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AWD combat system

An upgrade for the Aegis

109

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Introduction

The Integrated Investment Program (IIP), released alongside the 2016 Defence White Paper in February 2016, lists planned ADF capability acquisitions and their expected costs. One of the more curious is the planned A$4–5 billion of combat system upgrades for the three air warfare destroyers (AWDs) between 2017 and 2028.[1] It's not unusual for warships to undergo significant upgrades during their operational lives, but those upgrades are typically life extension or modernisation efforts, and usually occur well into the second decade of service. In the case of the AWDs, Defence is planning to spend billions upgrading the combat systems of the warships during their first decade of service.

And it's not a minor upgrade. The expected cost of the AWDs is currently around A$9.1 billion, which would make the cost of the upgrades half of the cost of building the ships in the first place.

HMAS *Hobart* sits in the shiplift prior to the official launch ceremony, 23 May 2015. Photo courtesy Department of Defence.

Also, the 2014 audit of the AWD Program by the Australian National Audit Office (ANAO) reported that the expected cost for three Aegis combat systems was about A$1.27 billion as at December 2013.[2] That's about A$1.32 billion in 2015 dollars, or about A$440 million each. There's no explanation of the cost of the upgrades in the IIP or elsewhere.

The answer may be that the Aegis combat system has developed faster than the ships have been built. The AWD Program is more than two years behind schedule, and the combat system for the AWDs was ordered some 10 years ago. In the meantime, the US Navy has developed an improved version of the Aegis system for its own guided missile ships, and is now incorporating a later version in its own builds.

This paper examines the delivery of the AWDs and the combat system to date, and explores what upgrades might be possible in the stated period. Two points emerge. First, the IIP figures are likely to overestimate the cost. Second, delays in the AWD Program have resulted in platforms with inferior capabilities to those of their American-built contemporaries. Naturally, the RAN wants to upgrade the vessels to regain parity with the US Navy. Doing so will result in downtime for the newly commissioned fleet while the changes are implemented.

Given the delays, it's understandable that the RAN wants the AWDs in service as soon as possible. A substantial change to the combat system specifications this late in the build will have implications for cost and schedule. But installing the latest Aegis combat system before the vessels are commissioned, rather than upgrading them in 8–10 years, would equip the AWDs with the most up-to-date capability, avoid the need for an outage later (after the Adelaide-class FFGs are retired) and might even save money in the long run.

1. Background, cost and schedule of SEA 4000

SEA 4000 had its genesis in the 2000 Defence White Paper and 2001 Defence Capability Plan. Preliminary work on the project commenced in 2002 (Phase 1), with plans to start the design phase (Phase 2) in 2005 and the build phase (Phase 3) in 2007.

By May 2005, the project was approved for transition to Phase 2, and the Australian Government selected ASC Pty Ltd as the shipbuilder for the AWDs. Two designs were still on the table: the Spanish F-100 design by Navantia and a smaller version of the US Navy's Arleigh Burke-class destroyer designed by Gibbs and Cox.

The Spanish Navy had commissioned two F-100 (Alvaro de Bazan-class) frigates by 2004, whereas the modified Burke was an untested design. The F-105 (modified F-100) was formally selected as the lower-risk design in June 2007, and contracts were signed in October 2007.

Table 1: SEA 4000 acquisition phases

SEA 4000	Description
Phase 1	Preliminary design and build strategy
Phase 2	Design
Phase 3	Build
Phase 3.1[a]	Aegis acquisition
Phase 3.2	SM-2 missile upgrade
Phase 3.3	DDG test and evaluation
Phase 4	Cruise missile acquisition

a Integrated into Phase 3.

Sources: ANAO, *Air Warfare Destroyer Program*, audit report no. 22 of 2013–14.

Build phase

At the time of approval, the three vessels were scheduled to be completed by December 2014, March 2016 and June 2017, respectively, at a cumulative cost of around A$7.2 billion (2007 dollars).[3]

However, the build phase has endured multiple setbacks. Early in construction, several sections of the hull required substantial reworking after fabrication, leading to a 12-month delay. Further delays resulted from confusion over the design documentation, and some of the manufacturing was reallocated among the subcontractors.

