedented scale of the government's planned investment in guided weapons, Australia's substantial industrial capability in guided weapons and adjacent sectors, and the willingness of overseas partners to develop and build missiles and components here, the prospects for an Australian guided weapons industry are dim if Defence continues to do business the way it has. To fully realise the opportunities that the government's investment plan and its defence industry policy present, Defence needs to adopt an enterprise approach to guided weapons.

Let's use a fictional case study to illustrate this. As the threat posed by unidentified flying objects (UFOs) rises dramatically, the ADF's platforms will require anti-UFO missiles. As an outcome of its force design process, Defence has programmed several new projects across the 2020s and 2030s to acquire anti-UFO capabilities for the ADF. That includes weapons for fast jets, maritime patrol aircraft, the Loyal Wingman UAV, large surface combatants, an enhanced, up-gunned offshore patrol vessel fleet, and short- and medium-range ground-based UFO defences. Since so many different kinds of platforms across the ADF will require anti-UFO missiles, Defence could eventually acquire several thousand weapons.

Despite the economies of scale that demand generates and the strategic need for the weapons, Defence's traditional process won't necessarily lead to domestic manufacture and greater sovereign military and industrial capability. Generally, weapons have been selected by platform projects to suit their own requirements, schedules, risk appetites and budgets. Commonality across the services has generally not been a consideration, in large part because the services have sought to deliver different effects and faced different threats.[44] Moreover, Defence is loath to make decisions about weapons in advance of acquiring the platforms that the weapons are to be integrated into.

There are several reasons for this. One is that Defence has historically liked to conduct competitions for individual weapons in the belief that such competitions preserve its commercial leverage. Another is that weapons are generally seen as secondary to the platform itself; getting the decision right on the platform is the higher priority, and it's assumed that weapons will fall into place once that's done. And, finally, there's a view that Defence will be able to find what it needs whenever it goes to the market.

While there's some validity to each of those arguments, overall they're inconsistent with the government's defence industry policy, the importance of guided weapons in modern warfare and the inability of the international weapons market to respond rapidly in times of crisis.[45] That approach exposes us to the risks that were so brutally realised at the onset of the Covid-19 crisis.

In our hypothetical example, an established missile producer might have a suitable anti-UFO weapon for maritime platforms. With sufficient R&D investment, that weapon also has the potential for land and air launch. It could also be developed into a family of weapons for short- and long-range uses. Australian industry could not only be involved in the assembly of the missiles and the production of their components, but also in the R&D effort to develop them for multiple platforms and to evolve their performance over time.

However, establishing a production facility and R&D partnerships with Australian companies and universities takes time and money. The potential manufacturer needs an early commitment that it can invest in developing those facilities and relationships. If it doesn't get that signal, it won't invest, even though those start-up costs could be a relatively small part of the overall acquisition cost. Without that early investment, a locally produced weapon won't be ready when the platform is. Consequently, it will be tempting for a platform project to simply buy off the shelf from overseas, particularly if the project itself is responsible for absorbing the cost and risk of establishing domestic production.

This process will be repeated by subsequent projects, with the result that:

- each platform will acquire a different missile
- each missile type will be bought off the shelf overseas
- Australian industry won't develop the capability to design and manufacture missiles and their components
- FIC overheads, such as sustainment pipelines, will multiply
- in the event of a UFO invasion of Australia, we'll be dependent on the supply of anti-UFO missiles from allies who are likely to also be combating a UFO invasion.

Precedents for enterprise-level approaches

An alternative strategy would be to adopt a more strategic enterprise-level approach. Defence has several successful precedents for enterprise approaches to industry capability. For example, in October 2017, the government announced that all RAN vessels would use Saab's combat management system where Aegis was not required. The announcement highlighted the weaknesses of previous, disjointed approaches:

> In the past, Defence has taken the tendered combat management systems individually, which has meant that the Navy has operated numerous systems at the same time. This has not allowed defence industry to strategically invest for the long-term and has also increased the cost of training, maintenance and repair.[46]

If the 'in the past' approach sounds like the hypothetical case study above, that's because it's often been the reality of Defence's acquisition philosophy. In contrast, the new, enterprise-level approach 'guarantees the development of a long-term sustainable Australian Combat Management System industry, which is integral to the implementation of the Government's Naval Shipbuilding Plan'.

Similarly, the government's decision that the Hunter-class future frigate would use the weapons already in service with the RAN provides certainty about the natures of weapons that will be acquired and used. The choice of CEA Technologies' phased-array radar on the Hunter class is another enterprise-level approach. This has been supported by R&D agreements between CEA and Defence Science and Technology as well as a $90 million loan agreement awarded under the Defence Export Facility to finance a new manufacturing facility to supply both export and ADF demand.[47]

The Navy's approach to guided weapons has also adopted elements of an enterprise approach. After the success of the ESSM Block 1 program, it entered into the Block 2 program without conducting a competition, even though there were other, mature short-range air-defence missiles on the market such as Sea Ceptor, which other Western navies had selected. That, however, hasn't led to local production.

