THE FUTURE ROYAL AUSTRALIAN NAVY

Alternative Surface Combatant Force Structures

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GLOSSARY OF ABBREVIATIONS & ACRONYMS

AAW: Anti-Air Warfare
ADF: Australian Defence Force
AMDR: Air Missile Defense Radar (aka AN/SPY-6)
ASROC: Anti-Submarine Rocket
ASuW: Anti-Surface Warfare
ASW: Anti-Submarine Warfare
AWD: Air Warfare Destroyer
BMD: Ballistic Missile Defence
C2: Command and Control
CEC: Cooperative Engagement Capability
CIC: Command Information Centre
CIWS: Close In Weapons System
COP: Common Operating PIcture
DDG: Guided Missile Destroyer
DoD: Department of Defence
EEZ: Exclusive Economic Zone
ESSM: Evolved Sea Sparrow Missile
EW: Electronic Warfare
F-35A: Joint Strike Fighter (Conventional Take-off & Landing variant)
FCS: Fire Control System
FOB: Forward Operations Base
GPS: Global Positioning System
HELO: Helicopter
HVU: High Value Unit
IFF: Identification Friend or Foe
LCS: Littoral Combat Ship
LRASM: Long-Range Anti-Ship Missile
MFTA: Multi-Function Towed Array
MIDS: Multifunctional Information Distribution System
MMC: Multi-Mission Combatant (Austal)
NCW: Network Centric Warfare
OCV: Offshore Combatant Vessel
O&S: Operating & Support
OTH: Over-The-Horizon
PAR: Phased Array Radar
PLA: People's Liberation Army
RAAF: Royal Australian Air Force
RAM: Rolling Airframe Missile
RAN: Royal Australian Navy
RDT&E: Research Development Test and Evaluation
RHIB: Rigid Hull Inflatable Boat
SAR: Search and Rescue
SCS: Surface Combat Ship (Lockheed Martin)
SLOC: Sea Lines of Communication
SLS: Shoot-Look-Shoot
SM-2: Standard Missile 2
SM-3: Standard Missile 3
SM-6: Standard Missile 6
SSLS: Shoot-Shoot-Look-Shoot
TLAM: Tomahawk Land Attack Missile
UAV: Unmanned Aerial Vehicle
UNCLOS: United Nations Convention on the Law of the Sea
UUV: Unmanned Underwater Vehicle
VLS: Vertical Launching System

EXECUTIVE SUMMARY

Australia has over 34,000 kilometres of coastline and just below 15 million square kilometres of maritime territory, as bestowed by international law. Particularly within this maritime space, the Royal Australian Navy (RAN) and more broadly the Australian Defence Force (ADF) have been directed by successive Australian Government's to be capable of executing and sustaining concurrent military operations. The combination of Australia's vast maritime territory and concurrent operational requirements points to the need for a large multi-role RAN surface combatant force, that is capable of contributing to high-intensity warfighting and ocean-going force projection operations.

The 2009 Defence White Paper outlined the planned RAN surface combatant force structure of three Air Warfare Destroyers (AWD), eight Future Frigates and 20 Offshore Combatant Vessels (OCV). The problem with this force structure is that it imposes seven constraints on the RAN in terms of:

1. **Ship Availability**
2. **Critical Operational Enablers**
3. **Resilience to Force Attrition**
4. **Weapons Inventories**
5. **Rotary-Wing Naval Aviation**
6. **Crewing**
7. **Cost**

In order to address these constraints, this paper proposes three alternative surface combatant force structures. Option one is to acquire one additional AWD for a total of four ships, cancel the 20 OCVs and acquire 24 General Purpose Frigates of the Lockheed Martin or Austal designs. It would also enable the long-term deployment of two AWDs and eight General Purpose Frigates, or up to three AWDs and 16 General Purpose Frigates over short periods. Option one generates a total of 960 Mk-41 Vertical Launching System (VLS) cells and 52 MH-60R helicopters force-wide, costing an estimated $100 billion over 30 years or $3.33 billion per annum (2015 AUD).

Option two is to retain the three AWDs as well as acquire 24 General Purpose Frigates and three DDG-51 Flight III ships. This would enable the RAN to deploy one DDG-51 III, one AWD

and eight General Purpose Frigates for long-periods or up to two DDG-51s, two AWDs and 16 General Purpose Frigates over short periods. Option two generates 1,200 VLS cells and 57 helicopters force-wide, costing an estimated $124.33 billion over 30 years or $4.14 billion per annum (2015 AUD).

Option three is to retain the three AWDs, acquire 24 General Purpose Frigates plus three Ballistic Missile Defence (BMD) variants of the LPD Flight IIA ship class. This would enable the RAN to deploy one BMD LPD IIA, one AWD and eight General Purpose Frigates over long periods, or up to two LPD IIAs, two AWDs and 16 General Purpose Frigates over short periods. Option three generates 1,776 VLS cells and 57 helicopters force-wide, costing an estimated $129.51 billion over 30 years or $129.51 billion per annum (2015 AUD).

After considering all pathways, option three offers the strongest surface combatant force structure, since it substantially improves ship availability and resilience for force attrition, equips the RAN with a strong multi-domain area defence capability and is the most efficient as well as the most cost-effective way of generating large numbers of VLS cells. However at a 30 year estimated cost of $129.51 billion or $4.32 billion annually, it may not be affordable. This is particularly when considering the pressure that is likely to be exerted on future Australian Government budgets from competing areas of expenditure, as articulated in the 2015 Intergenerational Report. Option three also requires an increase of 406 personnel over the RAN's current crewing requirement, thereby increasing the risk of more frequent and severe crew shortages.

In the event that option three is deemed to be unfeasible, the next best alternative is option one, since it improves ship availability and resilience to force attrition. Option one also provides a low to medium area defence capability in a relatively efficient and cost-effective manner since it has the second lowest crew to VLS ratio and the lowest crew to helicopter ratio, as well as the third lowest cost per VLS cell and the lowest cost per helicopter. Furthermore, option one reduces the RAN's crewing requirement by 602 personnel and costs the least out of all three options at $100 billion over 30 years or $3.33 billion annually. It is also worth noting that option one forms the basic foundation of options two and three, thus the Australian Government could pursue option one and still pursue options two or three at a later point.

I. THE ADF & NAVAL OPERATIONS

Australian Maritime Territory

Geographically, Australia is the world's largest island with a total coastline of around 34,000 kilometres.[1] Under the United Nations Convention on the Law of the Sea (UNCLOS), Australia is entitled to exercise control over a maritime area just under 15 million square kilometres, including the Territorial Sea, Exclusive Economic Zone (EEZ) and Extended Continental Shelf rights.[2] This is an enormous maritime zone over which the RAN, and more broadly the ADF, aspires to credibly enforce Australian sovereignty.

ADF Strategic Objectives

Strategically, the ADF is required by the Australian Government to be capable of achieving several strategic objectives (see Table 1). Australia's Strategic Objectives vary ever so slightly between Defence White Papers, however the over the 2009 and 2013 White Papers some consensus has emerged. The first and foremost task of the ADF is to defend Australian territory from armed attacks. The second objective is to contribute to the security and stability of Australia's immediate geographic neighbours, including East Timor, Papua New Guinea and island-nations in the South Pacific. The third objective is to contribute to the security and stability of the broader Asia-Pacific region. The fourth objective is to contribute to the sustainment of a rules-based global security order.

ADF Operational Objectives

Operationally, these strategic objectives require the ADF to be capable of executing multiple types of military operations concurrently, or in careful sequence due the availability of critical operational enablers.[3] These operations include those designed to:

- **Assert control over Australia's air and maritime approaches[4]**
- **Project military power abroad[5]**
- **Detect & defeat hostile aircraft, surface ships, submarines and mines[6]**
- **Protect naval High Value Units (HVU)[7]**
- **Deploy, recover and support Amphibious Forces as well as Special Forces [8]**
- **Execute shipping protection, maritime patrol, peacekeeping, stabilisation, disaster-relief and rescue operations[9]**

ADF Network Centric Warfare Operations

When executing military operations, the ADF is likely to give preference to the doctrine of Network Centric Warfare (NCW). The very essence of NCW is all about efficiently achieving a force commanders' desired operational outcomes.[10] This involves communicating a commanders' intent across all levels of joint forces and efficiently using the available effector assets to execute that intent.[11] NCW broadly contains two key elements:

i. **Operational Combat Efficiencies:** Integrating the sensor data collected by multiple assets allows for the generation of a Common Operating Picture (COP), enabling the efficient use of available combat resources.[12] A COP means that every asset of the joint-force can see the same sensor data/target information.[13] For instance a ship on one side of the battlespace can see the same data/information as a ship on the other side of the battlespace. The existence of a COP provides force assets with early warning of threats, enables the synchronisation of military power across multiple warfare domains and against heavily defended targets, in addition to reducing the risk of 'friendly fire' incidents.[14]

ii. **Logistics Efficiencies:** By expanding force-wide integrated sensor data to also include the inventories of force assets, supplies can be automatically reordered as they are depleted, thereby enhancing the resupply of combat consumables into theatre.[15]

Networked joint-force assets may be drawn from across the air, land, surface, sub-surface, space and cyber domains. These networked ADF assets will work cooperatively in pursuit of common operational objectives by sharing data and leveraging generated COP to coordinate effector assets in the prosecution of targets. The advantage of the NCW doctrine is that it delivers superior warfighting results and can compensate for the shortcomings of individual assets. For instance, an AWD that has expended all ordinance can be protected by F-35A Joint Strike Fighters, by utilising its Cooperative Engagement Capability (CEC) to providing cueing for the F-35As weapons.

Although the ADF plans and prefers to fight using NCW operations individual effector assets, particularly vulnerable surface ships, must have the capacity to operate independent of partial or complete support from other joint-force assets. For instance, RAN surface ships must have the capacity to defend themselves against air and surface threats without relying on fixed-wing air support from RAAF combat aircraft. The reason why this independent capacity must be preserved is that potential adversaries are developing sophisticated ways of disrupting NCW operations, temporarily or indefinitely. For instance the People's Liberation Army (PLA), or Chinas' armed forces, is developing sophisticated capabilities to disable global communications and Global Positioning System (GPS) satellites, jam data-links and/or interfere with the accuracy of an adversaries NCW COP.[16] Consequently, the ADF cannot assume that NCW operations will always be feasible in future generations and must prepare for this possibility. From a practical perspective this means having assets that can operate in non-permissible environments, irrespective of substantial support from other joint-force assets. For example, Over-The-Horizon (OTH) land attack missiles that can operate independent of GPS satellite data or survivable multi-role surface combatants.

A Surface Combatant Focus

Surface Combatants are surface ships with the capacity to engage hostile targets across multiple warfare domains including air, surface, sub-surface and land threats.[17] Although RAN surface combatants are unlikely to operate in high-intensity warfighting environments without support from other ADF or allied assets, they should be capable of doing so. Consequently the shape and strategic weight of the future RAN surface combatant force requires a focussed examination, and is the exclusive focus of this paper for two reasons:

Firstly, Australia's island geography means that military operations to achieve any one Strategic Objective will require assets of the RAN and/or the RAAF. Indeed, the pivotal role of naval surface combatants in enabling ADF operations is recognised by successive Defence White Papers.[18] Secondly, the Department of Defence (DoD) is currently in the process of planning for the replacement of its RAN surface combatant force. Consequently, now is the most critical time for extensive and rigorous debate regarding the RAN's future surface combatant force, well before major acquisition decisions are finalised. Overall, this paper is intended to contribute to the debate surrounding the shape and strategic weight of the future RAN surface combatant force.