The 2014 ANAO audit into the AWD Program found that Defence's risk mitigation activities prior to construction had been insufficient. This led to delayed construction, and productivity shortfalls blew out the cost of block construction by 60%.

At the time of writing, the delivery of the first vessel is expected to be about 30 months behind schedule, in June 2017. The second is due between June and September 2018 (27–30 months behind schedule), and the third between December 2019 and March 2020 (30–33 months late). Following a 'forensic audit' commissioned by the government, an additional $1.2 billion was approved in 2015 to complete construction, bringing the total cost of SEA 4000 Phase 3 (not including Phases 3.2 or 3.3) to A$9.1 billion (2016 dollars).[4]

Combat system

The Australian Government selected the Aegis combat system for the AWDs in August 2004, several months before SEA 4000 Phase 2 commenced. Both of the designs considered in Phase 2 were based on existing Aegis-equipped vessels, which it was hoped would reduce the technical risks associated with integrating the combat system.

In late 2005—more than a year before the design was to be selected—the future of the Aegis production line was cast in doubt. The US Navy's Arleigh Burke-class Flight IIA production was, at the time, scheduled to end with the delivery of the USS *Michael Murphy* in late 2010.[5] Flight IIA production was eventually restarted to compensate for the reduction in the number of Zumwalt-class (DDG-1000) destroyers to only three, and Flight III was conceived as an alternative to the next-generation guided missile cruiser (CG-X) Ticonderoga-class replacement program.

The Australian Government entered into a foreign military sales (FMS) contract in 2006 for three Aegis combat systems in order to avoid the expense of paying to reopen the Aegis production line at a later date. As a result, the combat system was spun off from Phase 3 into a new Phase 3.1. However, once Phase 3 commenced, spending on the combat system was recombined into Phase 3.

The future of the AWDs and Aegis

The Australian combat systems were ordered 10 years ago. And, rather than ending production of Aegis combat systems, the US Navy continued to develop the system for its new-build Aegis warships. As a result, the package ordered in 2006 and produced in 2009 is no longer state of the art and will be even further out of date by 2019–20 when the last AWD is delivered.

That probably explains why the RAN wants to upgrade the AWDs relatively early in their service. It's instructive to look at the state of Aegis-equipped vessels in service, particularly the modernisation upgrades to the combat system on US Navy vessels.

2. The global Aegis fleet

Aegis controls the ship's anti-air, anti-submarine, anti-surface, electronic warfare and ballistic missile defence (BMD) capabilities in a unified combat system. The key components of the system are the AN/SPY-1 air search radar, the command and control systems, the Mk 41 vertical-launch missile system (VLS) and the Standard Missile series of guided missiles (SM-2, SM-3, SM-6). The combat system also integrates with controls for the Phalanx close-in weapon system (a Gatling gun for defence against anti-ship missiles), Harpoon anti-ship missile launchers, torpedo launchers, the Tomahawk cruise missile control system, a naval artillery gun, and additional radars.

Global Aegis-equipped vessels

Globally, there are 103 active vessels equipped with Aegis, including 22 outside the US Navy.[6] Of the 103, 33 American vessels and 6 Japanese vessels are currently equipped with BMD capabilities, but the US Navy's destroyer modernisation program plans to increase that number substantially.[7] The US is also establishing Aegis Ashore sites (land-based facilities equipped specifically for BMD) in Romania and Poland.

Table 2: Complete list of Aegis-equipped vessels as at mid-2016

Class	Operator	Active / planned	BMD / planned	Aegis baseline	VLS cells
Arleigh Burke—Flight I/II	USA	28/28	28/28	5,9	90–96
Arleigh Burke—Flight IIA	USA	34/45	0/26	6,7	96
Arleigh Burke—Flight III	USA	0/22	–/22	9	96
Ticonderoga	USA	22/22	5/5	5,6,8,9	122
Kongō	Japan	4/4	4/4	4,5	90
Atago	Japan	2/4	2/4	7	96
Sejong the Great	South Korea	3/3	0/0	7	80
Alvaro de Bazan	Spain	5/5	0/0	5	48
Fridtjof Nansen	Norway	5/5	0/0	n.a.[a]	8
Hobart	Australia	0/3	–/0	8	48
Total		**103/141**	**39/74**	–	–

a Fridtjof Nansen-class frigates' Aegis baseline is not referenced anywhere. The class operates the unique SPY-1F radar and an 8-cell VLS with evolved Sea Sparrow missiles.