In fact, the government's Naval Shipbuilding Program is itself described as an enterprise. There, the government has made decisions that represent in-principle commitments that will last for decades and will govern the kinds of ships that will be produced, the designs that will be used, the number of ships and the rate of production. While many key details will only be worked out and agreed over time, the enterprise approach provides Defence's industry partners with confidence to invest, train, recruit and build.

A guided weapons enterprise

Due to the scale of investment in guided weapons, involving potentially tens of billions being spent in Australia, an enterprise-level approach similar to that used in shipbuilding is warranted. The Australian Government has announced it will adopt an enterprise approach to guided weapons but given few details of what that will look like. Elements of that approach could include the following:

- Appoint an SES Band 2 public servant or a two-star ADF officer to coordinate the selection of guided weapons, including developing recommendations about which ones should be produced locally, to ensure that all factors are considered, not just individual project or service priorities (the Australian Government's recent announcement has made a start in this direction by nominating Defence's Chief of Joint Capabilities as the capability manager for the guided weapons enterprise).
- Manage the missile matrix to identify weapons or families of weapons that can be used on multiple platforms to reduce the proliferation of new types of weapon.
- Actively seek co-production partnerships with existing weapon suppliers to the ADF to produce high-priority weapons in country.
- Set ambitious targets to commence local production within two years in order to meet the urgency of our strategic environment.
- Support guided weapons precincts, located to take advantage of synergies with existing industry capability and missile-adjacent capability to create hotspots for innovation.
- Organise loans to establish production facilities.
- Establish a guided weapons 'college' modelled on the Naval Shipbuilding College.[48] It would begin as a virtual college that analyses workforce demand, identifies skills gaps, assesses current educational offerings and gaps, develops solutions with partners in the training and education sector to fill those gaps, and matches workers with employers.
- Increase and prioritise R&D funding for guided weapons technologies through Defence's two innovation funds: the Next Generation Technologies Fund and the Innovation Hub.[49]

Backing winners

Whatever criteria Defence uses for selecting guided weapons, it will consciously need to reduce as far as possible the number of different types of weapons it uses. This will generate many benefits: economies of scale in production; reduced duplication in sustainment systems and logistics trains; reduced duplication of test and evaluation requirements; the ability to share weapons across platforms; the ability to share tactics, techniques and procedures across platforms; and so on. The bottom line is that discipline in weapons selection will mean Defence can acquire more weapons of fewer types.

But to achieve those benefits Defence must take a top-down, programmatic approach to the selection of weapons in which the broader business case is weighed up. That may require picking winners in advance and declaring that, if we already have a weapon in our inventory that's good at prosecuting particular categories of target, all platforms will have to use it.

Defence has already taken steps in that direction, for example by choosing a solution to the Army's short-range air-defence requirement that uses missiles already in the Air Force's inventory, but this needs to be applied rigorously as a guiding principle.

Embarking on this course will be uncomfortable for some in Defence (not to mention the Treasury and the Department of Finance) because it involves picking winners up front, rather than competing every weapon on every platform, which could present commercial risks. But, in the light of the enterprise-level benefits it will deliver, backing proven winners up front makes sense.

What's the role of the strategic industry partner?

One detail that the government has released about its guided weapons enterprise is that it will 'select an experienced strategic industry partner to build a sovereign capability to manufacture a suite of precision weapons that will meet Australia's growing needs and provide export opportunities as a second source of supply'. The government further noted that 'we will work closely with the United States on this important initiative to ensure that we understand how our enterprise can best support both Australia's needs and the growing needs of our most important military partner.'[50]

Working with a strategic industry partner is consistent with the recommendations of the First Principles Review of Defence, which were accepted by the government and which Defence has implemented. What can we deduce from that about the role of the partner in the guided weapons enterprise? First, it appears that the partner will produce weapons used by both Australia and the US. That's pretty reasonable—most of the guided weapons used by Australia are designed and manufactured in the US and used by the US armed forces.

But is the role of the strategic partner to coordinate the production of other companies' weapons here in Australia? Or is the government planning to build only that partner's weapons here? Both approaches raise potential concerns.

If it's the former, it's not necessarily the case that another company would let the strategic partner produce its missiles here under licence. Missile companies are very protective of their intellectual property. That other company might produce its weapons in Australia only if it could do so itself, so that approach runs the risk of artificially limiting the weapons Australia could produce.

If the role operates under the latter concept (that is, the 'suite' of weapons that the government will build here would consist only of its strategic partner's weapons), then that too will run the (almost inevitable) risk of limiting the weapons Australia could produce. In fact, the only company with a portfolio of weapons that comes close to meeting the ADF's requirements is Raytheon Missile Systems.[51] But producing only Raytheon's weapons means that some weapons that the ADF currently has or is acquiring wouldn't be produced here.[52]

As this study has argued, long-term partnerships with industry are essential to a successful enterprise-level approach, but the government should avoid approaches that exclude the possibility of local production of some high-priority weapons. Such approaches would undermine the ability of the guided weapons enterprise to reduce supply-chain risks.

