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Navy Future Fleet Platform Architecture Study

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Executive Summary

The FY16 National Defense Authorization Act Section 1067 directed the Secretary of Defense to perform three independent studies of alternative future fleet platform architectures for the Navy in the 2030 timeframe. In response, the Chief of Naval Operations Director of Assessment Division, OPNAV N81, asked the MITRE Corporation's National Security Engineering Center (NSEC), a Federally Funded Research and Development Center (FFRDC), to deliver one of the three studies. The due date to submit this study to the congressional defense committees was originally specified as 1 April, 2016, one month after MITRE's actual funded start date of 29 February. MITRE was subsequently authorized a 90-day extension with a final report due date of 1 July, 2016. At the request of OPNAV N81, MITRE also submitted an interim report on 22 March, 2016.

Objectives

The recommended fleet architecture should include:

- The numbers, kinds, and sizes of vessels, the numbers and types of associated manned and unmanned vehicles, and the basic capabilities of each of those platforms;
- Other information needed to understand that architecture in basic form and the supporting analysis;
- Deviations from the current Annual Long-Range Plan for Construction of Naval Vessels required under section 231 of title 10, United States Code;
- Options to address ship classes that begin decommissioning prior to 2035; and
- Implications for naval aviation, including the future carrier air wing and land-based aviation platforms.

Approach

The study shall consider the following:

- The National Security Strategy of the United States (U.S.);
- Potential future threats to the U.S. and to U.S. naval forces in the 2030 timeframe;
- Traditional roles and missions of U.S. naval forces;
- Alternative roles and missions for U.S. naval forces;
- Other government and non-government analyses that would contribute to the study through variations in study assumptions or potential scenarios;
- The role of evolving technology on future naval forces, including unmanned systems;
- Opportunities for reduced operation and sustainment costs; and
- Current/projected capabilities of other U.S. armed forces that could affect force structure capability and capacity requirements of United States naval forces.

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Findings

- **The future international security environment continues to be complex and uncertain.** The current Department of Defense (DoD) planning, programming and budgeting process is being redirected by the national security challenges posed by China, Russia, North Korea, Iran, and the Islamic State.
- **The U.S. and its allies have maintained a decisive technological advantage for more than 40 years, but this advantage is rapidly disappearing as the guided missile age reaches full maturity.** Missile speeds, elusiveness, and precision – for example – all continue to increase. Coastal defense missile batteries can cover a radius of 700 or 800 miles today, compared to 70 or 80 miles just a few years ago. Supersonic anti-ship missiles that currently travel at Mach 2 will be supplanted by hypersonic missiles that will travel at speeds well in excess of Mach 5. As the costs of these weapons become increasingly inexpensive, they will continue to proliferate and adversary inventories will continue to increase.
- **Advances in sensor technology, including new passive and active methods, and its commercialization enable detection and targeting at extreme ranges.** Weapons with extended ranges are not fully effective unless an adversary can also identify targets at these ranges. In the past, nations spent enormous resources to build sensing capabilities that are commercially available today. For example, BlackSky plans to launch a sixty satellite constellation by 2019 that will provide in excess of 40 re-visits per day in the equatorial region [1]. The Navy should continue to invest in capabilities to prevent adversary targeting, but cannot rely on ships remaining hidden for extended periods in a 2030 environment.
- **The Navy's current force structure is essentially a scaled down version of the balanced force that exited World War II.** This force consists of attack submarines; aircraft carriers; large and small surface combatants; amphibious ships; and combat logistics. The only fundamentally new platform since World War II is the ballistic missile submarine, which is part of the nuclear triad.
- **Force structure decisions based on the post-Cold War peace dividend do not reflect the current national security environment.** In 2014, OPNAV N81 completed a force structure assessment to determine 2030 fleet warfighting requirements. After reviewing the original 2012 N81 analyses and the 2014 update, MITRE assessed the force structure needed to defeat one and deter another near-peer adversary in a revised scenario, which is more representative of the current world situation. Table 1 shows the expected FY30 force with the current 30-year shipbuilding plan, results of the OPNAV N81 force structure analysis in 2014, and the excursion performed by the study team using the N81 approach. Details of the excursion are contained in the classified annex. While this force structure level is not recommended, it does imply that the current Navy force structure and capabilities would not be sufficient to meet the DSG given the current world situation.

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Table 1. Summary of FY30 Force Structure Analysis

Ship Class	Today¹	FY30 Force: 30-Year Plan²	2014 Navy Force Structure Analysis³	Revised Defeat / Hold⁴
Aircraft Carrier	10	11	11	14
Large Surface Combatant	22	95	88	160
Small Surface Combatant	67	40	52	46
Ballistic Missile Submarine	14	11	12	12
Guided Missile Submarine	4	0	0	2
Attack Submarine	54	42	48	72
Amphibious Warfare Ships	30	37	38	38
Support & Auxiliary Ships	72	68	63	70
Total No.	273	304	312	414

1. <http://www.history.navy.mil/research/histories/ship-histories/us-ship-force-levels.html#2000>

2. Ronald O'Rourke, *Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress*, Congressional Research Service, 8 January 2016.

3. OPNAV N81, *Force Structure Analysis*, Briefing, SECRET//NOFORN, 2014.

4. Results of MITRE analysis using the OPNAV N81 approach with different scenarios.

- Navy's budget is insufficient to fund required force levels.** The Navy's budget is insufficient to develop, procure, operate, and sustain all the forces need to meet the revised defeat / hold scenario force structure. In addition, budget instability forces the Navy to make acquisition decisions that undermine affordability initiatives. By the end of 2016, the national debt will be \$20 trillion dollars – more than triple what it was on 11 September 2011 – and for the last four years, the Navy has been operating under reduced top-lines and significant shortfalls. There will likely continue to be increasing pressure on the procurement accounts, which in turn threatens the near-term health of the defense industrial base.

Recommendations

Table 2 contains a list of recommended modifications to the Navy's 30-Year shipbuilding plan. The analysis of a revised defeat / tailored hold scenario, summarized in Table 1, suggests a shortfall of 110 ships by FY30 with the current 30-year shipbuilding program. Building 110 additional ships is unrealistic, so MITRE makes recommendations across the full scope of the Future Fleet Architecture to improve its overall effectiveness. However, the only means achieving both effectiveness and capacity, within the constraints of affordability, is to build a mix of exquisite (i.e., high), capable (i.e., moderate), and expendable (i.e., low) platforms.

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Table 2. Summary of Recommendations for the 15-Year Shipbuilding Plan

Recommendation	Increase Effectiveness	Reduce Cost	Increase Capacity
1. Immediately cancel the Littoral Combat Ship (LCS) productions.		√	
2. Procure an additional DDG-51 per year, using funds available from LCS termination, until a new frigate for Integrated Air Missile Defense (IAMD) is under construction.	√		
3. Augment existing CG-47s and DDG-51s with a magazine ship to increase weapon capacity and provide a long-range strike capability to the surface force.	√		√
4. Fix the naval aviation shortfall by deferring or reducing the F-35C procurement for additional F/A-18 E/Fs.			√
5. Develop an aerial layer for Integrated Air Missile Defense (IAMD) that is integrated with the corresponding IAMD platforms in the surface force.	√		
6. Delay the <i>Ford</i> class CVN procurement to align with the number of CVWs.		√	
7. Modify the <i>Ford</i> design or develop a conventional alternative to reduce cost to less than \$11 billion.		√	
8. Continue <i>America</i> class amphibious assault ship procurement but consider a small carrier option, with catapults for fixed-wing flight operations, as a potential alternative in the late 2020s	√		
9. Do not procure any more <i>San Antonio</i> class LPDs beyond what is planned		√	
10. Consider some near-term alternatives to the current plans for the LXR class of ships to support disaggregated expeditionary operations.		√	√
11. Continue to build two <i>Virginia</i> class SSNs per year, each with VPMs after 2019.	√		√
12. License and produce diesel submarines as lower cost platform to augment the SSN force.		√	√

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The tradeoffs embedded within these recommendations are: 1) additional large surface combatants (LSCs) at the expense of small surface combatants (SSCs); 2) more attack submarines (SS); and 3) introduce lower cost ship concepts to pay for increased SS production. The total estimated shipbuilding cost for this battle force is about \$257 billion through FY30, which translates into an average shipbuilding budget of \$17.1 billion per year (not including support ships). Given the average Navy shipbuilding budget of \$16.9 billion between 2016 and 2025 (including support ships), the proposed shipbuilding plan is reasonable. It delivers 20 additional ships and a more capable force by 2030 within the existing shipbuilding budget, potentially with some moderate increases. Table 13 in the conclusions section provides the recommended 15-year shipbuilding plan for the Navy.