Sources: IISS, *The military balance 2016*; US Missile Defense Agency; US Navy Budget FY2017.

The first Aegis warship, commissioned in 1983, was the guided missile cruiser USS *Ticonderoga*. The equipment installed on new vessels was changed over time in periodic revisions called 'baselines'. New baselines included support for updated technologies, including better radars, improved missiles and new computer systems. For example, the first five Ticonderoga-class cruisers were Baseline 1, which didn't yet operate VLSs. Those five vessels were decommissioned between August 2004 and December 2005.

Vertical launch system

VLS capacity (Table 3) is measured in cells, and each cell houses one missile, with the exception of the 'quad-packed' evolved Sea Sparrow missiles (ESSMs). The SM-2 is the primary anti-aircraft missile, whereas the ESSM is a close-range defensive capability. The SM-6 is an evolution of the SM-2 and is being adapted to also be able to target surface vessels. The SM-3 is an anti-ballistic missile capability, equipped only on those Aegis vessels with BMD systems installed. SM-3 has a kinetic (hit-to-kill) rather than explosive warhead and exploits the weight and space saved to carry more fuel. Finally, the VL-ASROC is a vertical-launch vehicle for delivering an antisubmarine torpedo, and the Tomahawk is a long-range cruise missile for striking land targets.

Table 3: VLS-compatible missiles aboard Aegis vessels

Missile	Main role	Per cell	Range	Speed	Unit cost[a]
SM-2	Anti-air	1	>150 km	Mach 3	1.4 m
SM-6	Anti-air	1	>275 km	Mach 3.5	3.9 m
ESSM	Anti-air	4	>50 km	Mach 4	1.1 m
SM-3	BMD	1	<2,500 km	Mach 10+	14.5 m
VL-ASROC	Antisubmarine	1	<25 km	Subsonic	1.1 m
Tomahawk	Land attack	1	<1,500 km	Subsonic	1.1 m

a Unit cost in US$ FY2015.

Sources: US Navy budgets; US Missile Defense Agency budget; US Navy.mil fact sheets.

Cooperative engagement capability

Aegis Baseline 6 was installed on the first 12 Flight IIA Arleigh Burkes, commissioned between 2000 and 2003. It was the first to include cooperative engagement capability (CEC), which combines sensor data from multiple sources into a single, shared picture of tracked aerial threats.[8] This allows CEC-equipped vessels to fire missiles at aircraft or cruise missiles that don't appear on their own sensors. It's also useful in situations where multiple sensors can point at a target, reducing the effectiveness of adversaries' jamming or other electronic countermeasures.

CEC is a component of the US Navy plan for Naval Integrated Fire Control—Counter Air, a system to integrate sensors and weapons across air and sea platforms.[9] This will allow for further compatibility between Aegis vessels, Super Hornet and F-35 tactical aircraft, missiles, and airborne early warning aircraft such as the US Navy's E-2D Hawkeye (and possibly the RAAF's E-7A Wedgetail).[10]

Commercial computer technology

From Baseline 6, the Aegis system was hosted on a combination of commercial-off-the-shelf (COTS) and military specification (mil-spec) hardware. The use of COTS hardware reduces development costs and allows advances in commercial computing to be translated into additional capability.

The Arleigh Burke-class destroyer USS *Pinckney* was commissioned in 2004 and was the first to launch with Baseline 7, which is hosted entirely on COTS hardware. All Arleigh Burke-class destroyers commissioned between 2004 and 2012 currently operate Aegis Baseline 7.