Recommendation 1

The Department of Defence should adopt an enterprise-level approach to guided weapons that:

- considers all relevant capability and industry factors in the selection of weapons
- minimises as far as possible the number of new weapon types
- seeks to maximise economies of scale
- identifies weapon types that should be manufactured in Australia
- makes guided weapons a sovereign industrial capability priority
- supports industry to establish local weapon production
- does not limit local production to one company's offerings.

WHICH WINNERS SHOULD WE PICK?

The selection of weapons should be driven by an enterprise-level approach to guided weapons regardless of where they're made, but that approach also needs to present recommendations to the government on which weapons we need to build in Australia. As with all elements of defence spending, prioritisation is essential. We can't do everything here and shouldn't try, but Defence can determine what its highest priorities for domestic manufacture are.

So, which weapons should we build in Australia? There will certainly be a wide range of views on this. Here are some selection criteria to consider and an indicative, initial portfolio of weapons.

Seek economies of scale

Cottage production of boutique numbers of weapons is likely to come with large cost overheads. It will be more sustainable and economically viable to produce domestically where we can achieve economies of scale. As I've discussed, this can be supported by an enterprise-level approach to managing the missile matrix, in particular by selecting weapons that will be used by multiple platforms and families of weapons with significant commonalities.

Scale will also be achieved by producing the kinds of weapons that are likely to be used in large numbers in any future conflict. It's hard to predict how many weapons will be used in such a conflict (that's the key risk that we're seeking to mitigate through domestic production). History isn't necessarily the best way to assess this, since recent conflicts have involved adversaries without capable air defence systems. Western militaries have been able to use low-cost, direct-attack munitions; they haven't been forced to stand off and use more expensive weapons from long ranges. It's likely that larger numbers of the latter category will be required in conflicts with near-peer adversaries.

Nevertheless, low-cost—but still precise—weapons are likely to be used in any conflict because they can be used against a wide range of targets and adversaries using a wide range of platforms. Bolt-on kits such as the Joint Direct Attack Munition (JDAM; Figure 10) that affordably transform 'dumb' bombs into precision munitions fall into this category, as does the GBU-39 small diameter bomb.

That also appears to be Defence's view, as indicated by the RAAF's recent purchases, which suggest that it still assesses that it will continue to use large numbers of lower cost munitions. For example, in 2016, the US Defence Security Cooperation Agency notified Congress that Australia sought to acquire up to 2,950 small diameter bombs at a total cost of US$386 million.[53] That was followed in 2017 by the acquisition of up to 3,900 small diameter bombs at a total cost of $815 million.[54]

Figure 10: An RAAF armament technician with the Air Task Unit Strike Element loads a 500-lb JDAM bomb at Australia's main operating air base in the Middle East in 2016

Source: Defence image library, online.

Start with lower risk weapons

The government's 2020 DSU clearly articulates that we can no longer rely on lengthy warning times for future conflicts. Therefore, it's important that domestic manufacture produces capability quickly. It's likely that Australia will have to take a staged approach, starting with weapons that can be produced with lower risk. That would include:

- weapons that are mature and the production of which can be quickly established here under licence
- weapons that are relatively simple
- weapons for which Australia already participates in co-development programs and manufactures components
- weapons that are already integrated into ADF platforms.

Those weapons would involve working with an overseas partner with established products, but starting with lower risk weapons will help Australia develop industrial capability that can be used later to develop and produce indigenous weapons.

Seek greater sovereignty within the alliance

Australian production of US weapons offers value to our alliance partner while providing greater sovereign capability to Australia. There's strategic benefit to the US in having Australia as a capable, reliable source of advanced weapons in times of crisis and conflict. A single US-based production line poses risks to all customers, including the US; a second production line in Australia would increase capacity and redundancy. From the limited information available, it appears that the intent of the government guided weapons enterprise is to establish a second production line to meet both Australia's and the US's supply requirements.

The establishment of local production of US weapons is facilitated by US legislation that considers Australia to be part of the US national technology and industrial base (NTIB). It's true that Australia's inclusion in the NTIB hasn't yet realised the full potential either for Australia or the US that's inherent in the concept. Adherence to US International Traffic in Arms Regulations has acted as a form of inertia, hindering the greater industrial cooperation sought by the NTIB legislation.[55] That inertia has also been reinforced by members of Congress, who are anxious to avoid the

appearance of American jobs going overseas. Overcoming that is likely to need political engagement at the highest level, but there are benefits for both the US and Australia, and greater practical cooperation is entirely consistent with the reinvigoration of US alliances that we're seeing under the Biden administration.

Make some big bets

We shouldn't just take the safe path. We've seen that Australia has a long history of technological innovation, including developing revolutionary and world-leading defence capability. Australia should continue to place some big bets on emergent technologies that will have a disproportionate impact on war fighting. A big bet might not necessarily involve a lot of money, but rather a lot of imagination and faith in what Australian industry can achieve when working with the right international partners. That approach looks like it could pay off in the case of the Airpower Teaming System. Defence should be looking for similar possibilities with guided weapons.