Table 1. ADF Strategic Objectives

Strategic Objectives		ADF Operational Details
2009 Defence White Paper Strategic Objectives		
1	Deterring and Defeating Attacks on Australia	• Execute military operations to control Australia's air and maritime approaches, independent of allied nation's combat forces.[19] • Maritime focus requiring technologically sophisticated air and naval forces.[20] • Aimed at protecting Australian territory and major population centres, as well as critical infrastructure, offshore resources and Sea Lines of Communication (SLOCs).[21]
2	Contributing to Stability and Security in the South Pacific and East Timor	• Make substantial ADF contributions to secure and stabilise Australia's immediate neighbours, including East Timor and the island-nations in the South Pacific.[22] • ADF must be capable of deploying significant forces to counter natural disasters and or armed aggression.[23] • Other ADF operations include humanitarian disaster relief, stabilisation operations and the protection of Australian nationals.[24]
3	Contributing to Military Contingencies in the Asia-Pacific Region	• Contribute alongside allies and partners to meet common security challenges in low and high intensity domains.[25] • Low intensity operations include countering transnational terrorism and piracy, disaster relief, protecting critical SLOCs.[26] • High intensity operations include substantial ADF surface combatant, submarine, aircraft and special forces contributions to assist regional military aggression.[27]
4	Contributing to Military Contingencies in Support of Global Security	• Make ADF contributions to international military efforts aimed at ensuring the continuity of a rules-based global security order.[28]
2013 Defence White Paper Strategic Objectives		
1	Deter and Defeat Attacks on Australia	• Execute military operations to control Australia's sea and air approaches independent of allied combat forces (except when threatened by a major power).[29] • Maritime focus requiring strong ADF sea and air denial, strategic strike and power projection capabilities.[30]
2	Contribute to Stability and Security in the South Pacific and Timor-Leste	• Make substantial ADF contributions to secure and stabilise Australia's island neighbours in the South Pacific, as well as East Timor.[31] • Operations include humanitarian disaster relief, stabilisation operations and the evacuation of Australian nationals.[32]
3	Contribute to Military Contingencies in the Indo-Pacific Region	• Help secure and stabilise the Indo-Pacific region through ADF operations, with priority given to Southeast Asia.[33] • Low intensity operations: counter-terrorism, counter-piracy, disaster relief, protection of critical SLOCs.[34] • High intensity operations: ADF deployments to assist regional allies and partners counter regional aggression.[35]
4	Contribute to Military Contingencies in Support of Global Security	• Help ensure the stability and continuity of a rules-based global security order.[36]

II. PLANNED SURFACE COMBATANT FORCE STRUCTURE

Currently the RAN has four classes of surface ships. Four Adelaide Class guided missile frigates, eight ANZAC Class frigates, 14 Armidale Class patrol boats and six Huon Class mine hunters (see Table 2). This is supplemented by two classes of non-combat ships, two Leeuwin Class hydrographic ships and four Paluma Class survey ships. Across all six classes of ships a minimum of around 2,906 RAN personnel is required, working on the assumption of one crew per ship (see Table 2).

The 2009 and 2013 Defence White Papers announced that the future RAN surface fleet would be composed of 31 ships including three AWDs, eight Future Frigates and up to 20 multi-role OCVs.[37] The three AWDs will be delivered under the SEA 4000 project (see Table 3 & 4). SEA 5000 is planned to deliver eight Future Frigates (see Table 3) and SEA 1180 is planned to deliver up to 20 multi-role OCVs (see Table 3).[38] This paper estimates that the cost of all three projects in their current formulation would amount to $85.62 billion over 30 years, including Operating and Support (O&S) costs, or $2.85 billion per year (2015 AUD) (see Table 4 & 5).

Table 2. Current RAN Surface Fleet Crew Requirements

Adelaide Guided Missile Frigates	• 198 crew x 4 ships* **TOTAL: 792 RAN personnel**
ANZAC Class Frigates	• 174 crew x 8 ships **TOTAL: 1,392 RAN personnel**
Armidale Patrol Class Boats	• 21 crew x 14 ships **TOTAL: 294 RAN personnel**
Huon Class Mine Hunters	• 46 crew x 6 ships **TOTAL: 276 RAN personnel**
Leeuwin Class Hydrographic Ships	• 46 crew x 2 ships **TOTAL: 92 RAN personnel**
Paluma Class Survey Motor Launch Ships	• 15 crew x 4 ships **TOTAL: 60 RAN personnel**
TOTAL CREWING REQUIREMENT	**2,906 RAN personnel**

Source: RAN[39]

Table 3. Future Surface Combatant Roles

	Class Description & Warfare Responsibilities
Air Warfare Destroyer	The AWDs will be multi-role surface combatants capable of simultaneously executing Anti-Air Warfare (AAW), Anti-Surface Warfare (ASuW), Anti-Submarine Warfare (ASW) and Strategic Strike missions.[40] However the principal role of the AWDs is to provide deployed RAN task forces with an extended protection against air and maritime surface threats over protracted deployments abroad.[41] The ships themselves also have scope to be expanded to provide a theatre Ballistic Missile Defence (BMD) capability to deployed ADF forces.
Future Frigate	The Future Frigates will be multi-role surface combatants but with a strong suite of capabilities tailored for ASW.[42] The planned list of capabilities will include an integrated sonar suite, a towed sonar array and Unmanned Aerial Vehicles (UAV), in addition to a complement of rotary-wing naval aviation combat helicopters.[43] The Future Frigates will also include a land-attack capability, in addition to the inclusion of a phased-array radar and Vertical Launching System (VLS).[44]
Offshore Combatant Vessel	The OCVs will be inherently multi-role and will possess surface, sub-surface, and air warfare capabilities.[45] These ships will have a displacement around or exceeding 2000 tons, enabling the carriage of greater weapons and sensors, as well as greater stores for extended seagoing endurance.[46] The OCVs will also be designed to carry mission-specific modules to facilitate the ship's multi-role capability, as well as UAVs and naval aviation helicopters.[47] Using baseline and mission-module capabilities, the ships will be used for a range of missions including long-range offshore and littoral warfighting, maritime and border protection patrols, support to Special Forces, sea mine clearance, and hydrographic or oceanographic assessments.[48]

* Average across all four Adelaide Class Frigates. HMAS Darwin 199 crew, HMAS Melbourne 199 crew, HMAS Newcastle 184 crew, HMAS Sydney 210 crew.

Table 4. Planned Force Structure Cost Estimate

	#	Acquisition Cost/Unit	Annual O&S Cost/Unit	30 Year O&S Cost/Unit[ii]	Total 30 Year Cost/Class
Air Warfare Destroyer	3	n/a	n/a	n/a	$8,455,000,000
Future Frigate[iii]	8	$1,421,100,478	$105,436,487	$3,163,094,613	$36,673,560,735
Offshore Combatant Vessel[iv]	20	$534,248,300	$39,637,777	$1,189,133,313	$34,467,632,270
MH-60R Helicopters[v]	39	$49,403,724	$3,499,430	$104,982,914	$6,021,078,863
TOTAL SURFACE FORCE STRUCTURE COST (2015 AUD)					**$85,617,271,867**
ANNUAL FORCE STRUCTURE COST (2015 AUD)					**$2,853,909,062**

Source: ANAO & ASPI & Department of Defence & US Department of the Navy[49]

[ii] See rule 1 in Appendix 1 for O&S cost assumptions

[iii] Based on the ASPI estimate of each Future Frigate costing $1.33 billion in 2008 AUD. After indexation the cost per unit becomes $1,421,100,478 in 2015 AUD. See rules 1 & 3 in Appendix 1 for indexation and O&S cost assumptions.

[iv] Based on the 2012 Defence Capability Plan upper estimate of $10 billion in 2012 dollars for 20 OCVs (SEA 1180 Project). After indexation this figure becomes $10,684,966,004 in 2015 AUD. See rules in Appendix 1 for O&S cost assumptions.

[v] One MH-60R helicopter costs $37,052,793 in 2015 USD, based on figures listed in the FY2016 US Navy Shipbuilding and Conversion cost estimates. After currency conversion this figure becomes $49,403,724 in 2015 AUD. See rules 1 & 3 in Appendix 1 for currency conversion and O&S cost assumptions.

Table 5. Planned RAN Surface Force Structure Attributes

Overall Force Structure	• 3 Air Warfare Destroyers • 8 Future Frigates • 20 Offshore Combatant Vessels
Long-Term Ship Availability[vi]	• 1 AWD • up to 3 Future Frigates • up to 7 OCVs
Short-Term Ship Availability[vii]	• 2 AWDs • 6 Future Frigates • 14 OCVs
Mk-41 VLS Availability	• AWDs: 3 ships x 48 cells • Frigates: 8 ships x 48 cells **TOTAL: 528 Mk-41 VLS cells**[viii]
MH-60R HELO Availability	• AWDs: 3 ships x 1 HELO • Frigates: 8 ships x 2 HELOs • OCVs: 20 ships x 1 HELO **TOTAL: 39 MH-60R HELOs**[ix]
Crewing Requirement	• AWDs: 3 ships x 180 crew • Frigates: 8 ships x 176 crew[x] • OCVs: 20 ships x 29 crew[xi] **TOTAL: 2,528 RAN personnel**
Crewing Efficiency	• Crew/VLS Cell: 4.78 • Crew/HELO: 64.82
Cost-Effectiveness (2015 AUD)	• $/VLS Cell: $162,153,924 • $/HELO: $2,195,314,663
Estimated Total Cost/30 Years (2015 AUD)	**$85.62 billion**
Estimated Cost/Year (2015 AUD)	**$2.85 billion**

Source: Department of Defence[50]

[vi] Assuming one third of combatants will be available to deploy, on a long-term sustainable basis (deployment ratio 1:2)
[vii] Assuming two thirds of combatants will be available for a short-term surge, on an unsustainable basis (deployment ratio 2:1)
[viii] Assuming that each Future Frigate has 48 Mk-41 VLS cells and that each OCV carries no VLS cells.
[ix] Assuming that each Future Frigate carries two MH-60R helicopters due to its focus on ASW, and that each OCV carries one MH-60R.
[x] Assumes that each Future Frigate has 150 crew to run each ship plus an additional 26 personnel to operate two MH-60R helicopters
[xi] Assumes that each OCV requires a crew of 29. This is based on the 2009 White Paper's estimate of a 2000 ton OCV and the US Navy Independence Class Littoral Combat Ship (LCS) crewing requirement. The Independence Class displaces 2800 tons and requires a crew of 40 due to the significant integration of onboard systems (see references - Bath Iron Works. 2008. p. 8). The difference of 800 tons is 28.57% of the Independence Class displacement. When the Independence crewing requirement of 40 is decreased by the same percentage, the result after rounding is 29.

III. CONSTRAINTS OF THE PLANNED FORCE STRUCTURE

In its current form the planned RAN surface combatant force structure is likely to constrain the RAN's ability to support ADF joint operations. This is because it is generates constraints across seven dimensions:

1. **Ship Availability**
2. **Critical Operational Enablers**
3. **Resilience to Force Attrition**
4. **Weapons Inventories**
5. **Rotary-Wing Naval Aviation**
6. **Crewing**
7. **Cost**

1. Ship Availability

At any given time only a fraction of the total RAN fleet will be available for deployment. In order to sustain long-term ship deployments navies around the world rotate their ships. This rotational approach is critical because it allows for scheduled ship maintenance or repairs, pre-deployment training of ship crews, as well as transit time between a ships homeport and Area of Operations (AO).

Navies with global deployments, and particularly the US Navy, operate on a deployment ratio of at least 1:2.[51] This means that in order to sustain one ship on deployment, an inventory of two additional ships will be required, with one preparing to deploy and one undergoing scheduled maintenance or upgrades.[52] In some cases this deployment ratio may be 1:3 or 1:4, which depends on a variety of factors including the duration of on-station deployments, the duration of ship maintenance and ship transit time.[53] For instance, if a ship spends six weeks on deployment (including transit time) and each ship requires 18 weeks of maintenance before it can redeploy, then a total of five ships will be required for a deployment ratio of 1:4.[54] One ship will be on-station, one preparing to deploy and three in the maintenance cycle at six-week intervals, so that every six weeks a fresh ship will be released into the pre-deployment training phase.[55]

The problem with the RAN's planned surface force structure is that it will realistically limit long-term ship availability to one AWD, up to three Future Frigates and up to seven OCVs (see Table 5)[xii]. Given this low level of ship availability and Australia's vast maritime territory, it seems unlikely that the planned RAN surface force structure will be capable of adequately supporting concurrent and geographically dispersed ADF operations.

Unlike the US Navy, the RAN does not necessarily have to maintain ships on-station. However, the RAN must have the capacity to credibly sustain adequate naval forces to achieve the ADF's Strategic Objectives, and over protracted periods of time. This credibility is a critical component of the deterrence role performed by the RAN surface fleet and more broadly by the ADF.

[xii] Based on an approximate deployment ratio of 1:2. Two ships in support of each deployed ship.