Critical Enablers

There are a number of additional factors, other than ships, that contribute to the overall effectiveness of the force:

- **Aircraft procurement.** The recommendation to defer or reduce the F-35C procurement for additional F/A-18 E/Fs in Table 2 impacts the aircraft procurement line in the Navy budget, but has implications for the shipbuilding line.
- **Weapons procurement.** Three capabilities in this report require procuring four new weapon systems, in addition to more of what the Navy already has in the inventory. The development of these new weapons and procuring them in numbers sufficient to matter in 2030 impacts the weapons procurement budget.
- **Integrated Kinetic Effects.** A strategy is needed to defeat large raids of anti-ship cruise and ballistic missiles with a combination of long-range, mid-range, and point defense capabilities – from both surface combatants and aircraft – as well as more long-range offensive strike options. Implicit within this strategy is the ability to: 1) place naval forces in positions that are useful, 2) coordinate the employment of different weapons and platforms to mitigate the raid or achieve the desired effect, and 3) optimize the use of the force (e.g., appropriate target-weapon pairing). This implies: assured command and control (C2) functions for planning and coordination across the force, tactical data links to support cooperative engagement, and fusing data from both tactical and national sensors to detect, track, and identify targets.
- **Integrated Non-Kinetic Effects.** The ability to control a ship's signature, create false targets, seduce adversary weapons away from ships, etc. are all key capabilities to create uncertainty within an adversary's kill chain and reduce their effectiveness. While this study mainly focuses on a range of kinetic capabilities and effects required by the fleet, non-kinetic effects are also needed to increase the survivability of the force. The ability to reduce adversary re-visit rates over the naval force or getting them to commit to the wrong area correspondingly reduces the number and, potentially, the size of raids the naval force must overcome. Also, no defense is perfect, so it is critical to have non-kinetic effects to defeat whatever missiles or platforms leak through the Integrated Air and Missile defense (IAMD) of the naval force. Similarly, cyber effects are a critical aspect of future wars and are described in the classified annex to this report.

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- **Undersea Enablers.** “Networked undersea forces will act as a key to unlock the door for decisive force to enter the fight and seize and maintain the initiative.” [2] To achieve this end, the capability to connect submarines, autonomous unmanned vehicles, distributed sensor networks, undersea cables, and a variety of other systems is a critical enabler for not only building and sharing a comprehensive understanding of the undersea environment, but maintaining a comparative advantage in the undersea domain. Similarly, the global proliferation of stealthy submarines with advanced capabilities and the growing threat that these undersea forces pose necessitates that the Navy must sustain and recapitalize its fixed, mobile, and deployable acoustic arrays that provide vital tactical cueing to anti-submarine warfare (ASW) forces.

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Introduction

The sea connects the nations of the world, even those that are landlocked. Geoffrey Till described the importance of the sea as a: [3]

- **Resource.** As energy becomes increasingly scarce and prices rise, competition for sources under the ocean will escalate. The Pacific Outer Continental Shelf Region has an estimated cumulative production and reserves of 1,604,497,165 billion barrels of oil and 2,362 trillion cubic feet of natural gas [4].
- **Medium of transport.** According to the United Nations Conference on Trade and Development, maritime transport is the backbone of international trade and a key engine driving globalization. Roughly 80 percent of global trade by volume and over 70 percent by value is carried by sea and is handled by ports worldwide [5].
- **Medium of information.** Submarine cables are a critical enabler of today's global information infrastructure. A common misconception is that most of today's international communications use satellites, when over 95 percent of this traffic is actually delivered via submarine fiber-optic cables [6]. Terabit Consulting estimates the submarine cable market averages \$2.25 billion worth of investment, with 50,000 kilometers of deployment, per year. As of 2012, lit transatlantic and transpacific capacity was 19.8 and 15.2 Tbps, respectively [7].
- **Medium for dominion.** Naval forces are inherently flexible, self-sustaining, and capable of projecting power from the sea into the littoral regions of the world whenever needed. By the end of December 2001, naval aircraft from aircraft carriers conducted over 4,900 strike sorties in Afghanistan – a land locked country over 700 miles away from the carriers operating in the Indian Ocean – and accounted for 75 percent of all strike sorties by U.S. forces. [8]

Sea power is the ability to use the oceans for military and/ or commercial purposes while precluding an adversary from do so when required [9]. As U.S. security and prosperity are inextricably linked with those of others, U.S. maritime forces will be deployed to protect and sustain the peaceful global system comprised of interdependent networks of trade, finance, information, law, people, and governance [10].

U.S. Maritime Strategy

The U.S. Maritime Strategy employs global reach, persistent presence, and operational flexibility to accomplish six key tasks, or strategic imperatives. Where tensions are high or the U.S. wishes to demonstrate its commitment to security and stability, U.S. maritime forces will be characterized by *regionally concentrated, forward-deployed task forces with the combat power* to limit regional conflict, deter major power war, and – should deterrence fail – win wars as part of a joint or combined campaign. In addition, *persistent, mission-tailored maritime forces will be globally distributed* to contribute to homeland defense-in-depth, foster and sustain cooperative relationships with an expanding set of international partners, and prevent or mitigate crises. [10]

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The Center for Naval Analyses (CNA) succinctly captured this strategy for sea power when it described a “global navy” that is dominant, ready, and influential. A *dominant naval force* must, when measured against potential adversaries and challengers, be able to exert sea control when and where needed; to sustain operations in these areas; to support and influence operations on land; and to ensure freedom of movement for a nation’s forces. A *ready naval force* is deployed globally to quickly respond to crises with its deployed, as well as surge, forces adequately trained, manned, and equipped. An *influential naval force* is a visible force for reassuring allies and partners that the nation is committed to them and has resolved to place its military forces in harm’s way in support of its commitments. [11]

National Security Environment

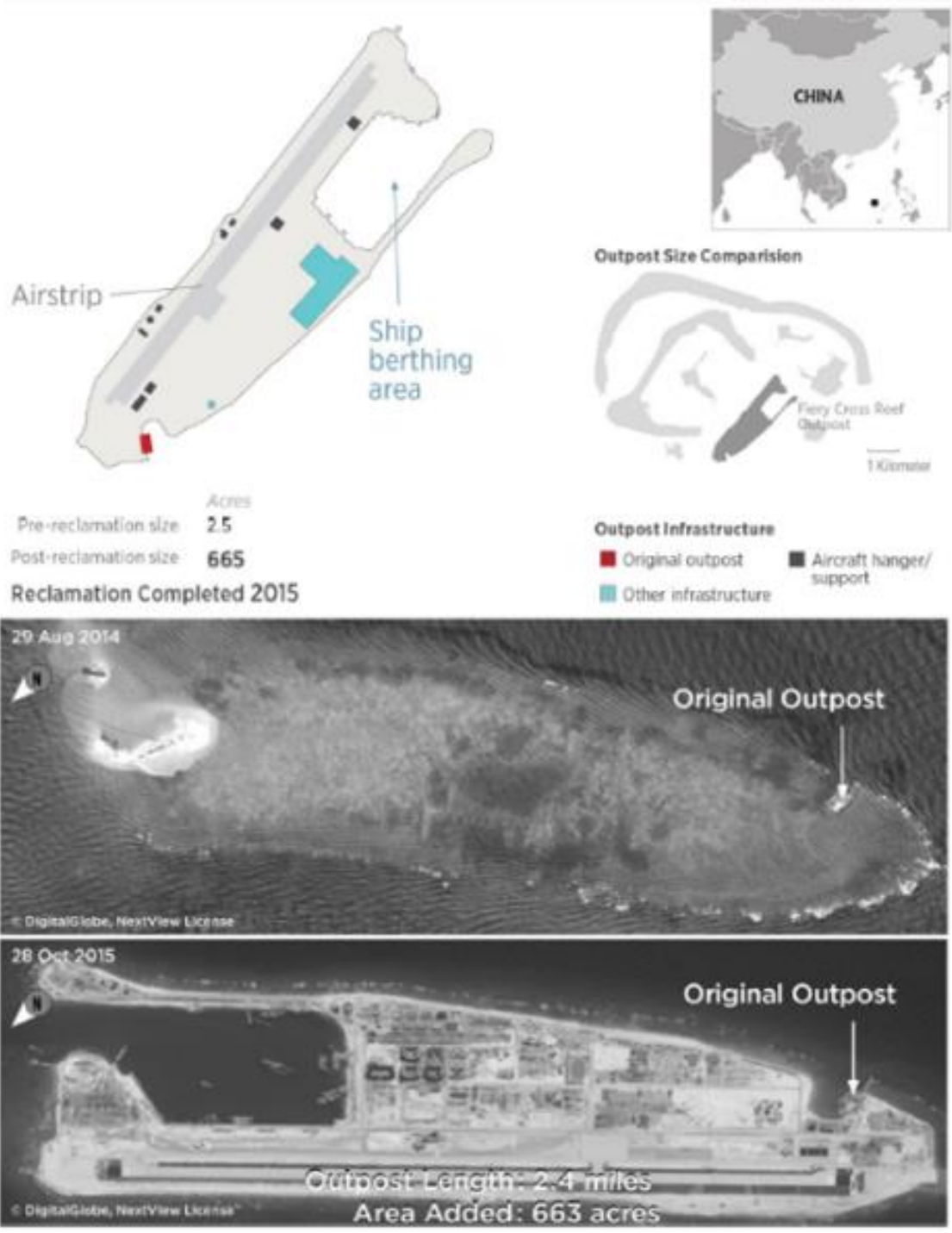
The current national security environment is very complex when compared to the environment only a few years ago. The end of the Cold War in 1991 ushered in a period of peace, which resulted in a drawdown of U.S. forces as part of the “peace dividend”. The last future fleet architecture study was authorized in the FY04 Defense Appropriations Bill (House Resolution 1588, passed as Public Law 108-136) and tasked the Secretary of Defense to submit two studies to Congress in January 2005. The major national security challenge post-9/11 was addressing the ongoing conflicts in Iraq and Afghanistan, with some consideration of the U.S. force structure after the conclusion of Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). Today, however, the U.S. currently faces a myriad of challenges, from five major state and non-state actors, that were not foreseen five to ten years ago:

- **China.** Claims roughly 80 percent of the South China Sea inside their “nine-dash line” and has recently accelerated construction and militarization of its outposts in the Spratly Islands, as shown in Figure 1. These outposts include harbors, communications, surveillance systems, logistics facilities, and airfields to enhance both its presence in the South China Sea and ability to project sea control in the region. China’s building of these outposts in disputed territories have significantly increased tensions in the region.
- **Russia.** Has become increasingly aggressive over the last couple of years. Russia annexed Crimea from the Ukraine in 2014, invaded the Republic of Georgia, and directly intervened in Syria’s civil war in 2015 with both ground and air forces. Formal Russian nuclear doctrine contemplates the employment of nuclear strikes in an “escalate to de-escalate” strategy that conveys to an adversary Russia’s willingness to employ nuclear retaliation in the conflict. Presumably, this doctrine is directed at the United States and its North Atlantic Treaty Organization (NATO) allies. [12]
- **North Korea.** Continues to conduct provocative missile tests and claims against the United States and South Korea. However, the world was surprised by North Korea conducting a sophisticated cyber-attack against Sony Pictures in retaliation for the production of a movie [13]. Recent investigations into hacking of the Society of Worldwide Interbank Financial Telecommunications (SWIFT) system, used to transfer funds between 10,000 member institutions around the world, revealed cyber tools identical to those employed in the attack on Sony Pictures [14].

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Figure 1. China's Fiery Cross Reef Outpost



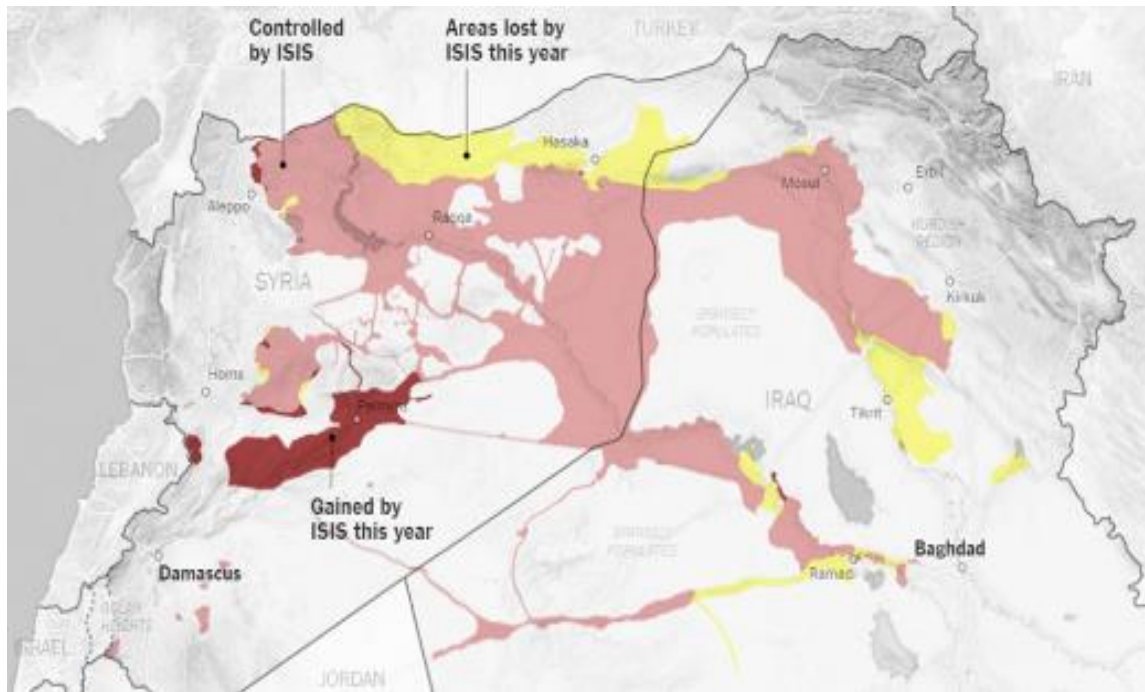
Source: Department of Defense, Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2016, 26 April 2016.

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- **Iran.** Signed a nuclear agreement with the United States in 2015, which lifted sanctions against Iran in exchange for it scaling back its nuclear program. Yet, the United States Navy recently intercepted arms shipments from Iran to Houthi fighters in Yemen [15]. Iran also recently tested a ballistic missile with a range of 850 miles [16] and purchased Russian S-300 missiles for its air defense system [17].
- **Terrorism.** Al Qaeda's influence diminished since 9/11 and, with the death of Osama Bin Laden in 2011, it was hoped the fight against terrorism had turned a corner. However, the Islamic State proclaimed a worldwide Caliphate in June 2014 and seized territory in Iraq (see Figure 2). The Islamic State claimed responsibility for the recent attacks in Paris and Belgium that killed 130 and 32 civilians, respectively. The potential transfer of Russian Yakhont anti-ship cruise missiles from Syria to Hezbollah illustrates how the current, complex security environment facilitates weapons proliferation, even to non-state actors [18].

Figure 2. Gains and losses shown occurred between 5 Jan and 14 Dec 2015



Way Ahead

The purpose of this study is to assess alternative future fleet platform architectures for the U.S. Navy in the 2030 timeframe. The report next examines the historical context for the current fleet platform architecture and, based on the current U.S. Maritime Strategy and national security environment, assesses the suitability of the current 30-year shipbuilding plan for the expected 2030 environment. In subsequent sections, the report describes a counter Anti-Access/Area Denial (A2AD) strategy, guiding principles for a future force architecture, and a detailed set of analyses and recommendations for the surface combatant, aircraft carrier, submarine, and amphibious force structure.

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Fleet Force Structure

The pedigree of the force structure of today's U.S. Navy can be traced back to the wartime experience and lessons learned from World War II. The Pacific theater was an offensive campaign with power projected from fast moving task forces, based around aircraft carriers, and an island hopping campaign spearheaded by amphibious forces. The U.S. Navy also waged a devastating campaign of unrestricted submarine warfare against Japan. By the end of the war, U.S. and allied submarines sank 4,861,300 tons of Japanese ships, which is roughly 54 percent of their total losses. Carrier aviation, by contrast, sank 1,452,900 tons, or 16 percent of the total losses, of Japanese ships [19]. The Atlantic theater was a defensive campaign focused on protecting the maritime lines of communication used to re-supply Allied forces from German submarines. At the end of World War II, the U.S. Navy consisted of roughly 6,768 ships – including 28 fleet carriers, over 250 submarines, and enough amphibious lift for over 400,000 troops – and the primary issue was what portions of this force should be retained, vice what to build.

The planning for the post-World War II fleet began in late 1943 and was focused around three broad principles [20]:

- **A balanced Navy.** The Navy planned to keep each type of ship and weapon on active duty until it was clear that it was no longer operationally useful. The ratio of aircraft carriers to surface combatants, for example, were determined by the relationships defined during World War II.
- **A forward Navy.** The idea was to have oversea bases and protected lines of communication to enable naval forces to be on, or near, the scene of any disturbance to quickly deal with it and prevent further escalation.
- **A Navy second to none.** Planners defined this as superiority in each ship type when compared to the next largest Navy.