Given the gap between where the ADF is now and where it needs to be, there's a need for rapid innovation. Hypersonic weapons are certainly one bet that the government is pursuing, but it needs to ensure that success involves local production. Another is in antisubmarine warfare (ASW). In the light of the glaring risk of both of the Navy's main ASW platforms (the Collins-class submarine and the Anzac-class frigate) ageing out or becoming obsolete before they're replaced, Defence needs to get more ASW capability to sea quickly. Options include the development of an ASW weapon launched from ships' vertical launch system cells (a son of the Ikara) or even an unmanned loitering UAV delivering the Mk-54 torpedo responsively and at range.

A potential portfolio

Applying the principles listed in this report produces a portfolio of local weapons that looks something like the following:

- *Spike LR2 missiles.* The Spike LR2 has already been selected by the government for mounted and dismounted use, and Rafael Advanced Defense Systems has offered to build it in Australia. What's needed in the short term is a contract giving Rafael the certainty to invest in establishing local production. Mandating that it also be used on other ADF platforms, such as helicopters, UAVs and potential future small autonomous land and maritime platforms, would boost economies of scale, as would the selection of other variants of the Spike family of missiles for longer range applications.
- *A family of tactical loitering drones.* One example would be Defendtex's Drone 40. It's indigenously developed, well advanced and likely to be buoyed by export opportunities.
- *Air-delivered laser-guided bombs or JDAM class weapons.* Kits that can turn iron bombs into precision weapons are likely to be used extensively across the spectrum of combat operations. They'll be employed by current manned aircraft as well as future unmanned systems and are relatively simple to produce. Defence has a good understanding of the technology, having used such weapons extensively in Middle East operations. Moreover, Defence Science and Technology and its industry partners have been involved in the development and production of an extended-range variant of the JDAM.
- *Evolved Sea Sparrow Missile.* The ESSM is a higher value weapon, costing around $2.4 million, but in a high-end conflict it's also likely to be required in high volume. Australia is likely to require well over 500 missiles to fit out a surface combatant fleet based on the air warfare destroyers and the Hunter class. In a protracted conflict against a peer or near-peer adversary, the RAN will consume even larger numbers in protecting its surface combatants and their crews. Those numbers generate economies of scale. Furthermore, Australian industry has been deeply involved in the development and manufacture of key components of the weapon.
- *Hypersonics.* In contrast to the other weapons in this portfolio, hypersonic weapons are not mature and would be a big bet. However, Australia has already acknowledged the key role hypersonics will play in future conflict and entered into a cooperative agreement with the US to develop deployable hypersonic weapons (Figure 11). Due to their likely significance and consumption rate in future war fighting, we should also seek to manufacture them here. The business case to do that would be bolstered if we develop and manufacture a weapon or family of weapons that could be used across multiple platforms to prosecute a range of targets.

Figure 11: Test launch of a hypersonic missile at Woomera test range, May 2016

Source: Defence image library, online.

This portfolio (or one developed using the same criteria) would provide a balanced, low-risk path to guided weapons production, but it would not be the final step. There are other potential paths that Australia could explore, whether they involve the co-production of existing complex weapons under licence (such as the LRASM, SM-2, SM-6 or long-range ground-based missiles and rockets) or the indigenous development of new weapons. However, the successful establishment of an initial portfolio would help to build the local industrial capability necessary for those following steps.

If the government's strategic industry partner is going to manufacture only its own weapons here, then a portfolio such as this is incompatible with that concept. The government should ensure that the role it envisages for its partner doesn't limit the range of weapons it can produce here.

Don't wait for perfection

The key is to start soon. It's important to develop a SICP implementation plan for guided weapons, but we shouldn't wait until the perfect plan has been developed. Indeed, we don't need to. There are mature weapons for which the ADF has an identified requirement, and we don't need to build shipyards costing half a billion dollars before we can start.

Recommendation 2

Defence should seek the government's agreement to an initial portfolio of guided weapons that will be manufactured in Australia.

Production of these weapons should commence as soon as possible.

An indicative initial portfolio of high-priority weapons for local production would include:

- Spike LR2 missiles
- a family of tactical loitering drones
- air-delivered laser-guided bombs, JDAM-class weapons, or both
- the Evolved Sea Sparrow Missiles
- hypersonics.