2. Critical Operational Enablers

Out of all 31 planned surface ships the AWDs and Future Frigates will be critical enablers of ADF warfighting and force projection operations (see Table 3). This is because their large displacements offer significant scope to support the space, weight, cooling and power requirements of highly capable weapons or sensor systems, e.g. Mk-41 VLS cells (see Table 3). Whereas the 2000 ton OCVs have considerably less scope to support highly capable weapons and sensor systems, therefore are unlikely to be suitable for participation in high-intensity warfighting or ocean-going force projection operations.[56] Furthermore, extensive US Navy experience indicates that 3000 tons is the minimum practical displacement for ships participating in ocean-going force projection or high-intensity warfighting roles.[57]

With only 11 major surface combatants (AWDs and Future Frigates) the RAN will be severely constrained in its ability to support concurrent and geographically dispersed warfighting operations (Table 1 & 3). As outlined earlier, only a fraction of the RAN surface combatant force will be available for continuous deployment. Further compounding the issue is that the 11 vessels will be specialised in AAW or ASW types, as opposed to multi-role ships that are highly competent across multiple warfare types (see Table 3).[58] This two-tier structure increases the risk that insufficient specialist ships will be available to meet competing operational demands, resulting in the cancellation of operations or the exposure of ADF assets and personnel to greater levels of risk.

For instance, RAN AWDs are critical enablers of naval force projection operations since their primary role is to provide escorted HVUs with area defence against air, surface and sub-surface threats. However with only three ships, concurrent deployment priorities may leave other HVUs, such as replenishment ships, without adequate escort protection or diminish the combat effectiveness of other operations that would benefit from an AWDs participation.

The constraints resulting specialised ship classes is also articulated by former Chief of Defence Force Admiral Barrie. He argues that Australia should be able to support 12 first-rate ships that are highly competent across multiple warfare types, since it would endow ADF commanders with substantially greater flexibility to meet competing operational priorities.[59]

3. Resilience to Force Attrition

Reduced resilience to ship losses and/or incapacitation is another constraint imposed by the planned RAN force structure. With only 11 major surface combatants divided into two specialised tiers supporting concurrent deployments was always going to be challenging, even without the added complication of force attrition. For instance, if one AWD was destroyed or incapacitated only two ships would remain. With a significant heavy-maintenance backlog the RAN could possibly surge the remaining two AWDs for a relatively short period of time, however this would certainly be unsustainable over protracted periods of time (see Table 5). Even deploying one AWD while maintaining the other is a dubious proposition, since it would neglect critical stages in the force rotation cycle that are essential for long-term sustainability, e.g. pre-deployment crew training and heavy maintenance. For these reasons three AWDs does not provide adequate resilience to force attrition. In fact, even four AWDs would only provide limited resilience, since the RAN would be able to absorb the loss of one ship before detracting from the minimum sustainable deployment ratio of 1:2.

It is also important to remember that anti-ship cruise and ballistic missiles, as well as highly capable submarine forces are being developed throughout the Asia-Pacific region. This regional threat environment only increases the risk of RAN ship losses in future combat operations.

4. Weapons Inventories

The size of a ship's multi-purpose weapons battery is one critical enabler of a sea-based multi-domain area defence capability. This is because it provides escorted HVUs and deployed forces with protection from air, surface, sub-surface and ballistic missile threats. The Mk-41 VLS is the RAN's integrated weapons storage and launching system, enabling a single ship to launch multiple weapons simultaneously.[60] The Mk-41 is cellular in design with each VLS cell capable of accommodating four Evolved Sea Sparrow Missiles (ESSM) or one long-range weapon.[61] ESSMs are particularly significant because they quadruple a ships defensive firepower and defend against a broad threat spectrum including fixed-wing aircraft, helicopters, missiles and small maritime surface craft.[62] The Mk-41 VLS can also carry a variety of long-range weapons including Anti-Submarine Rockets (ASROC) for engaging submarines at extended ranges, Tomahawk Land Attack Missiles (TLAM), in addition to the Standard Missile 2 (SM-2) and Standard Missile 6 (SM-6) for long-range air defence, as well as the Standard Missile 3 (SM-3) for theatre BMD.[63] The Mk-41 VLS will also be capable of launching the future Long-Range Anti-Ship Missile (LRASM) that is currently being developed to replace the RGM-84 Harpoon as the principal anti-ship missile of the US and Allied Navies.[64]

A concern with the planned RAN force structure is the potential for a force-wide shortfall in Mk-41 VLS cells. The AWD is the only future ship class dedicated to providing multi-domain long-range area defence and is equipped with 48 Mk-41 VLS cells (see Table 3).[65] Given the AWDs specialisation in area defence, it suggests a trajectory whereby the Future Frigates will have equal or less VLS capacity than the AWDs. Furthermore the substantially smaller 2000 ton OCVs are unlikely to be capable of supporting anything close to 48 Mk-41 VLS cells, let alone the additional Phased Array Radar (PAR) and integrated combat system that would be required to support it. Consequently, the inferred assumption is that the AWDs and Future Frigates will each support up to 48 VLS cells, for a maximum of 528 VLS cells across all 11 ships (see Table 5).

The problem with 48 cells per ship is that it limits the weapons inventory of each ship to 48 long-range area defence missiles (SM-2/SM-6) or alternatively 192 short-range ESSMs[xiii].

[xiii] However RAN AWDs will more likely deploy with a load-out of 32 SM-2/SM-6 weapons and 64 ESSMs.

Although these numbers appear significant, it is a distorted misconception due to four factors:

i. **Increased Missile and Aircraft Survivability:** One missile does not necessarily equal one successful intercept, in other words a kill ratio of 1:1 is not likely[xiv]. This is because stealthier designs, as well as chaff[xv], flares[xvi] and Electronic Warfare (EW) countermeasures are increasing the survivability of hostile missiles and aircraft against ship defences.[66]

ii. **Rapid Magazine Depletion:** To increase the probability of a 'kill' navies use a Shoot-Shoot-Look-Shoot (SSLS) policy.[67] This means that a ship's Command Information Centre (CIC) fires two missiles to engage each target and a third if these fail. While SSLS doctrine increases the probability of intercept it degrades the kill ratio to 2:1[xvii] or 3:1[xviii]. If the alternate Shoot-Look-Shoot (SLS) policy is used, kill ratios may improve to 1:1 and 2:1. However, the high speed of anti-ship missiles, plus the finite detection range of ship radars[xix] increases the risk of hostile missiles striking a ship before a second engagement can occur (under an SLS policy).[68] If an RAN AWD is loaded out entirely with SM-2 or SM-6 long-range area defence missiles, it could only engage 16-24 targets on a SSLS basis[xx], or 24-48 targets on a SLS basis[xxi], albeit with increased risk of foregone second engagements. If an RAN AWD was loaded out with short-range ESSMs it could engage 64 targets on a SSLS basis or 96 targets on a SLS basis[xxii], but with the increased risk of forgone second engagements especially due to the ESSMs considerably shorter range. The risk of loading an AWD with only ESSMs is further increased by the ESSMs lower kill probability than the SM-6, meaning that an SSLS doctrine is the most credible way of using ESSMs for ship defence.[69]

[xiv] 1:1 kill ratio means, one missile equal one successful target intercept
[xv] **Chaff:** metallic strips that are deployed to confuse and hide a target from an incoming radar-guided missile
[xvi] **Flares:** decoys to lure heat-seeking missiles away from the intended target
[xvii] **2:1 Kill Ratio:** two missiles per successful intercept
[xviii] **3:1 Kill Ratio:** three missiles per successful intercept
[xix] A ship's radar is limited in its ability to detect sea-skimming missiles/aircraft by the horizon, around 10 nautical miles. This organic detection range increases significantly if the hostile missile/aircraft is flying at high altitude.
[xx] Assuming that Over-The-Horizon (OTH) targeting data is provided by external platforms such as high-altitude aircraft/UAVs, satellites, submarines or other surface ships. 16 successful intercepts on a 3:1 kill ratio or 24 successful intercepts on a 2:1 kill ratio.
[xxi] 24 successful intercepts on a 2:1 kill ratio or 48 successful intercepts on a 1:1 kill ratio.
[xxii] 48 Mk-41 VLS cells with quad-packed ESSMs for a total of 192 interceptors. 64 successful intercepts on a 3:1 kill ratio and 96 successful intercepts on a 2:1 kill ratio.

iii. **Multi-Domain Opportunity Cost:** Another problem with loading out an AWD with just air defence missiles is that it comes at the cost of other weapons that are just as critical to providing deployed ADF forces with a multi-domain area defence capability. For instance, LRASMs to neutralise enemy ships, ASROCs to neutralise submarines at long-range, TLAMs for land attack and SM-3s for BMD.

iv. **Unfeasible At-Sea Replenishments:** The Mk-41 VLS cannot as yet be reloaded at sea and rearming it requires port infrastructure.[70] This means that as soon as a ship depletes its magazine it would be forced back to Australia or to a nearby Forward Operations Base (FOB). The problem is that when fighting capable adversaries, FOBs will be high value targets for interdiction operations by hostile forces, and protecting such critical in-theatre infrastructure would only further strain the planned RAN surface combatant force structure.

In order to provide RAN and ADF task forces with extended multi-domain area defence[xxiii], the AWD design should have carried at least 96 Mk-41 VLS cells. This is because 96 cells would have enabled each ship to carry 48 SM-2/SM-6/SM-3 missiles, plus 16 TLAMs, 16 ASROCs and 64 quad-packed ESSMs. However, like it or not the AWDs are just years away from delivery and will form part of the future RAN surface force, irrespective of what decisions are made. Therefore every effort must be made to equip other RAN ship classes with substantial numbers of Mk-41 VLS cells. This will give ADF operational commanders greater capacity to defend ships and forces ashore from a lethal multi-domain threat spectrum.

[xxiii] Air, land, surface, sub-surface and space domains.

5. Rotary-Wing Naval Aviation

The second enabler of a multi-domain area defence capability is rotary-wing naval aviation (helicopters). This is because helicopters make significant contributions to ASW and ASuW. The MH-60R is the RAN's choice of naval combat helicopter and is capable of executing ASW, ASuW, MIW, as well as Search and Rescue (SAR) operations.[71] With an approximate combat radius of 245 nautical miles the MH-60R is particularly useful to the RAN by providing its parent vessel with some level of OTH ASuW and ASW capability.[72] For hunting ships the MH-60R uses radar and anti-ship missiles for target prosecution.[73] For hunting submarines the MH-60R uses radar for periscope detection plus the AN/AQS-22 airborne dipping sonar and sonobuoys for detecting submerged submarines, as well as the Mk-54 lightweight torpedoes for target prosecution.[74] Naval aviation helicopters are vital for ASW operations since their airborne dipping sonars can detect submarines in maritime conditions that inhibit the effectiveness of a ships hull-mounted sonar.[75] For instance, the temperature differential between layers of ocean can confuse a ships hull-mounted sonar signals, whereas the AN/AQS-22 airborne dipping sonar can be lowered beneath such layers with 2,550 feet of cable.[76]

A concern with the planned RAN surface force structure is the risk of a force-wide shortfall in embarked helicopters. The AWDs carry one MH-60R helicopter and this is the only future ship class with its specifications announced.[77] Due to their ASW focus, the Future Frigates are likely to carry two MH-60R helicopters per ship. Additionally, the RAN's OCVs may be capable of embarking a helicopter but this is not certain, as postulated by the 2009 Defence White Paper.[78] If these assumptions are realised the total force-wide number will be 39 MH-60Rs, three less than if the AWDs carried two helicopters (see Table 5). The problem is that with numerous Asia-Pacific powers rapidly acquiring fleets of advanced submarines, a total force-wide number of 39 naval combat helicopters may not be sufficient to help protect the RAN fleet from submarine attacks.[79] This is particularly given that only a fraction of these helicopters will be deployed with surface ships at any given time.

For a surface combatant, carrying more than one helicopter is quite important because they make invaluable contributions to the ASW and ASuW aspects of multi-domain area defence.

Although one embarked helicopter may instinctively appear sufficient to provide persistent flight operations, it is a misconception for two reasons:

i. **Crewing & Maintenance:** One crew of 13, including flight and maintenance personnel, allows one MH-60R to maintain flight operations for 10 out of every 24-hour period.[80] With a second crew of 13, 24-hour flight operations are feasible (minus refuelling, rearming and crew change-over time), but would be unsustainable over protracted deployments without incurring significant maintenance backlogs.[81] Over long deployments this means that one embarked helicopter would leave its parent surface combatant with considerable gaps between ASW or ASuW flight operations, thereby increasing the ships risk exposure.

ii. **Patrol Coverage:** A single MH-60R is limited to operations approximately 50 nautical miles from its parent ship, so as to preserve its patrol endurance and ability to prosecute detected targets.[82] Due to availability limitations, one embarked MH-60R will limit a ship's persistent patrol coverage since it can only scan in one location at any given time.[83] With two helicopters a single ship can increase its ASW and ASuW patrol coverage by sustaining continuous 24 hour flight operations. Additionally, during high-threat periods a second embarked MH-60R can be deployed to surge the ships ASW and/or ASuW capability.