Figure 3 depicts the force structure of the U.S. Navy from 1946 to the present. Despite the post-World War II planning, the number of Navy ships declined precipitously to roughly 600 ships by 1950, less than 10 percent of the force in 1945. The National Security Council Memorandum 68 (NSC-68), published in 1950, articulated a national strategy of containment against the Soviet Union. NSC-68 stated:

"We have failed to implement adequately these two fundamental aspects of "containment". In the face of obviously mounting Soviet military strength ours has declined relatively. Partly as a byproduct of this, but also for other reasons, we now find ourselves at a diplomatic impasse with the Soviet Union, with Kremlin growing bolder..."

and

"It is true that the United States armed forces are now stronger than ever before in other times of apparent peace; it is also true that there exists a sharp disparity between our actual military strength and our commitments. The relationship of our strengths to our present commitments, however, is not alone

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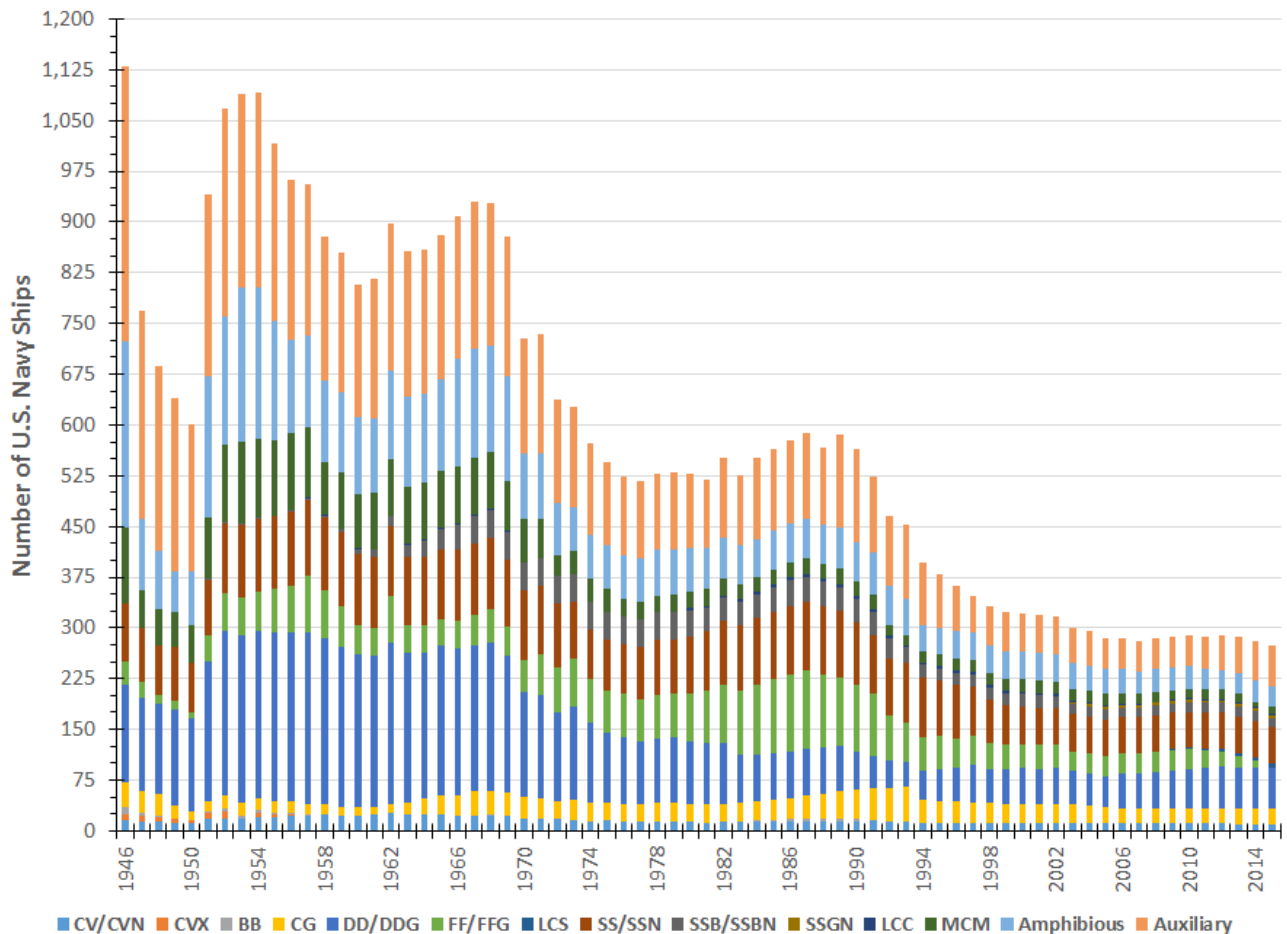
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the governing factor. The world situation, as well as commitments, should govern; hence, our military strength more properly should be related to the world situation confronting us. When our military strength is related to the world situation and balanced against the likely exigencies of such a situation, it is clear that our military strength is becoming dangerously inadequate."

The NSC-68 planning articulated the need for 12 aircraft carriers, 100 attack submarines, and amphibious lift for 39,000 troops [20].

Figure 3 illustrates the concept of a balanced force, since the ratios between different types of platforms has remained approximately the same for the last 70 years. Figure 3 also illustrates how the fleet force structure grows or shrinks relative to the world situation. The major peaks coincide with the Korean War, Vietnam War, and end of the Cold War. The salient question is whether the current 273 ship force is sized and structured appropriately given the current world situation and commitments of the United States.

Figure 3. Size and Composition of the U.S. Navy since World War II



Source: <http://www.history.navy.mil/research/histories/ship-histories/us-ship-force-levels.html#2000>

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Other Navies

Post-World War II Navy planners envisioned a fleet that was “second to none”. Their definition of this concept requires a comparison of the U.S. battle force today to that of the Russia and China, the second and third largest navies respectively. The United States maintains unprecedented superiority in numbers of aircraft carriers and large surface combatants. The Chinese and Russian superiority in small surface combatants – namely frigates, corvettes, missile boats, etc. – is a consequence of their emphasis on a regional force. The differential in attack submarines, and to a lesser extent amphibious assault ships, could be a cause for concern. During World War II, ship classes in different navies were fairly comparable. Today, however, a significant difference exists in the quality of U.S. ships and their counterparts in other navies. The broader question is the differential, in terms of an ability to project power to either gain sea control or influence events on land, of the respective battle forces, not simply numbers.

Table 3. Summary of U.S., Chinese, and Russian Naval Battle Forces in 2016 and 2020

Ship Class	U.S. 2016 ¹	China 2016 ²	Russia 2016 ³	U.S. 2020 ⁴	China 2020 ⁵	Russia 2020 ⁶
Aircraft Carrier	10	1	1	11	2	1
Large Surface Combatant	84	30	19	95	34	11
Small Surface Combatant	5	72	86	33	88	106
Ballistic Missile Submarine	14	5	13	14	5	12
Guided Missile Submarine	4	0	7	4	0	6
Attack Submarine	54	63	40	52	73	33
Amphibious Warfare Ships	30	68	19	33	55	22
Total No.	201	235	185	242	257	191

1. <http://www.history.navy.mil/research/histories/ship-histories/us-ship-force-levels.html#2000>

2. https://en.m.wikipedia.org/wiki/List_of_active_People%27s_Liberation_Army_Navy_ships

3. https://en.m.wikipedia.org/wiki/List_of_active_Russian_Navy_ships

4. Ronald O'Rourke, *Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress*, Congressional Research Service, 8 January 2016.

5. Ronald O'Rourke, *China Naval Modernization: Implications for U.S. Navy Capabilities – Background and Issues for Congress*, Congressional Research Service, 31 March 2016

6. Dmitry Gorenburg, *Russian Military Reform: Tracking Developments in the Russian Military*, Harvard University, 29 October 2015.

Note: This table does not include patrol boats, mine countermeasure ships, combat logistics ships or other support/auxiliary ships.

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U.S. Power Projection

An aircraft carrier and its air wing are capable of delivering significant firepower over a sustained period of time. For example, the raid by the Fast Carrier Task Force 58 – consisting of five fleet and four light carriers – on the Japanese-held Truk Atoll delivered 2,200 strike sorties and 740 tons of ordnance, over less than two days from a launch point 78 nautical miles away [21]. In 1997, USS *Nimitz* successfully executed a high-intensity strike campaign over four days, during Joint Task Force Exercise 97-2, that generated 975 fixed-wing sorties and delivered 1,336 bombs, roughly 334 tons, on targets within 200 nautical miles [22]. By the end of December 2001, naval aircraft from two aircraft carriers conducted over 4,900 strike sorties in Afghanistan, a land locked country over 700 miles away from the carriers operating in the Indian Ocean [23]. Aircraft carriers are capable of sustained power projection assuming that they can be protected and their air wings do not suffer significant losses during the operation.