APPENDIX 1: PREVIOUS AND CURRENT ADF GUIDED WEAPONS ACQUISITIONS

Table 1: Previous and current ADF guided weapons acquisitions

Project (where known)	Weapon	Expenditure	Notes	Date
	Harpoon missiles	$98.3 million (total approval)		
JP 1 Phase 1	Harpoon missile Block 2 upgrade	$32 million		
	Penguin missile	$172 million	Cancelled when Super Seasprite helicopter was cancelled as weapon; was not integrated into any other ADF platform.	
AIR 5398 Phase 1	AGM-142 Popeye / Have Nap air-to-surface missile	$450 million	After a long, difficult integration, the missiles were 'orphaned' with the retirement of the F-111.	
AIR 5400 phases 1/2/3	Air-to-air missiles	$440 million	Weapons for the F/A-18 A/B.	
AIR 5409 Phase 1	JDAM	$50 million	Acquired JDAM guided bombs.	
AIR 5418 Phase 1	JASSM	$284 million	Long-range strike weapon integrated onto the F/A-18 A/B; its future after the retirement of the classic Hornet is not yet clear.	
AIR 6000 Phase 3	Air-to-surface weapons and countermeasures	$822 million (approved funding; not yet spent)	Includes SDB I and II; LGB: JDAM for F-35A and Super Hornet.[a]	
AIR 6000 Phase 5	Air-to-air weapons for the new air combat capability	$911 million (approved funding; not yet spent)	Weapons for the F-35A and Super Hornet.	
JP 2090 phases 2 & 3	MU90 lightweight torpedo	$596 million	Originally planned for integration on FFG, Anzac, AP-3C, Super Seasprite and S-70B-2 Seahawk. Integration on all three air platforms was cancelled. Now used only on Anzac.	
FMS acquisition	Up to 4,002 M1156 precision guidance kits for 155-mm munitions[b]	US$54 million	GPS-guided fuse for 155-mm rounds.	2013
FMS acquisition	Up to 200 Mk 54 torpedoes[c]	US$169 million	Acquired for the MH-60R maritime combat helicopter.	2010
FMS acquisition	100 Mk 54 torpedoes[d]	US$83 million	Acquired for the P-8A maritime patrol aircraft.	2013
FMS acquisition	Up to 110 AIM-120-C-7 AMRAAM[e]	US$202 million	Acquired for the Super Hornet.	2011

Project (where known)	Weapon	Expenditure	Notes	Date
FMS acquisition	Up to 70 AGM-88B HARM missiles & 40 AGM-88E AARGM[f]	US$137.6 million	Acquired for the Growler electronic attack aircraft.	2017
FMS acquisition	Up to 14 AGM-88B HARM missiles & 16 AGM-88E AARGM missiles	US$69 million	Platform not stated but presumably Growler.	2015
FMS acquisition	Up to 200 AGM-158C LRASM	US$990 million	To be acquired for Super Hornet.	2020
FMS acquisition	17 SM-2 Block IIIB telemetry missiles[g]	US$46 million	Test firings for the air warfare destroyers.	2010
LAND 40 Phase 1	Javelin missiles	$135 million	Initial acquisition of Javelin for dismounted troops.	
FMS acquisition	200 Javelin FGM-148E missiles[h]	US$46 million	To 'fill a short-term short-fall in … inventory'.	2020
FMS acquisition	Up to 80 SM-2 Block IIIB missiles[i]	US$301 million	Acquired for the air warfare destroyers.	2016
FMS acquisition	Up to 108 AIM-120C-7 AMRAAM missiles[j]	US$240.5 million	Acquired for LAND 19 Phase 7B ground-based air defence project.	2019
FMS acquisition	Up to 2,950 GBU-39/B small diameter bomb I[k]	US$386 million	Acquired for the F-35A.	2016
FMS acquisition	Up to 3,900 GBU-53/B small diameter bomb increment II[l]	US$815 million	Acquired for the F-35A.	2017
FMS acquisition	Up to 450 AIM-120 AMRAAM missiles[m]	US$1.22 billion	Acquired for the Super Hornet, Growler and F-35A.	2016
FMS acquisition	Up to 350 AIM-9X-2 Sidewinder tactical missiles[n]	US$534 million	Acquired for Hornet, Super Hornet and F-35A.	2014
SEA 1229 Phase 2/4	Nulka active missile decoy	$193 million		
SEA 1397 Phase 5A	Nulka war stock replenishment	$86 million		
SEA 1397 Phase 5C	Nulka enhancements	$174 million (total approval)		
SEA 1348 Phase 3	Harpoon	$156 million	Harpoon missile launch capability for the Anzac frigates.	
SEA 1352 Phase 1	ESSM Block 2	Total approval in 2016–17 was $396 million, before approval to acquire missiles		
SEA 1390 Phase 4A/4B	SM-2	$356 million	Replacement of SM-1 on the FFG class	
SEA 1428 phases 2A/2B/3/4	Evolved Sea Sparrow Missile	$695 million		
SEA 1429 Phase 2	Mk-48 heavyweight torpedo	$338 million	Heavyweight torpedo for the Collins-class submarine.	
SEA 4000 Phase 3.2	SM-2 conversion and upgrade	$112 million total approval	Converted existing SM-2 stocks for use on the air warfare destroyers.	

a Andrew McLaughlin, 'AIR 6000 Phase 3 weapons project announced', ASBR, 16 April 2019, online.

b Defense Security Cooperation Agency (DSCA), 'The Government of Australia—Munitions', news release, US Government, 12 August 2013, online.

c DSCA, 'Australia—MK 54 lightweight torpedoes', news release, US Government, 4 October 2010, online.

d DSCA, 'Australia—MK 54 lightweight torpedoes', news release, US Government, 2 July 2013, online.

e DSCA, 'Australia—AIM-120C-7 advanced medium range air-to-air missiles', news release, US Government, 2 June 2011, online.