Baseline 7 COTS Refresh 2, also known as Advanced Capability Build 8, was the first baseline to incorporate an open architecture computing environment. This version was ordered for the AWDs in 2006, and has since been renamed Baseline 8.[11] Seven Baseline 2 (commissioned between 1986 and 1989) Ticonderoga cruisers were upgraded to Baseline 8 between 2008 and late 2012.

Baseline 9 and ballistic missile defence

Baseline 9 is the newest Aegis revision, which is being installed on new-build Arleigh Burke destroyers and retrofitted to a number of older Arleigh Burke- and Ticonderoga-class vessels. In 2013, the USS *Chancellorsville*, a Ticonderoga cruiser, became the first vessel to field the upgrade. Baseline 9 is hosted on COTS hardware, and also embraces the US Navy's move to modular, open architecture computing, offering a more modular and cost-effective approach to capability.

Importantly, any vessel with Baseline 9 can be given a BMD capability via an optional module. Previous Aegis baselines had to have a parallel BMD capability integrated separately. And although the upgraded Ticonderoga cruisers will receive the BMD module, no SM-3s will be installed in any of them (except for the five ships that already have the missiles).

Baseline 9 also includes the multi-mission signal processor for integrated air and missile defence, which allows an Aegis-equipped ship to target aircraft and ballistic missiles simultaneously. Previously, the combat system could only target one or the other at any given time. At the time of writing, four Arleigh Burkes and three Ticonderogas have completed upgrades to Baseline 9.

The Japanese Atago-class destroyers are the only non-US Aegis vessels currently planned to receive Baseline 9, and it's likely that they'll field the 9C variant, since they are BMD-capable. The two planned new Atago-class destroyers are also likely to field Baseline 9 combat systems.

3. IIP combat system upgrade budget

The IIP includes a provision for A$4–5 billion worth of upgrades to the AWD combat system between 2017 and 2028. Unhelpfully, the IIP doesn't describe what these upgrades are likely to be. But Aegis is a US Navy combat system and the US Department of Defense is much more transparent and accountable about its budgets and future plans. As a result, it's possible to reverse-engineer (based on planned upgrades for US Navy Aegis vessels) what upgrades might be available to Australia's AWDs out to 2028.

US Navy upgrades

The US Navy is modernising its entire fleet of Aegis vessels, and began with the upgrade to Baseline 8 of seven Ticonderoga-class cruisers. The Arleigh Burke-class modernisation program has completed Baseline 9 upgrades on four vessels to date, and a fifth is due to return to service later in 2016. The first upgraded Baseline 9 cruiser, USS *Chancellorsville*, returned to service in April 2013, and two more have been completed since. Current plans include Aegis upgrades for two cruisers in each of 2018–19 and 2021–22, with a view of upgrading at least 11 of the remaining 12 vessels.[12]

Hull, mechanical and electrical modernisations are planned for up to 59 of the 62 Arleigh Burke vessels commissioned to date. Combat system upgrades are less ubiquitous: about 35 appear to have been planned at present, 22 of which are either completed or scheduled for completion by 2026. This is especially important for Baseline 6 and 7 Flight IIA vessels, which don't have pre-existing BMD capabilities. Those that don't receive combat system upgrades will continue to lack BMD.

Table 4 shows the unit costs of most of the upgrades taking place on the US Navy's Aegis ships. Hull, mechanical and electrical upgrades are excluded, as they are customised to the hull type rather than the combat system. The highlighted cells are those that appear likely to characterise an upgrade from Baseline 8 to 9. They include an upgrade to the weapon system, features not included in Baseline 8 upgrades, and the SQQ-89A antisubmarine warfare system that's being installed on several (but not all) Baseline 9 ships.