Given the importance of persistent ASW and ASuW flight operations to a maritime multi-domain area defence capability, it is vital that future RAN surface combatant classes carry at least two helicopters.

6. Crewing

Another constraint of the planned RAN force structure is the high likelihood of crew shortages across the future 31 surface combatants. Each AWD requires a crew of 180 for a total of 540 personnel across all three ships (see Table 5). The Future Frigates are yet to be defined but will likely embark two MH-60R naval helicopters due to their ASW focus (see Table 3). Working on the assumption that the Future Frigates require crews of 176 (150 ship and 26 flight operations personnel), all eight ships will need 1,408 personnel (see Table 5). The problem is that in the past the RAN has been unable to indefinitely maintain crews of 174 for each of its eight ANZAC Class Frigates.[84] For instance, in the 2010-2011 Financial Year two ANZAC Frigates were unable to deploy, solely due to crew shortages.[85] Similarly, the 20 OCVs are also yet to have their specifications defined. Assuming that each ship requires a crew of 29, all 20 ships will require a total of 580 personnel (see Table 5).[xxiv]

Across all 31 planned surface combatants approximately 2,528 RAN personnel will be required (see Table 5). Although this is substantially less than the current RAN surface ship crewing requirement of around 2,906 personnel, 2,528 personnel it is still too high and particularly in light of the numerous other constraints that the planned force structure imposes on the RAN (see Table 2 & 5). It is also important to note that personnel costs amount to around 50% of ships O&S lifecycle sustainment costs.[86] Therefore increasing the efficiency of the RAN surface combatant fleet by reducing crewing requirements is essential, not only to decrease O&S sustainment costs but also to reduce the risk of future crew shortages.

[xxiv] Assumes that each OCV requires a crew of 29. This is based on the 2009 White Paper's estimate of a 2000 ton OCV and the US Navy Independence Class Littoral Combat Ship (LCS) crewing requirement. The Independence Class displaces 2800 tons and requires a crew of 40 due to the significant integration of onboard systems (see references - Bath Iron Works. 2008. p. 8). The difference of 800 tons is 28.57% of the Independence Class displacement. When the Independence crewing requirement of 40 is decreased by the same percentage, the result after rounding is 29.

7. Cost

The planned RAN surface force structure is projected by this paper to cost $85.62 billion over 30 years in 2015 AUD and inflicts numerous constraints on the future RAN (see Table 4 & 5). Indeed, the problem is that current plans fail to deliver adequate capability to the RAN while imposing a high fiscal cost, and is therefore not a cost-effective option. Finding a cost-effective force structure is essential because future Australian Federal Budget's will be under pressure to divert increasingly scarce resources to bolster the Healthcare, Education and Social Welfare portfolios, due to significant demographic shifts within Australian Society.

According to the 2015 Intergenerational Report as published by the Australian Treasury, in 2055 Australian's will have some of the longest life expectancies world-wide, as well as substantially fewer numbers of working Australian's to persons over the current pension age of 65 (see Table 6).[87] These are just two factors that will exert increasing pressure on the Australian Federal Budget throughout the forward estimates, promising to generate fierce inter-Departmental and inter-Ministerial Portfolio competition over finite budgetary resources. In fact, evidence of this trend is visible in the way successive Australian Government's have allocated budgetary funds. Over the last nine Federal Budget's, both Labor and Liberal, the broad trend has been significant increases to Social Security and Health, with only minor increases to defence spending (see Table 7). Over this period Social Security spending increased by 58.99% and Health spending increased by 68.09%, whereas Defence spending increased by only 35.95% (see Table 7).[xxv] These figures illustrate the rapid pressure being exerted on the Australian Federal Budget by issues emanating from changing demographics. Consequently, the future RAN surface combatant force structure must be cost-effective.

[xxv] Calculations exclude indexation and were based solely on data extracted from Federal Budget Overview's as published by the Australian Treasury.

Table 6. Number of Working Australians' to People 65+

	1975	2015	2055
Number of Working Australian's (15-64 years) Per Person 65+	7.3	4.5	2.7

Source: Commonwealth of Australia[88]

Table 7. Australian Government Federal Budgets 2006-2014

(AUD billions)	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total Federal Budget	$220.0	$236.0	$292.5	$338.2	$354.6	$365.8	$376.3	$398.1	$414.9
Social Security	$91.7	$96.4	$102.4	$110.9	$114.9	$121.9	$131.7	$138.1	$145.8
Health	$39.8	$42.9	$46.0	$51.2	$56.9	$59.9	$61.0	$64.6	$66.9
Education	$16.6	$17.7	$18.7	$35.2	$32.9	$29.9	$29.6	$29.7	$29.6
Defence	$17.8	$19.8	$17.9	$20.9	$21.0	$21.3	$21.6	$22.0	$24.2

Source: Commonwealth of Australia[89]

IV. FUTURE FORCE STRUCTURE GUIDELINES

The RAN's fleet of future surface combatants should be guided by five criteria:

1. **Resilient Ship Availability:** This requires sufficient surface combatant numbers to credibly meet all ADF operational requirements over protracted periods of time, provide a margin against the risk of force attrition and enable concurrent deployments.

2. **Area Defence Capability:** This requires high magazine capacity area defence ships to serve as the centrepiece of RAN multi-domain defence operations, augmented by substantial numbers of naval aviation helicopters and highly capable General Purpose Frigates.

3. **General Purpose Frigate Capability:** Significant numbers of multi-purpose ships will be required to execute a wide-range of roles from mine-hunting, hydrographic survey, offshore patrol and border protection missions through to force projection and high-intensity warfighting operations. This broad operational spectrum means that the baseline ship design should include reasonable numbers of Mk-41 VLS cells plus hangar and flight deck space to support two MH-60R helicopters.

4. **Minimal Crewing Requirement:** The future RAN surface combatant force structure should have reduced crewing requirements, thereby increasing the efficiency of the RAN's surface combatant capability.

5. **Cost-Effectiveness:** With vast maritime territories, an aging population and the promise of future budgetary challenges, the future RAN surface force must efficiently deliver significant surface combatant capability for every dollar spent (see Table 6 & 7).

V. ALTERNATIVE SURFACE COMBATANT FORCE STRUCTURES

Option One: Consolidated Posture

Option one is to acquire one additional AWD for a total of four ships under the SEA 4000 Project, cancel all 20 OCVs under SEA 1180 and expand the Future Frigate program to 24 General Purpose Frigates under SEA 5000 (see Table 11). Overall, it would generate 960 Mk-41 VLS cells and 52 MH-60R helicopters force-wide, with a crewing requirement of 2,305 personnel (see Table 11). The estimated 30 year cost of option one is $100 billion (2015 AUD) or $3.33 billion (2015 AUD) per annum over the same period (see Table 10 & 11).

In terms of the 24 General Purpose Frigates, Lockheed Martin's Surface Combat Ship (SCS) and Austal's Multi-Mission Combatant (MMC) are two credible designs. This is because they feature a shallow draft[xxvi], significant stability in high sea states[xxvii], a low crew of 66 and significant multi-domain warfare capabilities (see Table 8). Both designs include a PAR, hull-mounted and towed sonar arrays, a 32 cell Mk-41 VLS, two torpedo launchers, two quad Harpoon anti-ship missile launchers, one medium calibre gun and an open architecture combat system, plus flight deck and hangar space for two MH-60R helicopters (see Table 8).

The extensive list of armaments carried by both designs is significant because it enables a single General Purpose Frigate to simultaneously execute AAW, ASW, ASuW, MIW and Special Forces support missions. It is also important to note that both designs displace greater than 3000 tons, making them suitable for participation in ocean-going force projection and fleet escort roles[xxviii](see Table 8).[90] Consequently, General Purpose Frigates of either design would support RAN ocean-going force projection operations, not only in a blue-water escort function but also in a littoral fire-support role capable of supporting: Special Forces close to shore, amphibious assault operations and ADF forces ashore with on-demand naval gunfire.[xxix]

[xxvi] **Draft:** distance between a ships keel and waterline
[xxvii] **Sea State:** a numerical scale indicating the wave and wind volatility of a maritime environment
[xxviii] US Navy experience since World War II indicates that 3000 tons is the minimum displacement for ships participating in ocean-going force projection operations.
[xxix] In a blue-water escort function these General Purpose Frigates would help a naval task force counter air, surface, sub-surface and mine threats. In a littoral role the frigates would provide; a protective anti-air umbrella for amphibious landings or forces ashore, protection from surface, submarine and mine threats, plus gunfire support to forces ashore and infiltration/exfiltration support to Special Forces.

The designs also feature significant reconfigurable space to meet unique mission requirements, and even greater space if both helicopters are disembarked.[91] Furthermore, the open architecture combat system enables new hardware and sensors to be quickly integrated into the ships digital infrastructure. In practice, these features could enable General Purpose Frigates to also be used for patrol boat and hydrographic survey roles.

In a patrol boat configuration both MH-60R helicopters could be disembarked and replaced by multiple UAVs for extended surveillance, supported by additional Rigid Hull Inflatable Boats (RHIB) for maritime interceptions. It is also likely that UAVs would require specialist Command and Control (C2) consoles in order to operate, the installation of which would be greatly simplified by the ships open architecture combat system. It is therefore a possibility that a single General Purpose Frigate with 66 personnel, including ship, RHIB and UAV crew, could provide the equivalent maritime patrol, surveillance and interception capability of several Armidale Patrol Class boats.

In a hydrographic survey configuration helicopters and watercraft could be disembarked and replaced with data processing equipment, as well as multiple Unmanned Underwater Vehicles (UUV) fitted with echo sounders and specialist sonars. In theory, this would enable a General Purpose Frigate to more efficiently survey a greater maritime area than a current hydrographic survey ship of the RAN fleet.

Table 8. General Purpose Frigate Designs

	Lockheed Martin Surface Combat Ship	Austal Multi-Mission Combatant
Displacement	3600 tons	3120 tons
Speed	40 knots	40 knots
Range	4000 nautical miles	4500 nautical miles
Draft	4.2 meters	4.4 metres
Minimum Crew	66[xxx] (including 26 flight operations personnel)	66[xxxi] (including 26 flight operations personnel)
Weapons	• 32 cell Mk-41 VLS • 2 Mk-32 torpedo launchers (port & starboard) • 2 Mk- 141 quad Harpoon launchers (8 missiles) • 1 Mk-45 5" Lightweight Gun (foredeck) • 1 CIWS (aft) • 4 .50 calibre machine guns	• 32 cell Mk-41 VLS • 2 Mk-32 torpedo launchers (port & starboard) • 2 Mk-141 quad Harpoon launchers (8 missiles) • 1 Mk-45 5" Lightweight Gun (foredeck) • 2 CIWS (aft) • 4 .50 calibre machine guns
Sensors	• AN/SPY-1F or CEAFAR & CEAMOUNT[xxxii] • Hull mounted sonar • Towed sonar array	• AN/SPY-1F or CEAFAR & CEAMOUNT[xxxiii] • Hull mounted sonar • Towed sonar array
Combat System	Lockheed Martin COMBATSS-21 (open architecture)	Unknown (open architecture)
Rotary-Wing Naval Aviation	2 MH-60R helicopters	2 MH-60R helicopters
Water Craft	2 RHIBs	2 RHIBs
Launch/Recover Aircraft	Up to Sea State 5	Up to Sea State 5
Launch/Recover Watercraft	Up to Sea State 4	Up to Sea State 4

Source: Austal & Bath Iron Works & Lockheed Martin & Murphy.M.N & O'Rourke.R & RAN[92]

[xxx] Based on Freedom Class LCS baseline crew of 40, plus 26 crew dedicated to the flight operations of two MH-60R helicopters.

[xxxi] Based on Independence Class LCS baseline crew of 40, plus 26 crew dedicated to the flight operations of two MH-60R helicopters.

[xxxii] It is assumed that SPY-1F can be replaced with the CEAFAR PAR, since it would almost certainly be the RAN's preference. CEAFAR is the S-band PAR that detects air and surface threats, whereas the CEAMOUNT is the X-band array that illuminates targets in a fire-control function.