f DSCA, 'Government of Australia—Anti-radiation missiles', news release, US Government, 28 April 2017, online.

g DSCA, 'Australia—SM-2 Block IIIB standard missiles', news release, US Government, 26 October 2010, online.
h DSCA, 'Australia—Javelin missiles', news release, US Government, 30 October 2020, online.
i DSCA, 'Australia—SM-2 Block IIIB standard missiles', news release, US Government, 31 May 2016, online.
j DSCA, 'Australia—AIM-120C-7 advanced medium-range air-to-air missiles', news release, US Government, 13 March 2019, online.
k DSCA, 'Australia—GBU-39 (small diameter bomb increment I)', news release, US Government, 6 April 2015, online.
l DSCA, 'Australia—GBU-53/B small diameter bomb increment II (SDB II)', news release, US Government, 2 October 2017, online.
m DSCA, 'Australia—AIM-120D advanced medium-range air-to-air missiles', news release, US Government, 25 April 2016, online.
n DSCA, 'Australia—AIM 9X-2 Sidewinder missiles', news release, US Government, 13 May 2014, online.

APPENDIX 2: THE MISSILE MATRIX

- Green weapons are in ADF service.
- Blue weapons have been announced by the government but are not yet in service.
- Red weapons are potential future options.

This table is not comprehensive. There are, for example, other weapons that could be modified to be suitable for use on ADF platforms.

Target class→ Launch platform↓	Surface ships	Submarines	Small vessels	Cruise missiles	Aircraft	Ballistic missiles	Long-range land strike	Armoured vehicles / bunkers / buildings
Surface ships	• Harpoon • SM-2 • SM-6 • LRASM • NSM • Tomahawk Block V • Hypersonics	• MU90 torpedo • Mk 54 torpedo • Vertical launch anti-submarine missile	• ESSM	• ESSM • SM-2 • SM-6	• ESSM • SM-2 • SM-6	• SM-6 • SM-3	• Harpoon • TLAM • NSM • Hypersonics	
Submarines	• Mk-48 torpedo • Harpoon • LRASM • NSM • Tomahawk Block V	• Mk-48 torpedo			• IDAS		• Harpoon • TLAM • NSM	
Super Hornet	• Harpoon • JSOW • LRASM		• LGB • SDB		• AIM-9X • AIM-120 AMRAAM		• JASSM	• JSOW • JDAM • LGB • SDB
F-35A	• NSM • LRASM		• LGB • SDB		• AIM-9X • AIM-120 AMRAAM		• JSM • JASSM	• JSOW • LGB • JDAM • SDB
Sky Guardian UAS			• Spike • Brimstone		• AIM-92 Stinger • AIM-9X			• Hellfire • LGB • JDAM • SDB • Spike • Brimstone
P-8A maritime patrol aircraft	• Harpoon • LRASM	• Mk 54 torpedo	• LGB • SDB				• Harpoon • Other options	

Target class→ Launch platform↓	Surface ships	Submarines	Small vessels	Cruise missiles	Aircraft	Ballistic missiles	Long-range land strike	Armoured vehicles / bunkers / buildings
MH-60R maritime combat helicopter		• Mk 54 torpedo	• Hellfire • 70mm guided rockets					
Attack helicopters			• Hellfire • 70mm guided rockets • Spike		• AIM-9X • Other options			• Hellfire • Spike • Brimstone
Land-based long-range fires	• Harpoon • LRASM • JSM						• HIMARS • ATACMS • TLAM • Precision Strike Missile • Hypersonics	
Ground-based air defence				• RBS-70 • AIM-9X • AIM-120 AMRAAM • Patriot • Other options	• RBS-70 • AIM-9X • AIM-120 AMRAAM • Patriot • Other options			
Ground-based BMD						• Patriot • THAAD • SM-3/Aegis Ashore		
Land vehicles								• Spike • Other options, e.g. loitering munitions
Infantry								• Javelin • Spike • Other options, e.g. loitering munitions

NOTES

1 Department of Defence (DoD), *2020 Defence Strategic Update*, Australian Government, 2020, online.

2 Scott Morrison, Peter Dutton, Melissa Price, Christian Porter, 'Morrison government accelerates sovereign guided weapons manufacturing', media release, 31 March 2021, online.

3 Benjamin S Lambeth, *NATO's air war for Kosovo*, RAND Corporation, Santa Monica, 2001, 88, online.

4 Lambeth, *NATO's air war for Kosovo*, 88.

5 T Michael Moseley, *Operation Iraqi Freedom—by the numbers*, US Air Force, 2003, 11, online.

6 These include US Navy concepts such as 'distributed maritime operations', 'littoral operations in a contested environment' and 'expeditionary advanced base operations' and the 38th commandant of the US Marine Corps' intent.

7 Joseph Trevithick, 'Ship-launched version of the Israeli Harop suicide drone will be sailing with an Asian navy', *The Drive,* 3 February 2021, online.

8 While Israel has sought to address this threat by improving the defensive countermeasures on its vehicles, it has also developed its precision strike capabilities in order to avoid having to put troops on the ground in the first place.