The U.S. developed the vertical launch system (VLS) as part of the Aegis combat system. VLS canisters can be equipped with land attack, anti-ship, and anti-air missiles. Large surface combatants of the U.S. are equipped with the following number of VLS cells: *Ticonderoga* class cruisers have 122, *Arleigh Burke* class destroyers have 96, and *Zumwalt* class destroyers have 80. This gives the current U.S. surface fleet roughly 8,800 cells of missiles capable of long-distance engagements and, depending on the load out, operational flexibility. For example, the Block IV Tomahawk Land Attack Missile (TLAM) E carries a conventional, 1,000-pound warhead up to ranges of 900 nautical miles [24]. Seven *Arleigh Burke* class destroyers fully loaded with TLAMs could deliver in excess of 334 tons of ordnance on targets within 900 nautical miles, which is comparable to what the USS *Nimitz* accomplished in the earlier example.

U.S. attack submarines are equipped with both torpedoes and missiles for land attack. Most U.S. submarines have VLS cells: Flight 2 and 3 *Los Angeles* class submarines have 12, *Virginia* class submarines have 12, and converted *Ohio* class submarines have 154. Consequently, the current United States submarine fleet, in addition to a normal complement of torpedoes for maritime interdiction, has roughly 1,100 cells of missiles capable of long-distance, land attack.

The U.S. has a sufficient number of amphibious ships to deliver nine Marine Expeditionary Units (MEUs) with all of their equipment and supplies. Each MEU has a Ground Combat Element (GCE) based on a reinforced infantry battalion with an artillery, amphibious assault vehicle, light armor reconnaissance, and logistics platoon. It also has an Air Combat Element (ACE) with detachments of rotary- and fixed-wing aircraft.

Table 4 summarizes a cursory analysis for the offensive capabilities of the 2016 battle force of the United States, China, and Russia. The analysis shows the U.S. Navy has a decisive advantage in terms of striking power from aircraft carriers, surface combatants, and amphibious forces. Clearly, the quality and capacity of U.S. Navy ships exceeds that of their counterparts in other fleets. However, while the ships of the U.S. Navy are second to none, a question that still must be answered is whether their military strength is commensurate with their commitments.

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Table 4. Summary of U.S., Chinese, and Russian Naval Offensive Power in 2016

Ship Class	U.S. Estimate	China Estimate	Russia Estimate
Aircraft Carriers	10	1	1
Total Surface Combatant Vertical Launch Inventory	8,800	1,800	1,700
Total Surface Combatant Horizontal Launch Inventory	230	620	480
Total Submarine Vertical Launch Inventory	1,100	0	400
Total Submarine Horizontal Launch Inventory	2,000	1,100	626
Amphibious Troop Lift	30,000	11,000	6,000
Amphibious Vehicle Lift	126	286	100
Amphibious Rotary Wing	207²	16⁴	0
Amphibious Fixed Wing	54³	0	0

1. A MEU Ground Combat Element has 8 Light Armored Vehicles (LAVs) and 6 M777A2 artillery pieces.
2. A MEU Air Combat Element has 12 MV-22Bs, 4 CH-53Ks, 4 AH-1Ws, and 3 UH-1Ns.
3. A MEU Air Combat Element also has 6 AV-8Bs, which will soon be replaced by F-35Bs.
4. The *Yuzhao* class amphibious transport dock ship carries 4 Z-8 Super Frelon helicopters.

Force Structure Analysis Excursion

OPNAV N81 periodically performs force structure analyses to assess the suitability of the planned naval force. The Defense Strategic Guidance (DSG) is based on a strategy to defeat one adversary while deterring, or holding, another and defending the homeland [25]:

“Even when U.S. forces are committed to a large-scale operation in one region, they will be capable of denying the objectives of -- or imposing unacceptable costs on -- an opportunistic aggressor in a second region”

The force structure analysis applies the DSG, using approved Defense Planning Guidance scenarios, and evolving threats, planned capabilities, expected force structure, etc. to set near-future force structure objectives. Global presence estimates based on historical Combatant Commander (COCOM) requirements are used to reflect global presence requirements while the defeat and hold strategy is executed.

A OPNAV N81 force structure assessment determined the 2030 fleet warfighting requirements. MITRE, after reviewing the original 2012 N81 analyses and the 2014 update, assessed the force structure to defeat one and deter another near-peer adversary – a revised defeat and hold scenario more representative of the current world situation. Table 5 shows the FY30 force with the current 30-year shipbuilding plan, the 2014 OPNAV N81 force structure results, and the revised defeat / hold excursion performed by MITRE. Details of the excursion are contained in a classified appendix. While this force structure level is not recommended, it does imply that the current Navy force structure and capabilities would not be sufficient to meet the DSG given the current world situation.

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Table 5. Summary of FY30 Force Structure Analysis

Ship Class	FY30 Force: 30-Year Plan	2014 Navy Force Structure Analysis	Revised Defeat / Hold Scenario
Aircraft Carrier	11	11	14
Large Surface Combatant	95	88	160
Small Surface Combatant	40	52	46
Ballistic Missile Submarine	11	12	12
Guided Missile Submarine	0	0	2
Attack Submarine	42	48	72
Amphibious Warfare Ships	37	38	38
Support & Auxiliary Ships	68	63	70
Total No.	304	312	414

Drivers

The major challenge for the U.S. Navy is to project sufficient power across two oceans to successfully execute the DSG to deter, and when required win, wars in the face of active A2AD strategies designed to counter U.S. naval capabilities. Admiral Horatio Nelson once observed that “a ship's a fool to fight a fort”. Adversaries with regional navies are using long-range, shore-based missiles – to augment the offensive capabilities of their regional navies – with the objective of keeping the U.S. Navy at ranges that prevent the employment of its most potent weapon – aircraft carriers.

The problem with comparing numbers and types of ships, as done in Tables 3 and 4, is that it fails to account for the impact of the “fort” that is governed by three major capabilities:

- **Anti-ship ballistic missiles (ASBMs).** China is fielding a growing number of conventionally armed, medium-range, ASBMs – namely the Dong Feng 21D (DF-21D) – with a range of 810 nautical miles and a maneuverable warhead to attack ships. China already holds U.S. bases and infrastructure in the Western Pacific at risk with its current inventory of ballistic and cruise missiles [26]. The ASBM targets the last uncontested airfields – aircraft carriers – and, if successful, enables China to directly challenge the United States Navy [27].

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- **Anti-ship cruise missiles (ASCMs).** China continues to modernize its advanced ASCMs and associated over-the-horizon targeting systems for anti-surface warfare. Russia continues to be one of the leaders in the development of advanced ASCMs, which it exports. Table 6 compares the range, speed, and time of flight over various ASCMs. Note the general trend towards ASCMs with longer ranges and supersonic speeds.