[xxxiii] It is assumed that SPY-1F can be replaced with the CEAFAR PAR, since it would almost certainly be the RAN's preference. CEAFAR is the S-band PAR that detects air and surface threats, whereas the CEAMOUNT is the X-band array that illuminates targets in a fire-control function.

Table 9. General Purpose Frigate Cost Estimate

Item	Cost/Item[xxxiv]
LCS Baseline Ship[xxxv]	$634,266,667
32 Cell Mk-41 VLS[xxxvi]	$24,272,222
2 Mk-32 Torpedo Tubes[xxxvii]	$3,856,667
2 Mk-141 Quad Harpoon Missile Launchers[xxxviii]	$19,253,893
Mk-45 Lightweight Gun (5”)[xxxix]	$33,419,333
2 Mk-15 Phalanx Block 1B CIWS[xl]	$21,261,333
Integrated Weapons System[xli]	$136,491,563
Mk-160 Gunfire Control System[xlii]	$4,244,000
AN/SQQ-89A(V)15 ASW Combat System[xliii]	$51,672,667
AN/SLQ-32 EW & Mk-53 Nulka Decoy[xliv]	$26,131,333
AN/SLQ-25 NIXIE Torpedo Decoy[xlv]	$2,048,000
Mk-12 Identification Friend or Foe (IFF)[xlvi]	$8,533,333
CEC: AN/USG-2B Block II[xlvii]	$7,506,667
EXCOMM[xlviii]	$63,442,000
AN/USQ 82(V) Gigabit Ethernet Network[xlix]	$5,947,333
ESTIMATED COST/FRIGATE (2015 AUD)	**$1,042,347,011**

Source: CEA & Commonwealth of Australia & Defense Security Cooperation Agency & Director Operational Test and Evaluation & Sagem & US Department of the Navy & US Navy[93]

[xxxiv] All line items were converted from 2015 USD into 2015 AUD. See rule 2 in Appendix 1 for currency conversion details.

[xxxv] The US Navy Freedom & Independence Class LCS is the baseline design of the Lockheed SCS and Austal MMC ships. One baseline LCS of either design costs $475.7 million (2015 USD) and $634.3 million (2015 AUD).

[xxxvi] DDG-51 IIAs carry 96 Mk-41 cells costing $54,612,500 (2015 USD). A Lockheed SCS/Austal MMC carries one third of 96 cells, costing $18,204,167 (2015 USD) or $24,272,222 (2015 AUD).

[xxxvii] Four Mk-32 units (of a DDG-51 IIA) costs $5,785,000 (2015 USD), two units costs $2,892,500 (2015 USD) or $3,856,667 (2015 AUD).

[xxxviii] Egypt purchased 20 RGM-84 missiles, 4 control consoles, 4 Mk-141 quad launchers, software, spares, training and support for $145 million (2009 USD). After indexation this package became $158,642,519 (2015 USD), see rule 3 in Appendix 1. O&S is assumed to be two thirds of the sales package at $105,761,679 (2015 USD) and $52,880,840 (2015 USD) for acquisition (see rule 1 in Appendix 1). One RGM-84 costs $1.2 million with 20 costing $24,000,000 (2015 USD), leaving $28,880,840 (2015 USD) to acquire 4 consoles, 4 launchers and software. Therefore each SCS/MMC carries two launchers costing $14,440,420 (2015 USD) or $19,253,983 (2015 AUD).

[xxxix] The Mk-45 gun for two DDG-51IIAs costs $50,129,000 (2015 USD), one gun costs $25,064,500 (2015 USD) or $33,419,333 (2015 AUD).

[xl] Two Mk-15 Phalanx CIWS units costs $15,946,000 (2015 USD) or $21,261,333 (2015 AUD).

[xli] The Integrated Weapons System is assumed to be identical to the Anti-Ship Missile Defence upgrade on the RAN’s ANZAC Class Frigates, incorporating an S-band CEAFAR PAR, an X-band CEAMOUNT missile illuminator, a Sagem VAMPIR NG Infrared Search and Track (IRST) System, as well as a SAAB 9LV Combat Management System. These upgrades are being installed under the SEA 1448 Project (Phases 2A and 2B). Phase 2A is costed at $386,900,000 (2014 AUD) and Phase 2B is costed at $678,400,000 (2014 AUD). The total for Phases 2A and 2B is $1,065,300,000 (2014 AUD). Assuming an inflation rate of 2.5%, the total cost for Phases 2A and 2B is $1,091,932,500 (2015 AUD). The total cost of acquiring and installing an Integrated Weapons System is estimated to be $136,491,563 (2015 AUD).

[xlii] Two Mk-160 systems costs $6,366,000 (2015 USD), one system costs $3,183,000 (2015 USD) or $4,244,000 (2015 AUD).

[xliii] Two AN/SQQ-89 ASW combat systems costs $77,509,000 (2015 USD), one costs $38,754,500 (2015 USD) or $51,672,667 (2015 AUD).

[xliv] Two AN/SLQ-32 EW packages costs $39,197,000 (2015 USD), one package costs $19,598,500 (2015 USD) or $26,131,333 (2015 AUD).

[xlv] Two NIXIE units costs $3,072,000 (2015 USD), one unit costs $1,536,000 (2015 USD) or $2,048,000 (2015 AUD)

[xlvi] Two Mk-12 units costs $12,800,000 (2015 USD), one unit costs $6,400,000 (2015 USD) or $8,533,333 (2015 AUD).

[xlvii] Two CEC units costs $11,260,000 (2015 USD), one unit costs $5,630,000 (2015 USD) or $7,506,667 (2015 AUD).

[xlviii] Two EXCOMM systems costs $95,163,000 (2015 USD), one system costs $47,581,500 (2015 USD) or $63,442,000 (2015 AUD).

[xlix] Two DDG-51 IIA AN/USQ-82 shipboard ethernet network costs $26,763,000 (2015 USD), one costs $13,381,500 (2015 USD), and is assumed to be a scalable cost. An MMC displaces around 33% of a DDG-51 IIA, thus its Ethernet cost is assumed to be reduced by 66% (SCS cost assumed to be identical). The MMC/SCS USQ-82 cost is estimated at $4,460,500 (2015 USD) or $5,947,333 (2015 AUD).

Table 10. Force Structure Cost Estimate: Option One

	#	Acquisition Cost/Unit	Annual O&S Cost/Unit	30 Year O&S Cost/Unit[l]	Total 30 Year Cost/Class
Air Warfare Destroyer	3	n/a	n/a	n/a	$8,455,000,000
Additional AWD[li]	1	n/a	n/a	n/a	$2,818,333,333
General Purpose Frigate[lii]	24	$1,042,347,011	$77,335,423	$2,320,062,702	$80,697,833,115
MH-60R Helicopters[liii]	52	$49,403,724	$3,499,430	$104,982,914	$8,028,105,150
TOTAL SURFACE FORCE STRUCTURE COST (2015 AUD)					**$99,999,271,598**
ANNUAL FORCE STRUCTURE COST (2015 AUD)					**$3,333,309,053**

Source: ASPI & CEA & Commonwealth of Australia & Defense Security Cooperation Agency & Sagem & US Department of the Navy & US Navy[94]

[l] See rule 1 in Appendix 1 for O&S cost assumptions

[li] Calculated by dividing the total cost of the SEA 4000 AWD Program at $8.45 billion (2015 AUD), that includes 30 year O&S costs, by the three AWDs currently on order. This figure of $2,818,333,333 is the estimated total cost of a fourth AWD, including 30 year O&S costs.

[lii]The US Navy Freedom & Independence Class LCS is the baseline design of the Lockheed SCS and Austal MMC General Purpose Frigates. One baseline LCS of either design costs $475.7 million (2015 USD) and $634.3 million (2015 AUD), see rule 2 of Appendix 1 for currency conversion details. The cost of all anticipated sensors, systems and weapons is estimated in Table 9 based on prices listed in the FY2016 US Navy Shipbuilding and Conversion estimates as well as from Defence Materiel Organisation 2013-2014 Major Projects Report. These prices were converted into 2015 AUD using rule 2 in Appendix 1. See rule 1 in Appendix 1 for O&S cost assumptions.

[liii] One MH-60R helicopter costs $37,052,793 in 2015 USD, based on figures listed in the FY2016 US Navy Shipbuilding and Conversion cost estimates. After currency conversion this figure becomes $49,403,724 in 2015 AUD. See rules 1 & 3 in Appendix 1 for currency conversion and O&S cost assumptions

Table 11. Force Structure Attributes: Option One

Overall Force Structure	• 4 Air Warfare Destroyers • 24 General Purpose Frigates
Long-Term Ship Availability[liv]	• Up to 2 AWDs • Up to 8 Frigates
Short-Term Ship Availability[lv]	• Up to 3 AWDs • Up to 16 Frigates
Mk-41 VLS Availability	• AWDs: 4 ships x 48 cells • Frigates: 24 ships x 32 cells **TOTAL: 960 Mk-41 VLS cells**
MH-60R HELO Availability	• AWDs: 4 ships x 1 HELO • Frigates: 24 ships x 2 HELOs **TOTAL: 52 MH-60R HELOs**
Crewing Requirement	• AWDs: 4 ships x 180 crew • Frigates: 24 ships x 66 crew **TOTAL: 2,304 RAN personnel**
Crewing Efficiency	• Crew/VLS Cell: 2.4 • Crew/HELO: 44.3
Cost-Effectiveness (2015 AUD)	• $/VLS Cell: $104,165,908 • $/HELO: $1,923,062,915
Estimated Total Cost/30 Years (2015 AUD)	**$100 billion**
Estimated Cost/Year (2015 AUD)	**$3.33 billion**

[liv] Assuming one third of combatants will be available to deploy, on a long-term sustainable basis (deployment ratio 1:2)
[lv] Assuming two thirds of combatants will be available for a short-term surge, on an unsustainable basis (deployment ratio 2:1)

Option Two: Enhanced Posture

Option two is to proceed with the acquisition of 24 General Purpose Frigates as articulated above, retain the three AWDs and order three DDG-51 Flight III ships as used by the US Navy. This option delivers 1200 Mk-41 VLS cells, 57 MH-60R helicopters with a total force-wide crewing requirement of 2,952 personnel (see Table 15). The estimated 30 year cost of option two is $124.33 billion (2015 AUD) or an annual cost of $4.14 billion (2015 AUD) (see Table 14).

Just like the RAN's Hobart Class AWDs, the Arleigh Burke Class DDG-51 IIIs are equipped with the Aegis combat system, the AN/SPY family PAR, the Mk-99 Fire Control System (FCS) and the Mk-41 VLS.[95] However, the DDG-51 IIIs are distinctly superior to the RAN's AWDs in three critical areas. Firstly, each DDG-51 carries 96 Mk-41 VLS cells (see Table 12).[96] Secondly, each DDG-51 carries two MH-60R helicopters (see Table 12).[97] Thirdly, each DDG-51 III carries the US Navy's newest AN/SPY-6 Air Missile Defence Radar (AMDR) (see Table 12). The AN/SPY-6 AMDR aboard the DDG-51 IIIs is particularly significant because it is a 14 foot next-generation PAR that is designed to simultaneously support both air and ballistic missile defence missions.[98] The AMDR offers significant improvements in detection capability with a returning radar signal strength, as reflected off objects, that is 32 times greater than that of the AN/SPY-1D (V) PAR.[99] Additionally, the AMDR is capable of tracking and engaging over 30 times the number of threats as the AN/SPY-1D (V) PAR.[100]

Table 12. AWD-DDG-51 Flight III Comparison

	Hobart Class (AWD)	**Arleigh Burke Class (DDG-51 Flight III)[lvi]**
Displacement	7000 tons	9650 tons
Crew	180	276
Weapons	• 48 cell Mk-41 VLS • 2 torpedo launchers (port & starboard) • 2 Mk-141 Quad Harpoon ASCM launchers • 1 Mk-45 Lightweight Gun (5") • 2 Typhoon Cannons 25mm (port & starboard) • 1 Mk-15 Phalanx Block 1B CIWS	• 96 cell Mk-41 VLS • 2 Mk-32 torpedo launchers (port & starboard) • 1 Mk-45 Lightweight Gun (5") • 1 Mk-15 Phalanx Block 1B CIWS
Sensors	***Aegis Weapons System*** o AN/SPY-1D (V) PAR o Mk-99 FCS ***Additional Radars*** o AN/SPQ-9B o AN/SPS-67 ***Integrated ASW System:*** o Hull Mounted Sonar o Towed Sonar	***Aegis Weapons System*** o AN/SPY-6 Air Missile Defense Radar o Mk-99 FCS ***Additional Radars*** o AN/SPQ-9B o AN/SPS-67 ***Integrated ASW System:* AN/SQQ-89A(V)15** o AN/SQS-53C (hull-mounted sonar) o TB-37 Multifunction Towed Array (MFTA)
EW & Decoys	• EW Suite • Mk-53 Nulka Decoys • AN/SLQ 25 NIXIE Torpedo Decoys	• EW Suite: AN/ SLQ-32 EW • Mk-53 Nulka Decoys • AN/SLQ 25 NIXIE Torpedo Decoys
Electronics & Communications	• Secure Communications Suite • MIDS • CEC: AN/USG-7B Block II • IFF	• Secure Communications Suite: EXCOMM • Ethernet Network: AN/USQ-82 GEDMS • MIDS • CEC: AN/USG-2B Block II • Mk-12 IFF
Combat System	Aegis	Aegis
Naval Aviation	1 MH-60R HELO	2 MH-60R HELOs

Source: Aviation Week & AWD Alliance & Barr Aerospace Group & Director Operational Test and Evaluation & Global Security & Lockheed Martin & Navantia & RAN & Raytheon & US Navy[101]

[lvi] DDG-51 Flight III is assumed to have an identical crewing requirement, Mk-41 VLS capacity and MH-60R HELO capacity as a Flight IIA. A DDG-51 Flight IIA has a crewing requirement of 276 per ship, carrying 96 Mk-41 VLS cells and two MH-60R HELOs.