Table 4: US Navy Aegis ship upgrades (FY2015 US$ million)

Upgrade	Ticonderoga BL2 – BL8	Ticonderoga BL3 – BL9	Burke Flt I BL4 – BL9
Aegis weapon system	44.7	44.6	45.0
Mk 160 gun mod			4.1
Multi-mission signal processor		22.9	18.3
Multi-mission SSA/CWI		1.2	1.0
SPY-1 B/D transmitter upgrade		10.7	4.6
Multi-mission BMD capability		1.6	1.7
VLS upgrades	11.6	14.5	6.5
CEC	7.2	7.0	6.7
Mk 34 GWS upgrade	9.1	8.9	
SPQ-9B upgrade	8.8	8.5	
SQQ-89A (V15)		19.5	12.6
Total	**81.4**	**139.3**	**100.5**

Sources: US Navy budgets, 'Other Procurement, Navy'.

Atago upgrades

The upgrades for the Japanese Atago-class destroyers aren't documented to anywhere near the extent of the US Navy's upgrades. However, an FMS deal approved in December 2012 included up to US$421 million worth of equipment upgrades, parts, training and logistical support for the two Atago destroyers.[13] US Department of Defense contract listings for Atago upgrades total about US$250 million since 2013 (2013: US$65.0 million, US$29.5 million; 2014: US$53.6 million; 2015: US$69.7 million; 2016: US$33.1 million).[14]

We can estimate the upgrade cost to Japan because we know that Australia recently signed an FMS contract for US$275 million to sustain the combat systems for the AWDs, or about US$91.6 million each. The same services for two Atago-class ships would total US$183 million and, combined with the US$250 million, total US$433 million—not far off the 2012 FMS total figure, adjusted for inflation (US$440 million). This would suggest that it's expected to cost about $125 million per vessel to modernise the two Atago-class vessels, with an upgrade from Aegis Baseline 7 to Baseline 9 including BMD—a number comparable to the American costs shown in Table 4.

US Navy's new radar

A final potential upgrade for the AWDs could be a transition to the next-generation Aegis radar. There would be a capability gain in doing so but, for reasons explained below, it doesn't seem likely. The AN/SPY-6 air and missile defence radar (AMDR) is an 'active electronically scanned array' radar, unlike the passive electronically scanned array AN/SPY-1 as fitted to the three Hobart-class vessels under construction. Current US Navy procurement plans account for up to 22 AMDRs for the Flight III Arleigh Burkes. The AMDR is designed to be a modular and scalable, and the US Navy is installing a 14-foot wide version of the radar on the Flight III Burkes.

But it seems unlikely that the 7,000 tonne Hobart-class vessels could accommodate the new radar systems. For two main reasons, there are no plans to retrofit the radar to earlier Arleigh Burkes. First, it requires twice the power of the AN/SPY-1. The earlier Burkes have three 3 MW generators for hotel load and electrical systems, while the Flight III Burkes will have three 4 MW generators to compensate for the increased electrical requirements.[15] Greater power generation requires more cooling capacity and higher voltage cabling, and the radar itself needs more cooling as well.

Second, the AN/SPY-6 array is significantly heavier than the AN/SPY-1, and the Flight III Burkes will have design adjustments to compensate for the increased weight. Installation on an earlier Arleigh Burke would raise the centre of gravity, which could compromise vessel stability. The US Navy therefore decided to mount the new radar only on new purpose-built vessels rather than retrofit earlier vessels. The expected cost of each AN/SPY-6 is about $209 million. Further costs for installation would make the new radar an expensive upgrade for existing vessels even if no changes to the vessel's structure needed to be made.

As well as the difficulties of accommodating the power requirements of the new radar, a Hobart-class AWD is about 25% smaller than an Arleigh Burke Flight II, making the installation of AMDR on an AWD unlikely.

Total expenses

In March, Lockheed Martin began integration and testing of a Baseline 8 Aegis combat system into HMAS *Hobart*. The only conceivable upgrades available to the AWD combat system between now and 2028 are Baseline 9 upgrades, possibly including BMD and integrated air and missile defence capabilities, and a radar upgrade.

Even the US Navy, which is the lead customer for Aegis, appears to have only relatively minor upgrades planned for its existing Aegis vessels—the most significant of which is adding BMD to some vessels. The Arleigh Burke modernisation plan has a schedule that extends out to at least 2026, including incremental technology updates, and those technology updates are already included in the US$275 million AWD sustainment FMS deal of April 2016.