Table 6. Range, Speed, and Time of Flight of Modern Anti-Ship Cruise Missiles

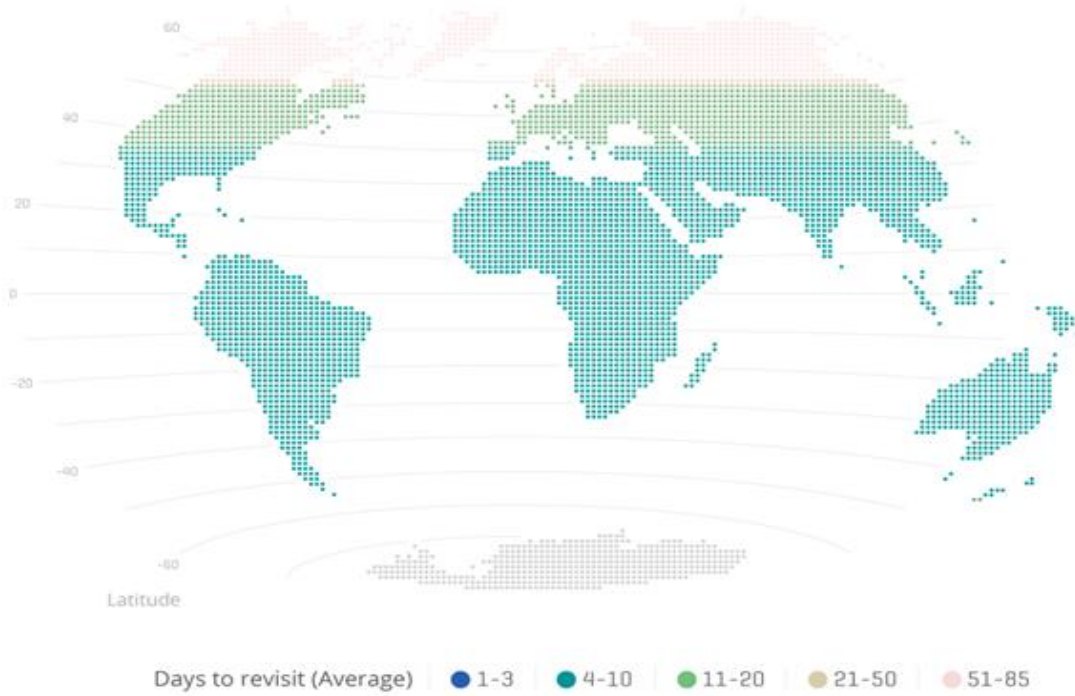
Missile	Range (n.mi.)	Cruising Speed (Mach)	Time of Flight (min)	Terminal Speed (Mach)
Exocet (France)	97	0.9	9.5	0.9
Harpoon Blk. 2 (U.S.)	67	0.7	8.6	0.7
Tomahawk (U.S.)	900	0.7	112	0.7
SM-6 (U.S.)	250	3.5	6.4	3.5
YJ-83 (China)	97	0.9	9.7	0.9
YJ-12 (China)	220	2.5	7.8	2.5
YJ-18 (China)	290	0.8	33	3
Brahmos (India/Russia)	160	3	4.9	3
SS-N-26 (Russia)	320	2.5	12	2.5
SS-N-27A (Russia)	360	0.8	40	2.9

- **Long-range targeting.** Our adversaries are developing and fielding a range of sensors and data fusion capabilities to enable sufficient over-the-horizon identification and targeting to engage the U.S. Navy at extreme ranges. In the past, nations spent enormous resources to build space sensing capabilities. Space sensing is now becoming a commercial product that can be bought as a service by any nation state or non-state actor. Figure 4 depicts the revisit rate for the current Planet Labs space sensing constellation. Figure 5 depicts the even higher revisit rate and ocean coverage of the planned, 60-satellite BlackSky system. Countries with their own space-launched or ground-based sensors can employ these capabilities to further reduce the revisit rates to improve their targeting and engagements. The Navy cannot rely on ships remaining hidden for extended periods in a 2030 environment.

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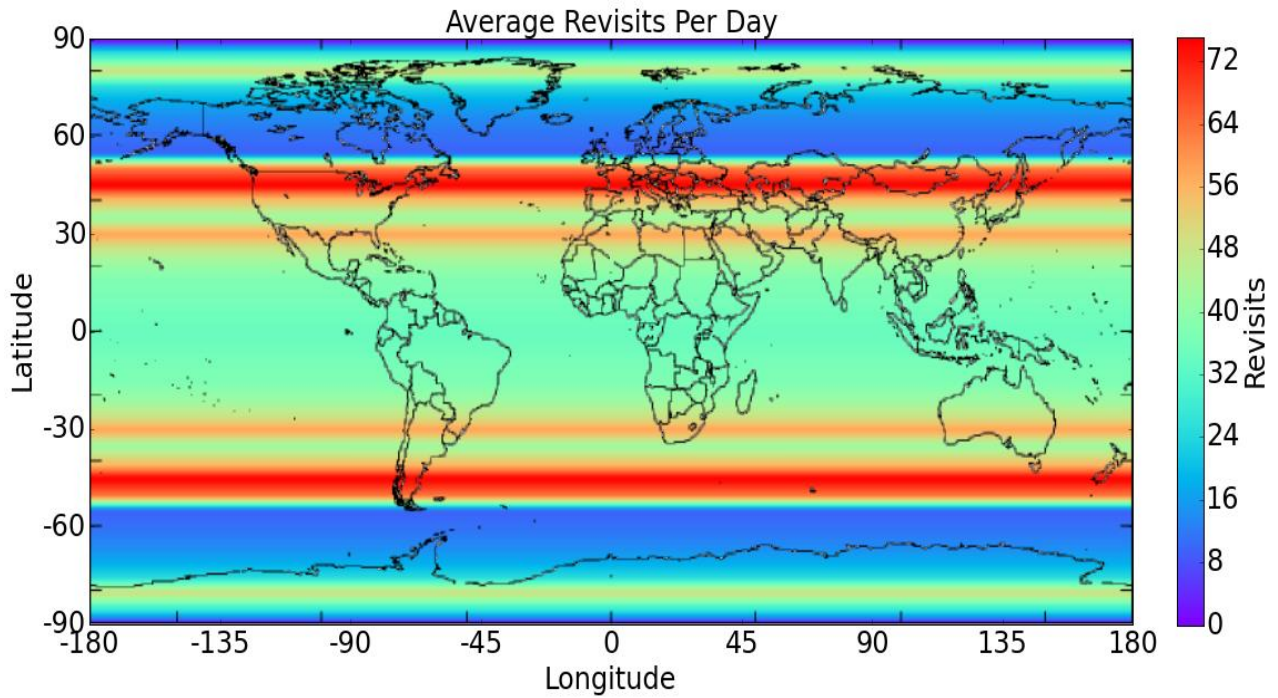
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Figure 4. Space Sensing Revisit Rates for Planet Labs in 1QFY16



Source: <https://www.planet.com/data/>

Figure 5. Revisits per day for Planned BlackSky Constellation of 60 satellites



Source: <http://spacenews.com/blacksky-global-says-its-poised-to-cover-globe-with-60-smallsats/>

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Naval Counter-A2AD Strategy

The U.S. Navy's peacetime and warfighting capabilities are provided by an evolving architecture that consists of platforms, sensors, weapons, C2, and supporting or enabling infrastructure, such as communications, intelligence or logistics. If properly integrated, this architecture is more than the sum of its constituent parts. The analysis of an alternative defeat and tailored hold scenario, summarized in Table 5, suggests a shortfall of 110 ships by FY30 with the current 30-year shipbuilding program. Building 110 additional ships is unrealistic. Consequently, this study makes recommendations across the full scope of the Future Fleet Architecture to improve its overall effectiveness, but these recommendations must be informed by a naval strategy to counter an adversary's A2AD capabilities.

The primary A2AD challenge the U.S. Navy must overcome to project power are the significant number of modern, long-range ASCMs and ASBMs supported by long-range targeting capabilities, both national and commercial. Addressing this challenge requires two new capabilities in the Future Fleet Architecture:

- **A layered, multi-tiered IAMD.** Given trends in commercial space sensing, hiding the naval force to avoid targeting will not be an option in 2030. Therefore, the future naval force must have sufficient defensive capabilities to defeat these threats. The Navy developed a layered defensive strategy to counter the Soviet Bear and Backfire bomber threat during the Cold War. The Future Fleet Architecture needs such a strategy to defeat large ASCM and ASBM raids with a combination of long-range, mid-range, and point defense capabilities that are affordable. Effective employment of these capabilities in a chaotic, evolving A2AD environment requires assured C2 supported by real-time or near-real time data links – such as the Cooperative Engagement Capability (CEC) – for coordinated, defensive fires.
- **A long-range power projection.** Given the extreme ranges of the ASCM and ASBM threats, it will take the naval force time to defeat them and obtain a position from which to unleash the offensive power of the aircraft carriers. If an adversary is able to achieve their objectives before the aircraft carriers are in a position to project power, then the U.S. will have lost the initiative. The Future Fleet Architecture needs sufficient long-range power projection to dissuade, disrupt, and delay an adversary from achieving their objectives before the larger naval force is in a position to counter them.

Strategies for achieving these two imperatives must first be developed, which can then be translated into recommendations for specific numbers, kinds, and sizes of ships.