Table 13. DDG-51 Flight III Cost[lvii]

Item	Cost/Item[lviii]
Planning Costs[lix]	$226,337,333
Basic Construction[lx]	$1,011,247,333
Change Orders[lxi]	$278,547,333
Electronics (sensors & decoys)[lxii]	$232,206,000
HM&E[lxiii]	$105,310,000
Other Costs[lxiv]	$54,860,667
Ordinance (weapons)[lxv]	$817,310,000
TOTAL COST/DDG-51 III (2015 AUD)	**$2,725,818,667**

Source: US Department of the Navy[102]

[lvii] 2016 included funds to acquire one DDG-51 IIA and one DDG-51 III. Costs for the DDG-51 Flight III ship were calculated by subtracting the 2015 line item cost a DDG-51 IIA from each equivalent 2016 line item (see Table 13).

[lviii] All line items were converted from 2015 USD into 2015 AUD. See rule 2 in Appendix 1 for currency conversion details.

[lix] Planning in 2016 costs $204,160,000, after subtracting $34,407,000 in planning costs for one 2015 DDG-51 IIA, a DDG-51 IIIs planning amounts to $169,753,000 (2015 USD) or $226,337,333 (2015 AUD).

[lx] Construction in 2016 costs $1,460,788,000, after subtracting $702,352,500 in construction costs for one 2015 DDG-51IIA, a DDG-51 IIIs construction amounts to $758,435,500 (2015 USD) or $1,011,247,333 (2015 AUD).

[lxi] Change in 2016 costs $229,981,000, after subtracting $21,070,500 in change costs of one 2015 DDG-51IIA, a DDG-51 IIIs change orders amounts to $208,910,500 (2015 USD) or $278,547,333 (2015 AUD).

[lxii] Electronics in 2016 costs $350,005,000, after subtracting $175,850,500 in electronics costs of one 2015 DDG-51IIA, a DDG-51 IIIs electronics amounts to $174,154,500 (2015 USD) or $232,206,000 (2015 AUD).

[lxiii] HM&E in 2016 costs $158,749,000, after subtracting $79,766,500 in HM&E costs of one 2015 DDG-51IIA, a DDG-51 IIIs HM&E amounts to $78,982,500 (2015 USD) or $105,310,000 (2015 AUD).

[lxiv] Other costs in 2016 amounts to $80,033,000, after subtracting $38,887,500 in other costs of one 2015 DDG-51IIA, a DDG-51 IIIs other costs amounts to $41,145,500 (2015 USD) or $54,860,667 (2015 AUD).

[lxv] Ordinance in 2016 amounts to $1,039,021,000, after subtracting $426,038,500 in ordinance costs of one 2015 DDG-51IIA, a DDG-51 IIIs ordinance amounts to $612,982,500 (2015 USD) or $817,310,000 (AUD).

Table 14. Force Structure Cost Estimate: Option Two

	#	Acquisition Cost/Unit	Annual O&S Cost/Unit	30 Year O&S Cost/Unit[lxvi]	Total 30 Year Cost/Class
Air Warfare Destroyer	3	n/a	n/a	n/a	$8,455,000,000
DDG-51 Flight III	3	$2,725,818,667	$202,238,159	$6,067,144,774	$26,378,890,323
General Purpose Frigate[lxvii]	24	$1,042,347,011	$77,335,423	$2,320,062,702	$80,697,833,110
MH-60R Helicopters[lxviii]	57	$49,403,724	$3,499,430	$104,982,914	$8,800,038,338
TOTAL SURFACE FORCE STRUCTURE COST (2015 AUD)					**$124,331,761,770**
ANNUAL FORCE STRUCTURE COST (2015 AUD)					**$4,144,392,059**

Source: ASPI & CEA & Commonwealth of Australia & Defense Security Cooperation Agency & Sagem & US Department of the Navy & US Navy[103]

[lxvi] See rule 1 in Appendix 1 for O&S cost assumptions

[lxvii]The US Navy Freedom & Independence Class LCS is the baseline design of the Lockheed SCS and Austal MMC General Purpose Frigates. One baseline LCS of either design costs $475.7 million (2015 USD) and $634.3 million (2015 AUD), see rule 2 of Appendix 1 for currency conversion details. The cost of all anticipated sensors, systems and weapons is estimated in Table 9 based on prices listed in the FY2016 US Navy Shipbuilding and Conversion estimates as well as from Defence Materiel Organisation 2013-2014 Major Projects Report. These prices were converted into 2015 AUD using rule 2 in Appendix 1.

[lxviii] One MH-60R helicopter costs $37,052,793 in 2015 USD, based on figures listed in the FY2016 US Navy Shipbuilding and Conversion cost estimates. After currency conversion this figure becomes $49,403,724 in 2015 AUD. See rules 1 & 3 in Appendix 1 for currency conversion and O&S cost assumptions

Table 15. Force Structure Attributes: Option Two

Overall Force Structure	• 3 DDG-51 Flight IIIs • 3 Air Warfare Destroyers • 24 General Purpose Frigates
Long-Term Ship Availability[lxix]	• Up to 1 DDG • Up to 1 AWD • Up to 8 Frigates
Short-Term Ship Availability[lxx]	• Up to 2 DDGs • Up to 2 AWDs • Up to 16 Frigates
Mk-41 VLS Availability	• DDGs: 3 ships x 96 cells • AWDs: 3 ships x 48 cells • Frigates: 24 ships x 32 cells **TOTAL: 1,200 Mk-41 VLS cells**
MH-60R HELO Availability	• DDGs: 3 ships x 2 HELOs • AWDs: 3 ships x 1 HELO • Frigates: 24 ships x 2 HELOs **TOTAL: 57 MH-60R HELOs**
Crewing Requirement	• DDGs: 3 ships x 276 crew • AWDs: 3 ships x 180 crew • Frigates: 24 ships x 66 crew **TOTAL: 2,952 RAN personnel**
Crewing Efficiency	• Crew Per VLS Cell: 2.46 • Crew Per Helicopter: 51.79
Cost-Effectiveness (2015 AUD)	• $/VLS Cell: $103,609,801 • $/HELO: $2,181,258,978
Estimated Total Cost/30 Years (2015 AUD)	**$124.33 billion**
Estimated Cost/Year (2015 AUD)	**$4.14 billion**

[lxix] Assuming one third of combatants will be available to deploy, on a long-term sustainable basis (deployment ratio 1:2)
[lxx] Assuming two thirds of combatants will be available for a short-term surge, on an unsustainable basis (deployment ratio 2:1)

Option Three: Localised Sea Control

Option three is to proceed with the acquisition of 24 General Purpose Frigates, retain the three AWDs, and order three BMD variants of the LPD Flight IIA by Huntington Ingalls Industries (see Table 19). This option generates 1,776 Mk-41 VLS cells and 57 MH-60R helicopters, with a total crewing requirement of 3,312 personnel (see Table 19). Over 30 years option three is estimated to cost $129.51 billion (2015 AUD) or $4.32 billion annually (2015 AUD) (see Table 18).

Just like the DDG-51 IIIs, the BMD variant of the LPD IIA can carry a sophisticated PAR and is assumed for the purposes of costing to be the same AN/SPY-6 AMDR as installed on the DDG-51 IIIs. Aside from the AMDR, the BMD LPD IIA design can accommodate up to 288 Mk-41 VLS cells which is a significant because it is three fold the magazine capacity of a DDG-51, and six fold the capacity of a Hobart Class AWD (see Table 16).

Table 16. AWD-BMD LPD IIA Comparison

	Hobart Class (AWD)	**BMD Variant LPD Flight IIA**[lxxi] (BMD LPD IIA)
Displacement	7000 tons	24,085 tons
Crew	180	396
Weapons	• 48 cell Mk-41 VLS • 2 torpedo launchers (port & starboard) • 2 Mk-141 Quad Harpoon ASCM launchers • 1 Mk-45 Lightweight Gun (5") • 2 Typhoon Cannons 25mm (port & starboard) • 1 Mk-15 Phalanx Block 1B CIWS	• 288 cell Mk-41 VLS • 2 Rolling Airframe Missile (RAM) launchers • 2 Mk-38 25mm cannons
Sensors	***Aegis Weapons System*** o AN/SPY-1D (V) PAR o Mk-99 FCS ***Additional Radars*** o AN/SPQ-9B o AN/SPS-67 ***Integrated ASW System:*** o Hull Mounted Sonar o Towed Sonar	***Aegis Weapons System*** o AN/SPY-6 AMDR o Mk-99 FCS ***Additional Radars*** o AN/SPQ-9B ***Integrated ASW System:*** **AN/SQQ-89A(V)15** o AN/SQS-53C (hull-mounted sonar) o TB-37 Multifunction Towed Array (MFTA)
EW & Decoys	• EW Suite • Mk-53 Nulka Decoys • AN/SLQ 25 NIXIE Torpedo Decoys	• EW Suite: AN/SLQ-32 EW • Mk-53 Nulka Decoys • AN/SLQ 25 NIXIE Torpedo Decoys
Electronics & Communications	• Secure Communications Suite • MIDS • CEC: AN/USG-7B Block II • IFF	• Secure Communications Suite: EXCOMM • MIDS • CEC: AN/USG-2B Block II • Mk-12 IFF
Combat System	Aegis	Aegis
Naval Aviation	1 MH-60R HELO	2 MH-60R HELOs[lxxii]

Source: Aviation Week & AWD Alliance & Director Operational Test and Evaluation & Huntington Ingalls Shipbuilding & Lockheed Martin & Navantia & Navy Recognition & RAN & Raytheon[104]

[lxxi] The LPD IIA baseline design includes AN/SLQ-25 NIXIE decoys, AN/SLQ-32, MK-36 chaff launcher, the AN/SPQ-9B radar, two Rolling Airframe Missile (RAM) launchers and two Mk-38 25mm cannons for point defence. The BMD LPD IIA carries 288 Mk-41 VLS cells as well as a PAR, assumed to be the US Navy's newest SPY-6 Air Missile Defence Radar (AMDR). In order to be capable of operating and surviving in high-intensity non-permissible warfighting environments this paper assumes that the BMD LPD IIA will need additional hardware, as installed on DDG-51 IIA ships. This additional hardware list includes the Mk-99 FCS, AN/SQQ-89 ASW combat system, MIDS, CEC, Mk-12 IFF, Mk-53 Nulka decoy launchers and EXCOMM.

[lxxii] The LPD IIA has hangar and flight deck space for two MV-22 Osprey aircraft that are larger than the MH-60R. Therefore it is presumed that the BMD LPD IIA can carry and house two MH-60R helicopters. See Huntington Ingalls Shipbuilding.