9 See Joseph Trevithick, 'British troops get small swarming drones they can fire from 40mm grenade launchers', *The Warzone,* 3 February 2021, online; N Leigh, 'British Army deploying Australian 40mm drone in Mali', *OvertDefence*, 2 February 2021, online. The drone is Defendtex's Drone 40; 'UAV: Defendtex unmanned aerial vehicles', Defendtex, no date, online.

10 The stages of the kill chain are often defined as find, fix, track, target, engage and assess. Negating one link in this chain can render an attack ineffective. There are kinetic and non-kinetic (such as hiding from or jamming a weapon) ways to do this, but guided weapons are likely to have utility in disrupting every link.

11 Stockholm International Peace Research Institute importer/exporter TIV tables, online.

12 The commandant of the US Marine Corps stated that 'we are witnessing the emergence of an era of missile warfare' and that the Corps needs to fundamentally change its balance of capabilities and its operating concepts in order to function successfully in that era. David H Berger, '38th Commandant's planning guidance', US Marine Corps, 2019, online.

13 DoD, *2020 Force Structure Plan*, Australian Government, 2020, online.

14 Whether any number of missiles can successfully defend warships against the combination of threats they will face now and in the near future is a separate issue. The combination of the ESSM, SM-2 and SM-6 is likely to have limited if any utility against hypersonic anti-ship missiles. See Andrew Davies, *Coming ready or not: hypersonic weapons,* ASPI, Canberra, 2021, online. That said, hard-kill defence measures are only one part of a layered defence that seeks to disrupt multiple links of the kill chain, so longer range strike missiles will also have a key role to play in protecting ships by destroying hostile launch platforms before they launch. That adds further urgency to the 2020 DSU's call for 'a different set of capabilities' to move the ADF beyond being a 'largely defensive force'. Missiles will play a key role in shifting the ADF's focus from defence to offence.

15 Between them, LAND 400 phases 2 and 3 are scoped to acquire around 660 vehicles, but not all will be variants equipped with turrets with missile launchers.

16 DoD, *Portfolio Additional Estimates Statements 2020–21, Defence portfolio,* Australian Government 2021, Table 67, online. There's no way to tell from the PAES how much of this is to be spent on guided versus unguided ordnance, how much is for 'top up' buys of weapons stocks, and how much is for the maintenance of existing stocks.

17 There are now nine fundamental inputs to capability (FICs): organisation; command and management; personnel; collective training; major systems; facilities and training areas; supplies; support; and industry. They're described in the DoD's *Capability life cycle manual* (version 2.1), 2020, online.

18 The long saga of the MU90 acquisition is unpacked in two Australian National Audit Office reports: *Lightweight Torpedo Replacement Project,* report no. 37 of 2009–10, online; *Remediation of the Lightweight Torpedo Replacement Project,* report no. 26 of 2012–13, online. Considering that a frigate is likely to have been sunk by a submarine before it can get close enough to use its lightweight torpedo and that the weapon wasn't successfully integrated onto any aircraft, one can wonder whether the project's $600 million expenditure was worth it.

19 And one that will be consigned to history when the Australian Tiger is replaced by the Apache in the middle of this decade.

20 Linda Reynolds, 'Long-range strike capabilities to maintain regional security', media release, 1 July 2020, online.

21 DoD, *2020 Force Structure Plan,* 82.

22 DoD, *2020 Defence Strategic Update,* 33.

23 DoD, *2020 Force Structure Plan,* 82.

24 Although outcomes have been mixed. There are cases in which those opportunities for various reasons have not resulted in actual Australian industry content.

25 For brief histories of these technologies, see the 'Our innovations' pages on the Defence Science and Technology website, online.

26 For a history of the long development process that produced the Nulka, see David Gambling, Mal Crozier, Don Northam, *Nulka: a compelling story,* Defence Science and Technology Organisation, Canberra, 2013, online.

27 Melissa Price, 'Australian defence industry to continue to sustain and export cutting edge technology', media release, 16 March 2021, online.

28 Email from Defence media, 19 February 2020.

29 BAE Systems, 'Australia to export sensor for Joint Strike Missile to Norway', news release, 22 October 2020, online. The development of the sensor was originally funded by Defence's Priority Industry Capability Program, the predecessor to its current industry R&D programs.

30 Marise Payne, 'Sharp spikes for Boxer', media release, 22 August 2018, online.

31 DoD, 'New long range weapon capability selected under the lethality system project (Land 159)', news release, 5 February 2020, online.

32 For example, in Australian Space Agency (ASA), *Economic snapshot of the Australian space sector: 2016–17 to 2018–19,* Australian Government, February 2021, online.

33 For an explanation of the term 'Space 2.0', see Malcom Davis, 'Space 2.0—why it matters for Australia's defence', *The Strategist,* 30 April 2018, online.

34 ASA, *Economic snapshot of the Australian space sector: 2016–17* to *2018–19,* 11.

35 On the implications of the fourth industrial revolution for defence, see Peter Layton, *Prototype warfare, innovation and the fourth industrial age,* Air Power Development Centre, Canberra, 2018, online.