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IAMD Strategy

Potential adversary's A2AD strategies place an asymmetric burden on the U.S. Navy due to the following factors:

- **Cost.** A U.S. ship must expend a fairly expensive Standard Missile (SM) to defeat the ASCMs or ASBMs. The procurement cost of 40 SM-3 Block IBs in 2015 was roughly \$14 million per missile [28]. The Navy's estimate for the cost of a Guided Missile Destroyer (DDG) in 2015 was \$1.7 billion [29]. Based on these figures, simply loading all of the DDG's 96 VLS cells with SM-3 will cost about \$1.4 billion. The exchange ratio is comparable at best for the missiles, so defeating missiles with missiles will be very expensive.
- **Capacity.** The cost of the U.S. Guided Missile Cruiser (CG) or Destroyer (DDG) that delivers that missiles is quite high and the adversary can, if they are only interested in regional sea control, invest in long-range coastal defense that are much less expensive and far easier to upgrade than large surface combatants, which enables them to buy more missiles and have greater capacity than the U.S. naval forces they will face.
- **Long lines of re-supply.** VLS cells cannot be reloaded at sea. Once a U.S. Navy ship has expended its SMs countering adversary air and missile raids, they must return to a port facility to re-arm. Since the U.S. Navy will be fighting forward, the time to transit out of the operational area, re-arm, and then return will take that ship out of the fight for several weeks at a minimum. The adversary has the advantage of interior lines of communication and logistics, and therefore does not have as far to go to re-arm their ships. It is also much easier for them to re-arm coastal defense batteries than ships at sea.

Therefore, the Navy must invert these burdens to inflict an asymmetric cost on the adversary, increase the depth of its ships' magazines, and enable re-arming at sea to defeat adversary A2AD strategies in a cost effective manner. The central question is can a ship defeat A2AD missile threats with a lower-cost round from a gun? If this can be technically achieved, then it addresses all of the issues that have been outlined above.

Hyper Velocity Projectile

Excalibur, a guided munition for 155mm Howitzers has been developed and deployed. Excalibur 1A uses fins to guide flight from apogee, on a non-ballistic flight path to the target, while extending the range of 155mm artillery to 50 kilometers. Excalibur 1B shells, with a longer range, are currently in production at roughly \$68,000 per unit. An Excalibur N5 variant is currently being developed to be employed from a Navy Mark 45 5" gun. The Mark 45 currently has a range of roughly 13 nautical miles. N5 munitions are expected to extend the range to between 20 and 26 nautical miles. The N5 shell was recently test fired from a Mark 45 gun [30],[31]. The Excalibur guided munition has been fired, in combat, from existing guns at a price point of tens of thousands – not millions – of dollars per shot. Can such munitions be used to engage a supersonic missile?

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A projectile must have sufficient energy to execute the maneuvers needed to kill an incoming supersonic missile, which may be maneuvering in an attempt to avoid such an intercept. The Office of Naval Research (ONR) is funding development of the Hyper Velocity Projectile (HVP) for the electromagnetic rail gun (EMRG) program. The HVP is an unassisted, low drag projectile that can also be fired from a DDG/CG's 5" Mark 45 gun, DDG-1000's 155mm naval gun or 155 mm howitzer. Regardless of firing platform, the HVP is steerable and can be guided to target with in-flight updates. HVP is designed, as the name implies, for high velocity to increase the range and maneuverability of the projectile for land attack, Anti-Surface Warfare (ASuW), and IAMD. ONR expects to achieve ranges of 40 nautical miles with a 5"/54 Mark 45 Mod 2 gun, 43 nautical miles from with a 155 mm Howitzer, 50 nautical miles from the longer-barreled 5"/62 Mark 45 Mod 4 gun, and 100 nautical miles from an EMRG [32]. The HVP has recently been fired from a Mark 45 Mod 4 gun [33]. Recent live-fire testing of the EMRG in Dahlgren, VA indicates this implementation is also maturing rapidly.

Employment of HVP from an EMRG or existing 5" guns is potentially a game-changing capability for IAMD and must be a top priority for the Navy.

- **Mark 45 implementation.** Each Mark 45 can fire 16 to 20 rounds per minute and, with two on every CG and one on every DDG, the Mark 45 is already widely fielded. With the expected rate of fire and the standard 600 round magazine, each Mark 45 can rapidly engage a significant number of threats (see the classified annex for detailed calculations). At \$20,000 to \$70,000 per shell, the cost of HVP rounds is expected to be significantly less than corresponding missile systems. Additionally, replacing expended 5" gun ammunition is feasible as part of a standard underway replenishment via Combat Logistic Force (CLF) ships. Maturing the HVP for the Mark 45 gun, with shells designed for IAMD, should be the number one priority of the Navy since the potential implications for the current inventory of CG and DDG platforms are profound. The goal should be full rate production of 5" HVP variants by 2020 to have significant numbers of 5" munitions with HVP in the surface force by 2030.
- **EMRG implementation.** The EMRG is expected to have a rate of fire of 10 rounds per minute, but these projectiles have much more energy than those fired from a 5" gun. This additional energy enables the projectile to not only travel farther, but also maneuver to defeat more advanced missile or air threats. The challenge for EMRG deployment are twofold: 1) maturing the EMRG into a gun mount for ship installation and 2) electrical generating capacity on the ship for continuous operation of the EMRG. The goal should be a EMRG turret design by 2020 for integration into new ship designs, with increased electrical power, by 2025.

The HVP in either the Mark 45 or EMRG implementation is applicable to both large and small surface combatants. For the EMRG, a critical enabling technology is the maturation of ship electrical systems with greater surge capacity, as currently under examination by the Naval Sea Systems Command. Another critical enabling technology is to integrate a seeker that can guide the HVP, as opposed to relying on targeting information from the ship's radar when in flight.

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Aerial Layer

The carrier air wing (CVW) is a critical asset that can be employed in a layered defense to help attrite large missile and aircraft raids. The Navy developed such a layered defense strategy to counter the Soviet Bear and Backfire bomber threat during the Cold War. The F-14 Tomcat, with its long air-intercept range, was the aerial component of the U.S. strategy to defeat this threat. The F-14 was intended to intercept Soviet bombers, using AIM-54 Phoenix missiles as shown in Figure 6, before the bombers launched their ASCMs. The objective was for the F-14 Combat Air Patrols (CAPs) to thin the raid sufficiently for Aegis to successfully engage whatever ASCMs were launched by the surviving Soviet bombers. An aerial layer should be an integral part of the U.S. Navy's strategy to defeat large ASCM and ASBM raids with a combination of long-range, mid-range, and point defense capabilities that are affordable.

Figure 6. F-14D with AIM-54 Phoenix Missiles



Source: https://en.wikipedia.org/wiki/AIM-54_Phoenix

Power Projection Strategy

The CVW is a potent force for power projection and capable of sustaining high sortie rates within the combat range of its attack fighter aircraft. The combat ranges of current F/A-18 and planned F-35C aircraft are roughly 500 and 600 nautical miles, respectively, well inside the reach of A2AD defenses. While aerial refueling extends range, the U.S. Navy needs a long-range power projection capability to hold an adversary at risk until the aircraft carriers can sufficiently close the distance to deliver powerful strikes.

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Long-Range Sea Strike

The surface force requires a long-range strike capability to dissuade, disrupt, and delay an adversary at 1,000 to 2,000 nautical miles. The SM-6 does not have the necessary range. The TLAM has greater range, but it is too slow. Consequently, the surface force needs a new missile. The U.S. Army had a long-range strike capability with the Pershing 2 missiles. These missiles were decommissioned as part of the Intermediate-range Nuclear Forces (INF) treaty signed in 1988 [34]. However, the INF only covers ground launched systems. The U.S. Navy should pursue a Pershing 3 variant, to be launched from a large surface combatant, to provide a long-range offensive capability. More details on this topic are provided in the classified annex.

Submarine Interdiction

A submarine's freedom of maneuver and ability to conduct sustained forward-deployed operations make it an invaluable means for force projection and intelligence gathering. While the surface force must contend the challenging set of multi-axis, A2AD threats; the covertness of the undersea force enables it to operate inside A2AD environments. Attack submarines are designed to seek and destroy enemy surface ships and submarines. They can also project power ashore with TLAM strikes, and the ability of a submarine to operate close to their targets negates some of the disadvantages associated with the TLAM being a subsonic missile. Given these advantages, the submarine force is a critical component of any strategy to dissuade, disrupt, and delay an adversary from achieving their objectives before the surface force is in a position to counter them.