Table 17. BMD Variant LPD Flight IIA Estimated Cost

Item	Cost/Item[lxxiii]
LPD Flight IIA baseline ship[lxxiv]	$2,079,226,667
288 Mk-41 VLS cells[lxxv]	$436,900,000
2 Rolling Airframe Missile launchers[lxxvi]	$18,170,667
2 Mk-38 25mm cannons[lxxvii]	$7,426,000
Aegis Weapons System[lxxviii]	$541,560,667
AN/SPQ-9B Horizon Search Radar[lxxix]	$10,800,000
AN/SQQ-89A(V)15 ASW combat system[lxxx]	$51,672,667
AN/SLQ-32 EW (incl. Mk-53 Nulka)[lxxxi]	$26,131,333
AN/SLQ 25 NIXIE torpedo decoys[lxxxii]	$1,588,000
Secure Communications Suite: EXCOMM[lxxxiii]	$63,442,000
MIDS[lxxxiv]	$4,278,667
CEC: AN/USG-2B Block II[lxxxv]	$8,280,000
Mk-12 IFF[lxxxvi]	$11,277,333
TOTAL COST/BMD LPD IIA (2015 AUD)	**$3,260,754,000**

Source: US Department of the Navy[105]

[lxxiii] All line items were converted from 2015 USD into 2015 AUD. See rule 2 in Appendix 1 for currency conversion details.

[lxxiv] One San Antonio Class LPD-17 costs $1,792,976,000 (2015 USD) including all electronics and weapons. LPD-17 is the baseline design for the LPD Flight IIA BMD variant and is assumed to be the approximate baseline cost of an LPD Flight IIA, without weapons and sensors. One LPD-17 without any electronics, sensors or weapons costs $1,491,627,000 (2015 USD). Including the AN/WSN-7(V) 1 Ring Laser Gyro Navigation System as well as the shipboard data/communications network and navigation system, the cost of an LPD-17 hull becomes $1,559,420,000 (2015 USD) or $2,079,226,667 (2015 AUD).

[lxxv] A DDG-51 IIA ship carries 96 Mk-41 VLS cells costing $109,225,000 (2015 USD). The BMD LPD IIA variant carries 288 Mk-41 cells, three times the number of a DDG-51. Thus 288 MK-41 cells costs $327,675,000 (2015 USD) or $436,900,000 (2015 AUD).

[lxxvi] Two RAM launchers costs $13,628,000 (2015 USD) or $18,170,667 (2015 AUD).

[lxxvii] Four Mk-38 25mm guns costs $11,139,000 (2015 USD), two Mk-38 guns costs $5,569,500 (2015 USD) or $7,426,000 (2015 AUD).

[lxxviii] A DDG-51 IIA carries an Aegis Weapons System based around the AN/SPY-1D PAR and Mk-99 FCS. A DDG-51 III carries an Aegis Weapons System based around the AN/SPY-6 PAR and Mk-99 FCS. In 2015 two Aegis Weapons Systems for DDG-51 IIAs costed $441,659,000 (2015 USD), with one DDG-51 IIAs system costing $220,829,500 (2015 USD). For 2016 funds are appropriated to acquire one DDG-51 IIA and one DDG-51 III at a total of $627,000,000 (2015 USD). The cost of the DDG-51 IIIs Aegis Weapons System was calculated by subtracting the cost of one DDG-51 IIAs system of $220,829,500 (2015 USD) from the 2016 appropriated funds of $627,000,000 (2015 USD). Therefore the estimated cost of a DDG-51 IIIs Aegis Weapons System is $406,170,500 (2015 USD) or $541,560,667 (2015 AUD).

[lxxix] One AN/SPQ-9B costs $8,100,000 (2015 USD) or $10,800,000 (2015 AUD)

[lxxx] Two DDG-51 AN/SQQ-89 packages costs $77,509,000 (2015 USD), one system costs $38,754,500 (2015 USD) or $51,672,667 (2015 AUD)

[lxxxi] Two AN/SLQ-32 & Mk-53 packages costs $39,197,000 (2015 USD), one package costs $19,598,500 (2015 USD) or $26,131,333 (2015 AUD)

[lxxxii] AN/SLQ 25 NIXIE torpedo decoys for one LPD-17 costs $1,191,000 in 2015 USD or $1,588,000 (2015 AUD)

[lxxxiii] Two DDG-51 EXCOMM units costs $95,163,000 (2015 USD), one unit costs $47,581,500 (2015 USD) or $63,442,000 (2015 AUD).

[lxxxiv] Two DDG-51 MIDS unit costs $6,418,000 (2015 USD), one unit costs $3,209,000 (2015 USD) or $4,278,667 (2015 AUD).

[lxxxv] One CEC for an LPD-17 costs $6,210,000 (2015 USD) or $8,280,000 (2015 AUD).

[lxxxvi] One LPD-17 Mk-12 IFF costs $8,458,000 (2015 USD) or $11,277,333 (2015 AUD)

Table 18. Force Structure Cost Estimate: Option Three

	#	Acquisition Cost/Unit	Annual O&S Cost/Unit	30 Year O&S Cost/Unit[lxxxvii]	Total 30 Year Cost/Class
Air Warfare Destroyer	3	n/a	n/a	n/a	$8,455,000,000
LPD Flight IIA BMD Variant	3	$3,260,754,000	$241,926,910	$7,257,807,290	**$31,555,683,871**
General Purpose Frigate[lxxxviii]	24	$1,042,347,011	$77,335,423	$2,320,062,702	**$80,697,833,110**
MH-60R Helicopters[lxxxix]	57	$49,403,724	$3,499,430	$104,982,914	**$8,800,038,338**
TOTAL SURFACE FORCE STRUCTURE COST (2015 AUD)					**$129,508,555,318**
ANNUAL FORCE STRUCTURE COST (2015 AUD)					**$4,316,951,844**

Source: ASPI & CEA & Commonwealth of Australia & Defense Security Cooperation Agency & Sagem & US Department of the Navy & US Navy[106]

[lxxxvii] See rule 1 in Appendix 1 for O&S cost assumptions

[lxxxviii] The US Navy Freedom & Independence Class LCS is the baseline design of the Lockheed SCS and Austal MMC General Purpose Frigates. One baseline LCS of either design costs $475.7 million (2015 USD) and $634.3 million (2015 AUD), see rule 2 of Appendix 1 for currency conversion details. The cost of all anticipated sensors, systems and weapons is estimated in Table 9 based on prices listed in the FY2016 US Navy Shipbuilding and Conversion estimates as well as from Defence Materiel Organisation 2013-2014 Major Projects Report. These prices were converted into 2015 AUD using rule 2 in Appendix 1.

[lxxxix] One MH-60R helicopter costs $37,052,793 in 2015 USD, based on figures listed in the FY2016 US Navy Shipbuilding and Conversion cost estimates. After currency conversion this figure becomes $49,403,724 in 2015 AUD. See rules 1 & 3 in Appendix 1 for currency conversion and O&S cost assumptions

Table 19. Force Structure Attributes: Option Three

Overall Force Structure	• 3 LPD Flight IIAs • 3 AWDs • 24 Frigates
Long-Term Ship Availability[xc]	• Up to 1 LPD • Up to 1 AWD • Up to 8 Frigates
Short-Term Ship Availability[xci]	• Up to 2 LPDs • Up to 2 AWDs • Up to 16 Frigates
Mk-41 VLS Availability	• LPDs: 3 x 288 cells • AWDs: 3 x 48 cells • Frigates: 24 x 32 cells **TOTAL: 1,776 cells**
MH-60R HELO Availability	• LPDs: 3 x 2 HELOs • AWDs: 3 x 1 HELO • Frigates: 24 x 2 HELOs **TOTAL: 57 HELOs**
Crewing Requirement	• LPDs: 3 x 396 crew • AWDs: 3 x 180 crew • Frigates: 24 x 66 crew **TOTAL: 3,312 personnel**
Crewing Efficiency	• Crew/VLS Cell: 1.86 • Crew/HELO: 58.1
Cost-Effectiveness (2015 AUD)	• $/VLS Cell: $72,921,484 • $/HELO: $2,272,079,918
Estimated Total Cost/30 Years (2015 AUD)	**$129.51 billion**
Estimated Cost/Year (2015 AUD)	**$4.32 billion**

[xc] Assuming one third of combatants will be available to deploy, on a long-term sustainable basis (deployment ratio 1:2)
[xci] Assuming two thirds of combatants will be available for a short-term surge, on an unsustainable basis (deployment ratio 2:1)

RECOMMENDATIONS

Under the 2009 White Paper, the RAN will revitalize its surface combatant force structure with three AWDs, eight Future Frigates and 20 OCVs. The problem is that it imposes seven constraints on the RAN in terms of: ship availability, critical operational enablers, resilience to force attrition, weapons inventories, rotary-wing naval aviation, crewing and cost.

This paper suggests three alternative surface combatant force structures to address these seven constraints. Option one is to acquire one additional AWD for a total of four ships, cancel the 20 OCVs and acquire 24 General Purpose Frigates of the Lockheed Martin or Austal designs (see Table 8 & 11). Option two is to retain the three AWDs, acquire 24 General Purpose Frigates as well as three DDG-51 Flight III ships (see Table 12 & 15). Option three is to retain the three AWDs, acquire 24 General Purpose Frigates and three BMD variants of the LPD Flight IIA class (see Table 16 & 19). These alternative force structures have been comparatively assessed in accordance with the following five criteria:

1. **Resilient Ship Availability**
2. **Area Defence Capability**
3. **General Purpose Frigate Capability**
4. **Minimal Crewing Requirement**
5. **Cost-Effectiveness**

1. Resilient Ship Availability

Option one would enable the deployment of up to two AWDs and eight General Purpose Frigates on a sustainable deployment ratio of 1:2, or alternatively three AWDs and up to 16 General Purpose Frigates on an unsustainable deployment ratio of 2:1 (see Table 20). It would also offer limited resilience to the risk of force attrition, with the capacity to lose one AWD and the General Purpose Frigates before the RAN would be incapable of continuously deploying one AWD and seven General Purpose Frigates.

In contrast, options two and three can deploy up to one high-capacity area defence ship[xcii], one AWD and 16 General Purpose Frigates on a sustainable deployment ratio of 1:2 (see Table 20). On an unsustainable basis, options two and three can deploy up to two high-capacity area defence ships, two AWDs and 16 General Purpose Frigates. Both options feature a total of six area defence ships[xciii] plus 24 General Purpose Frigates. Consequently, options two and three offer significantly greater resilience to force attrition than option one. This is because options two and three could lose up to three area defence ships and three General Purpose Frigates before either option would be incapable of continuously deploying one area defence ship and seven General Purpose Frigates.

All three options represent a significant improvement over the planned RAN surface combatant force structure. However, options two and three offer a substantially greater availability of area defence ships, as well as superior resilience to the risk of force attrition during combat operations. Therefore, in terms of providing the RAN with resilient ship availability, options two and three are the optimum choices.

[xcii] For the purpose of this paper a 'high-capacity area defence ship' is classed as a DDG-51 III or BMD LPD IIA.
[xciii] For the purpose of this paper an 'area defence ship' is classed as an AWD or DDG-51 III or BMD LPD IIA.

2. Area Defence Capability

Option one offers a total of 960 Mk-41 VLS cells and 52 MH-60R helicopters force-wide (see Table 20). In contrast, option two offers 1,200 VLS cells and 57 MH-60R helicopters, whereas option three offers 1,776 VLS cells and 57 helicopters (see Table 20). All three options represent a significant improvement over the planned RAN force structure that would provide an estimated 528 VLS cells and 39 helicopters. This is mostly due to the inclusion of 24 highly capable General Purpose Frigates that carry significant armaments, enabling them to defend other ships and freeing up area defence ships to focus on theatre-wide air defence, BMD or land-attack roles.

Option one offers a moderate capacity to provide a theatre air defence, BMD and/or land-attack capability. For instance, with a task force composed of four General Purpose Frigates and one AWD, each frigate could carry up to 128 ESSMs for localised air and surface defence. This would allow the sole AWD to dedicate its entire 48 cell VLS battery to long-range area defence weapons, including SM-6s for long-range air defence, SM-3s for BMD, TLAMs for land-attack or LRASMs for anti-ship strikes. In this instance, an AWD could be loaded out with 24 SM-6s, eight SM-3s, eight TLAMs and eight LRASMs to provide a low to moderate area defence capability.

In contrast, options two and three offer a substantially stronger multi-domain area defence capability for two reasons. Firstly, options two and three include three high-capacity area defence ships (DDG-51 III/BMD LPD IIA). A DDG-51 III has 96 MK-41 VLS cells that is three fold the firepower of an AWD, whereas a BMD LPD IIA has 288 Mk-41 VLS cells and is six fold the firepower of an AWD. For instance, a DDG-51 III could provide 48 SM-6s, plus 24 SM-3s, eight TLAMs and eight LRASMs, whereas a BMD LPD IIA could provide an ADF task force with 96 SM-6s, 96 SM-3s and 48 TLAMs plus 48 LRASMs.