36 Department of Industry, Science, Energy and Resources (DISER), *Make it happen: the Australian Government's modern manufacturing strategy,* Australian Government, 2020, online.

37 The government has now released road maps for all six of the priorities; online.

38 DISER, *Defence: national manufacturing priority road map,* Australian Government, 2021, online. The road map seems to be the first piece of defence industry policy that explicitly sets the creation of 'a larger number of medium-sized defence businesses' as a goal; that is, changing the current landscape from consisting primarily of a small number of very large international primes and a very large number of small enterprises.

39 DoD, *2016 Defence Industry Policy Statement,* Australian Government, 2016, online; DoD, *Defence Export Strategy,* Australian Government, 2018, online; DoD, *2018 Defence Industrial Capability Plan,* Australian Government, 2018, online.

40 Department of Finance, 'Consideration of broader economic benefits in procurement', Australian Government, August 2020, online.

41 DoD, *Sovereign Industrial Capability Priority Implementation Plan: munitions and small arms research, design, development and manufacture,* Australian Government, December 2019, online.

42 Interestingly, BAE's development of the passive RF sensor for the Joint Strike Missile was originally funded under the predecessor of the SICP program, Defence's Priority Industry Capability Program, in 2013.

43 Email from Defence media, 15 March 2021.

44 An exception has been LAND 19 Phase 7B, the Army's short-range air defence project, that obtained an early decision to use missiles already in service with the Air Force.

45 This final point runs directly against the intent of the Defence Industry Policy Statement, which declared industry to be a FIC, essentially giving Defence the obligation and mandate to actively create the industry landscape it requires, rather than sitting back and hoping industry will be able to supply it with what it wants.

46 Marise Payne, 'New approach to naval combat systems', media release, 3 October 2017, online.

47 Christopher Pyne, 'Advanced radar research agreement with CEA Technologies', media release, 1 March 2018, online; Melissa Price, 'Hundreds of jobs to flow from first Defence Export Facility loan', media release, 13 August 2019, online.

48 The functions of the Naval Shipbuilding College are outlined on its website, online.

49 Between them, these two innovation funds make up less than 0.5% of Defence's total budget. Defence has to do better in terms of R&D spending.

50 Morrison et al., 'Morrison government accelerates sovereign guided weapons manufacturing'.

51 Some of the current and planned ADF weapons manufactured by Raytheon include the AIM-9X and AMRAAM air-to-air missiles; the ESSM, SM-2 and SM-6 maritime air-defence missiles; and the Paveway laser-guided bomb. It's an extensive portfolio, but it won't cover all of the ADF's requirements.

52 Such as Lockheed Martin's LRASM, or Rafael's Spike LR2.

53 Defense Security Cooperation Agency (DSCA), 'Australia—GBU-39 (Small Diameter Bomb Increment I)', news release, US Government, 6 April 2016, online.

54 DSCA, 'Australia—GBU-53B Small Diameter Bomb Increment II (SDB II)', news release, US Government, 2 October 2017, online.

55 Heidi M Peters, *Defence primer: the national technology and industrial base,* Congressional Research Service, Washington DC, 3 February 2021, online; Brendan Thomas-Noone, *Ebbing opportunity: Australia and the US national technology and industrial base,* United States Studies Centre, Sydney University, 2019, online. The NTIB legislation is intended to draw on partner countries' industrial capability to deliver military capability to the US, so the case for Australian production of US missiles would likely be strengthened by emphasising that a second production line would benefit the US military in time of crisis.

ACRONYMS AND ABBREVIATIONS

ADF	Australian Defence Force
AMRAAM	AIM-120 Advanced Medium Range Air-to-Air Missile
ASW	antisubmarine warfare
ATACMS	MGM-140 Army Tactical Missile System
ATS	Airpower Teaming System
DSU	2020 Defence Strategic Update
ESSM	RIM-162 Evolved Sea Sparrow Missile
FIC	fundamental input to capability
FSP	2020 Force Structure Plan
Harpoon	AGM-84 Harpoon Anti-Ship Missile
HIMARS	M142 High Mobility Artillery Rocket System
JDAM	Joint Direct Attack Munition
JSF	Joint Strike Fighter
JSM	Joint Strike Missile
JSOW	AGM-154 Joint Stand-Off Weapon
LGB	laser guided bomb
LRASM	AGM-158C Long Range Anti-Ship Missile
NATO	North Atlantic Treaty Organization
NSM	Naval Strike Missile (closely related to the JSM)
NTIB	national technology and industrial base
R&D	research and development
RAAF	Royal Australian Air Force
RAN	Royal Australian Navy
RF	radio frequency
SDB	GBU-39/B Small Diameter Bomb and GBU-53/B Small Diameter Bomb II
SICP	sovereign industrial capability priority
SM-2	RIM-66 Standard Missile 2
SM-3	RIM-161 Standard Missile 3
SM-6	RIM-174 Standard Missile 6

THAAD	Terminal High Altitude Area Defense
TLAM	Tomahawk land attack missile
UAV	unmanned aerial vehicle
UFO	unidentified flying object

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