As far as we know, Australia's plans for the AWDs don't currently include BMD capabilities, but there will be likely to be additional, unique expenses associated with upgrades to the Australian warships. There will also be additional costs associated with the test and evaluation of the upgraded combat systems, but the hardware costs are interesting nonetheless.

To obtain a conservative estimate for the cost of upgrading the AWD's combat system, we added the total cost of all of the known hardware and computer upgrades planned for other Aegis vessels. That's not realistic, but it provides an upper bound for the total cost of the AWD combat system upgrades (Table 5).

Table 5: Possible AWD upgrades

Upgrade type	Vessel type	US$ per unit
Baseline upgrade + BMD	Atago (Baseline 7–9)	125.0
AN/SPY-6 radar	Arleigh Burke Flight III	209.0
Sustainment	Hobart AWD	91.6
Total (US$)		425.6
Total (A$)		575.3
AWD × 3 total (A$)		1,725.9

The estimated cost for full upgrades to all three AWDs, comprising Baseline 9, BMD capabilities and a new radar (excluding installation costs), would be just over A$1.7 billion. That's A$2.3 billion short of the *lower* figure stated in the IIP. We hope this doesn't mean that the Australian Government expects to spend another A$750–1,100 million per ship for installation, testing and evaluation of the improved combat system. That would be as much as a third again what it cost to build them in the first place—and they are already expensive examples of the type.

Conclusion

We're about to spend a lot of money completing the current three AWDs, only to turn around and spend a lot more money upgrading them. If the government wants to spend A$4–5 billion on improving naval capability over the next 12 years, there might be more useful ways to spend the money.

For example, a new-build Arleigh Burke Flight IIA costs about US$1.5 billion (A$2 billion), and a Flight III is expected to cost US$1.75 billion (A$2.37 billion).[16] The first Flight IIA to be built with Baseline 9 began construction in August 2012 and is scheduled for delivery to the US Navy in September 2016—a period of 49 months.[17] For A$5 billion, the RAN could buy two larger, more capable Arleigh Burke-class destroyers with the latest Aegis configuration (assuming the US shipyards had the capacity). In so doing, it would save money and possibly even receive the vessels before the upgrades to the AWDs are expected to be completed. A US-sourced buy isn't a likely outcome, given the priority being given to local naval shipbuilding, but the economics is suggestive.

An alternative solution is to simply upgrade the AWDs (or at least the latter two, which are less complete) to the latest baseline before they leave the shipyard. We wouldn't be able to recoup the costs of the Baseline 8 equipment, but that's a sunk cost. The advantage is that we'd avoid paying twice for installation, testing and evaluation of the combat systems. Changing the Aegis system now would cause further delays to the delivery of the warships, but such delays would probably be less significant than the amount of time required for upgrades in a decade's time—when the Adelaide class FFGs are no longer around to provide a stopgap capability. On top of that, the AWDs would be operating the latest version of the combat system sooner, maximising their capabilities and their interoperability with the US and Japanese navies.

Neither Defence nor the Australian Government can change the fact that the AWDs will cost at least A$9.1 billion and be more than two years overdue. However, by investing a little more time and money, they can ensure that we get a cutting-edge capability sooner rather than later.

Notes

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Acronyms and abbreviations

AMDR	air and missile defence radar
ANAO	Australian National Audit Office
AWD	air warfare destroyer
BMD	ballistic missile defence
CEC	cooperative engagement capability
COTS	commercial off-the-shelf
DDG	guided missile frigate
ESSM	evolved Sea Sparrow missile
FMS	foreign military sales
IIP	Integrated Investment Program
RAAF	Royal Australian Air Force
RAN	Royal Australian Navy
VLS	vertical launch system

About the author

James Mugg is a researcher at ASPI. His primary research interests are capability development and emergent military technologies, such as unmanned systems and advances in electronic warfare.

Acknowledgement

The author thanks the Department of Defence for commenting on an earlier version of this paper, but the analysis and conclusions are solely those of the author.

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