Secondly, options two and three include area defence ships that support the significantly more powerful and highly sensitive S-band AN/SPY-6 AMDR. The ADMR has a substantially improved ability to detect stealthy air, surface and ballistic missile targets over the AN/SPY-1D (V) that is installed on the AWDs.[107] An improved stealth detection capability is of growing importance since several Asia-Pacific nations, including the Peoples' Republic of China, are fielding new generations of stealthy surface ship and aircraft designs.[108] These fundamental stealth technologies and industrial expertise can also be applied to increase the survivability of future cruise and ballistic missile designs, against US Navy and RAN area defence capabilities.

3. General Purpose Frigate Capability

In terms of a General Purpose Frigate capability all three options include 24 frigates of the Lockheed Martin SCS or Austal MMC designs (see Table 20). Either design would substantially improve the RAN's area defence capability since it would allow General Purpose Frigates to protect themselves plus nearby ships. In turn, this would enable the RAN's dedicated area defence ships to focus solely on providing deployed ADF forces with theatre air defence, BMD, land attack and anti-ship capabilities.

4. Minimal Crewing Requirement

The planned RAN force structure requires 2,528 personnel force-wide, whereas option one requires an estimated 2,304 personnel (see Table 20). Option two requires 2,952 personnel and option three requires 3,312 personnel (see Table 20). Based on these figures, option one appears to be the most efficient option, however looks can be deceptive. On average, the planned force structure requires 4.78 crew per Mk-41 VLS cell and 64.82 crew per MH-60R helicopter. Option one requires 2.4 crew per VLS cell and 44.3 crew per helicopter. Option two requires 2.46 crew per VLS cell and 51.79 crew per helicopter, whereas option three requires 1.86 crew per VLS cell and 58.1 crew per helicopter.

Overall, option one is the most efficient way of generating deployable numbers of helicopters, and option three is the most efficient way of generating deployable VLS cells, even in spite of its' very high crewing requirement. This is because option three includes three BMD LPD IIAs, each with crews of 396 and 288 VLS cells. To contextualise the significance of this efficiency, it is equivalent to crewing an AWD on 66 personnel instead of its current requirement of 180.

Although VLS cells and helicopters are both important to a multi-domain area defence capability, VLS cells have been given greater priority in this paper for two reasons. Firstly, the marginal helicopter increase across options one to three is five, and in contrast to the significant increase in VLS cells (see Table 20). Secondly, Mk-41 VLS cells support weapons to defend against endo and exo atmospheric threat spectrums[xciv], whereas helicopters can only target low-altitude threats within the atmosphere and are best used for ASW, ASuW, MIW or SAR operations. Conversely, VLS cells carry long-range anti-air, anti-ship, land-attack and BMD weapons that provide a protective umbrella, enabling helicopters to operate in a considerably more benign environment.

Overall, options one and three are rated as the most efficient ways of generating an area defence capability, since they have the lowest crew to VLS cell ratio. However, when balanced against other concerns such as the deployable number of VLS cells and the need for force attrition resilience, option two that is slightly less efficient may be preferred.

[xciv] **Endo-Atmospheric:** within the atmosphere; **Exo-Atmospheric:** outside the atmosphere

5. Cost-Effectiveness

The planned force structure is estimated to cost $2.85 billion annually or $85.62 billion over 30 years (2015 AUD). Option one is estimated to cost $3.33 billion annually or $100 billion over 30 years (2015 AUD). Option two is estimated to cost $4.14 billion annually or $124.33 billion over 30 years (2015 AUD). Option three is estimated at $4.32 billion annually or $129.51 billion over 30 years (2015 AUD). Although the planned force structure has the lowest 30 year cost, it places numerous constraints on the RAN and has an average cost of $162,153,924 per Mk-41 VLS cell or $2,195,314,663 per MH-60R helicopter (2015 AUD).[xcv] Option one has an average cost of $104,165,908 per VLS cell and $1,923,062,915 per helicopter (2015 AUD).[xcvi] Option two has an average cost of $103,609,801 per VLS cell and $2,181,258,978 per helicopter (2015 AUD).[xcvii] Option three has an average cost of $72,921,484 per VLS cell and $2,272,079,918 per helicopter (2015 AUD).[xcviii]

Overall, option three is the most cost-effective way of generating VLS cells, with an average cost of $72,921,484 per VLS cell (2015 AUD), whereas option one is most cost-effective at generating helicopters with an average cost of $1,923,062,915 per helicopter (2015 AUD). However, as articulated earlier VLS cells should be given a higher priority since they carry weapons that enable maritime helicopters to operate in a less threatening environment. Therefore, option three is rated by this paper to be the most cost-effective force structure.

[xcv] Calculated by dividing the total 30 year cost by the total force-wide number of VLS cells or helicopters.
[xcvi] Calculated by dividing the total 30 year cost by the total force-wide number of VLS cells or helicopters.
[xcvii] Calculated by dividing the total 30 year cost by the total force-wide number of VLS cells or helicopters.
[xcviii] Calculated by dividing the total 30 year cost by the total force-wide number of VLS cells or helicopters.

Table 20. Comparison of Force Structure Options

	Planned Force Structure	Option One	Option Two	Option Three
Overall Force Structure	• 3 AWDs • 8 Future Frigates • 20 OCVs	• 4 AWDs • 24 Frigates	• 3 DDG-51 IIIs • 3 AWDs • 24 Frigates	• 3 BMD LPD IIAs • 3 AWDs • 24 Frigates
Long-Term Ship Availability[xcix]	• 1 AWD • up to 3 Future Frigates • up to 7 OCVs	• Up to 2 AWDs • Up to 8 Frigates	• Up to 1 DDG • Up to 1 AWD • Up to 8 Frigates	• Up to 1 LPD • Up to 1 AWD • Up to 8 Frigates
Short-Term Ship Availability[c]	• 2 AWDs • 6 Future Frigates • 14 OCVs	• Up to 3 AWDs • Up to 16 Frigates	• Up to 2 DDGs • Up to 2 AWDs • Up to 16 Frigates	• Up to 2 LPDs • Up to 2 AWDs • Up to 16 Frigates
Mk-41 VLS Availability	• AWDs: 3 x 48 cells • Frigates: 8 x 48 cells **TOTAL: 528 cells**	• AWDs: 4 x 48 cells • Frigates: 24 x 32 cells **TOTAL: 960 cells**	• DDGs: 3 x 96 cells • AWDs: 3 x 48 cells • Frigates: 24 x 32 cells **TOTAL: 1,200 cells**	• LPDs: 3 x 288 cells • AWDs: 3 x 48 cells • Frigates: 24 x 32 cells **TOTAL: 1,776 cells**
MH-60R HELO Availability	• AWDs: 3 x 1 HELO • Frigates: 8 x 2 HELOs • OCVs: 20 x 1 HELO **TOTAL: 39 HELOs**	• AWDs: 4 x 1 HELO • Frigates: 24 x 2 HELOs **TOTAL: 52 HELOs**	• DDGs: 3 x 2 HELOs • AWDs: 3 x 1 HELO • Frigates: 24 x 2 HELOs **TOTAL: 57 HELOs**	• LPDs: 3 x 2 HELOs • AWDs: 3 x 1 HELO • Frigates: 24 x 2 HELOs **TOTAL: 57 HELOs**
Crewing Requirement	• AWDs: 3 x 180 crew • Frigates: 8 x 176 crew • OCVs: 20 x 29 crew **TOTAL: 2,528 personnel**	• AWDs: 4 x 180 crew • Frigates: 24 x 66 crew **TOTAL: 2,304 personnel**	• DDGs: 3 x 276 crew • AWDs: 3 x 180 crew • Frigates: 24 x 66 crew **TOTAL: 2,952 personnel**	• LPDs: 3 x 396 crew • AWDs: 3 x 180 crew • Frigates: 24 x 66 crew **TOTAL: 3,312 personnel**
Crewing Efficiency	• Crew/VLS Cell: 4.78 • Crew/HELO: 64.82	• Crew/VLS Cell: 2.4 • Crew/HELO: 44.3	• Crew/VLS Cell: 2.46 • Crew/HELO: 51.79	• Crew/VLS Cell: 1.86 • Crew/HELO: 58.1
Cost-Effectiveness[ci] (Billions 2015 AUD)	• $/VLS Cell: 0.1622 • $/HELO: 2.20	• $/VLS Cell: 0.1042 • $/HELO: 1.92	• $/VLS Cell: 0.1036 • $/HELO: 2.18	• $/VLS Cell: 0.073 • $/HELO: 2.27
Estimated Total Cost/30 Years (Billions 2015 AUD)	**$85.62 billion**	**$100 billion**	**$124.33 billion**	**$129.51 billion**
Estimated Cost/Year (Billions 2015 AUD)	**$2.85 billion**	**$3.33 billion**	**$4.14 billion**	**$4.32 billion**

[xcix] Assuming one third of combatants will be available to deploy on a long-term sustainable basis (deployment ratio 1:2)
[c] Assuming two thirds of combatants will be available for a short-term surge, on an unsustainable basis (deployment ratio 2:1)
[ci] Calculated by dividing the total 30 year cost of each force structure in 2015 AUD by the number of VLS cells/HELOs.

Concluding Remarks

Option three is the best pathway for the future RAN surface combatant force. This is because it substantially improves ship availability and fleet resilience to force attrition, it offers the highest grade of multi-domain area defence capability to deployed ADF forces, through three BMD LPD Flight IIA ships and 24 General Purpose Frigates, it is also the most efficient and cost-effective way of generating deployable VLS cells (see Table 20). However option three may be unaffordable at an estimated 30 year cost of $129.51 billion or $4.32 billion per annum (see Table 20). This is particularly given the pressure that is likely to be exerted on future Australian Government budgets, as outlined in the 2015 Intergenerational Report. Furthermore, option three is likely to increase the future risk of more frequent and severe RAN crew shortages, since it requires an additional 406 personnel over the RAN's current surface combatant crewing requirement of 2,906 personnel (see Table 2 & 20).

If option three is determined by the Department of Defence and/or the RAN to be unattainable, option one is the next best alternative. This is because it provides improved ship availability, marginally improved resilience to force attrition, a low to medium area defence capability and a General Purpose Frigate capability, in a relatively efficient and cost-effective way. Option one is relatively efficient since it provides the second lowest crew to VLS cell ratio, and the lowest crew to helicopter ratio, but is also relatively cost-effective since it has the third lowest cost per VLS cell and the lowest cost per helicopter (see Table 20). However the most attractive aspect of option one is that reduces the RANs surface combatant crewing requirement by 602 personnel (from 2,906 to 2,304) and incurs the lowest 30 year cost out of all three options, at $100 billion over 30 years or $3.33 billion per annum (see Table 2 & 20).

Furthermore, the only substantial difference between options one and two or three is the addition of high-capacity DDG-51 III or BMD LPD IIA area defence ships. If it is feasible for the Australian Government to purchase completed ships of either type from US shipyards, option one could be pursued with the future option of advancing to options two or three should strategic circumstances rapidly deteriorate.

APPENDIXES

Appendix 1. Costing Methodology

1	**O&S Costs**	Operating & Sustainment (O&S) covers all operation, maintenance, modification, training and support costs necessary to sustain a military system, from its initial deployment until it reaches the end of its service-life.[109] The general rule of military system sustainment is one third for acquisition and two thirds for O&S sustainment costs.[110] However, the US Department of Defense provides more accurate, platform-specific sustainment cost data that is the basis of all O&S cost calculations in this paper.[111] According to the US Department of Defense surface ship O&S costs average at 69% of a military systems entire life-cycle costs, with the other 31% for acquisition, including initial Research Development Test & Evaluation (RDT&E).[112] Similarly rotary-wing aircraft O&S costs average at 68%, with the remaining 32% for acquisition, including RDT&E.[113] This paper also assumes that surface ships and rotary-wing aircraft will have a 30 year service-life.
2	**Currency Conversion**	All currencies were converted based on the assumption that $1 AUD equals $0.75 USD.
3	**Inflation Indexation**	All figures were indexed as necessary using the Reserve Bank of Australia Inflation Calculator and the US Inflation Calculator. • RBA Inflation Calculator: http://www.rba.gov.au/calculator/ • US Inflation Calculator: http://www.usinflationcalculator.com/

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