Expeditionary Advanced Bases

The U.S. Marine Corps is developing concepts to secure advanced expeditionary bases of operations as part of a naval campaign. The U.S. Marine Corps seized islands and atolls in World War II as part of a broader offensive campaign in the Pacific theater. The current Expeditionary Advanced Basing (EAB) concept is the 21st century equivalent of the Pacific campaign. EABs with long-range strike, anti-ship systems, anti-air systems, electronic warfare systems, and sensors can transform these outposts into bastions for sea control. As naval forces advance into heavily defended areas, EABs can help guard the lines of communications for the larger naval force as well as contribute to the overall defense of this force by providing advanced warning and active defense of various lines of approach. These expeditionary bases can also serve as a base for offensive actions to include – but not limited to – strikes, raids, or seizure of additional advanced bases. [35]

Proliferation Challenges

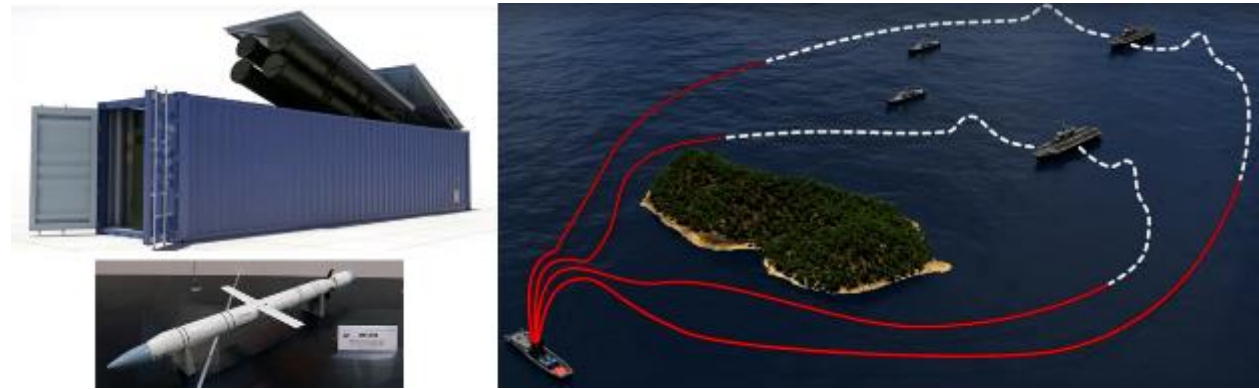
The proliferation of advanced ASCM has resulted in an increasingly dangerous littoral environment. Figure 7 shows the Russian 3M-54 Klub that fires Sizzler cruise missiles from a standard shipping container. With an estimated Sizzler range of up to 350 nautical miles, these weapons can be fired at U.S. Navy ships from either land-based or maritime launchers. A number of countries are acquiring these types of cruise missile systems [36]. Additionally, the potential transfer of Yakhont, an export variant of the Sizzler, from Syria to Hezbollah illustrates how the current, complex security environment facilitates weapons

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proliferation, even to non-state actors [37]. The U.S. Navy must be prepared to deal with these types of threats in opposed operations, not just conflicts with near-peer adversaries. Consequently, U.S. Navy ships must have sufficient point defense or non-kinetic capabilities to defeat these threats when they are in their terminal phase or operate with airborne sensors that can queue other systems to engage the threat at range.

Figure 7. Russian 3M-54 Klub System for Land Attack and Anti-Ship Cruise Missiles



Sources: https://en.wikipedia.org/wiki/3M-54_Klub and https://www.youtube.com/watch?v=mbUU_9bOcnM

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Study Methodology

“In sum, an all-high Navy would be so expensive that it would not have enough ships to control the seas. An all-low Navy would not have the capability to meet certain kinds of threats or perform certain kinds of missions. In order to have enough ships and good enough ships there had to be a mix of high and low.”
- Admiral Elmo R. Zumwalt, Jr. [38]

Admiral Zumwalt outlined a high-low concept in 1962 that is still relevant today. The only means of achieving both effectiveness and capacity, within the constraints of expected budgets, is to build varying amounts of exquisite (i.e., high), capable (i.e., moderate), and expendable (i.e., low) platforms. [39]

Guiding Principles

Three principles are used to guide and balance the study’s recommendations:

- **Increase Effectiveness.** Ships have a lifetime between 30 to 50 years, depending on the hull, so the fleet in 2030 will look very similar to the fleet today. The effectiveness of a ship, however, is a function of the weapons and sensors it carries. For example, a U.S. Navy ship may have more VLS capacity than an adversary but, if its missiles have only half the range of the adversary’s, it may not survive long enough to fire a salvo. The effectiveness of a naval task force is also determined by the command, control, and communications (C3) capabilities needed to coordinate the execution of missions, functions, and tasks it has been assigned. It is much easier to change the weapons, sensors, communications, etc. carried by ships to improve their effectiveness by 2030 than it is to design and build new ship classes in sufficient numbers to make a difference in 2030.
- **Improve Affordability.** Effectiveness must be balanced by affordability. For example, a missile may be very effective but, if it is too expensive, the U.S. Navy may not be able to afford enough of them to win a war. If ships are so expensive that the Navy can only buy a limited number of them, then it may not have enough of them to maintain global presence.
- **Increase Capacity.** The total number of ships directly impacts global presence. If the number of ships decrease, then the number of deployments also decreases and the only way to maintain presence is to increase the length or frequency of deployments. For example, between 2008 and 2011, Carrier Strike Group (CSG) deployments averaged about 6.5 months. From 2012 to 2014, these deployments have averaged 8.2 months to meet global commitments [40]. The number of ships is a quality in and of itself to ensure sufficient ships are deployed forward to deter an adversary and there is a sufficient, ready surge force to win a war.

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Assumptions and Constraints

The study team made the following assumptions:

- **Lethal force by unmanned systems.** It is assumed that the DoD will not allow independent employment of weapons by unmanned systems. Unmanned systems will continue to be employed to improve the survivability and effectiveness of manned platforms. However, advances in autonomy are required for them to act independently in a complex, warfighting environment. The degree to which unmanned systems can act independently will determine the amount of communications with and control by a human operator. Weapons release authority will continue to reside with the officer in tactical command of the unmanned system for the timeframe of this study.
- **Ohio-Replacement Program.** It is assumed that the *Ohio*-replacement nuclear ballistic missile submarine (SSBN) is a national strategic priority and will not be funded out of the existing Navy shipbuilding budget. The sole mission of SSBNs is strategic deterrence by providing the U.S. with a survivable and enduring nuclear strike capability as part of the nation's Nuclear Triad strategy. SSBNs are designed with extreme stealth to provide an undetectable launch platform for intercontinental missiles and the precise delivery of nuclear warheads. To recapitalize its aging *Ohio*-class SSBN force, the Navy is developing a follow-on nuclear ballistic submarine referred to as the *Ohio* Replacement. Several alternatives were exhaustively analyzed and considered during an Analysis of Alternatives including an SSBN design based on the *Virginia*-class submarine with an 87" D5 missile, a *Virginia*-based SSBN design but with a smaller new missile, and a resurrection of the *Ohio*-based SSBN design. Each of these options carried significant cost, technical, and schedule risks. In the end, the Navy chose a new design SSBN "that leverages the lessons from the *Ohio*, the *Virginia* advances in shipbuilding and improvements in cost-efficiency." [41] Navy acquisition plans call for designing and procuring a total of 12 *Ohio* Replacement SSBNs between 2021 and 2035, two less than the current SSBN force structure of 14. The Navy's calculus is based on maintaining 10 operational SSBNs, with the others in some phase of life cycle maintenance.
- **Budget Control Act (BCA) and Sequestration.** The study assumes the Navy will receive historical levels of funding and will not be subjected to further BCA or sequestration actions.
- **Rough order of magnitude cost assessments.** All cost estimates are based on analyses reported by the Congressional Budget Office, with rough extrapolations to estimate the cost of new ship classes it proposes. Detailed cost estimating would be required for all options recommended by this study.

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Applying the Principles to the Strategy

The subsequent sections describe how to implement the counter-A2AD strategies and, using the guiding principles described above, the recommended numbers, kinds, and sizes of ships for the following classes of ships:

- **Surface Combatant Force.** The high, medium, and low alternatives discussed are the existing cruisers and destroyers (high), new fast frigate (medium), and a new magazine ship (low).
- **Carrier Force.** It is not possible to make a recommendation on the number of aircraft carriers without first addressing the number of CVWs and their composition. The high, medium, and low alternatives for tactical aircraft discussed are the F-35C (high), F/A-18 E/F (medium), and unmanned systems (low). A reasonable future CVW composition and the number of air wings is estimated using analyses and data that are available. This estimate is then used to assess the number of aircraft carriers that are needed – with recommendations to explore options to reduce the cost of existing nuclear aircraft carriers (high), a conventional aircraft carrier design with the same hull (medium), and smaller conventional aircraft carrier design (low).
- **Submarine Force.** The high, medium, and low alternatives discussed are the existing nuclear attack submarines (high), conventional attack submarines (medium), and unmanned systems (low).
- **Amphibious Force.** It is not possible to make a recommendation on the number and type of amphibious warships without first addressing how future expeditionary operations will be conducted. Several options are discussed and force structure recommendations are based on one of them. The high, medium, and low alternatives discussed are the amphibious assault ships (high), landing dock ships (medium), and a new class of landing ship dock (low).

A classified annex to this report provides additional analyses supporting the recommended Future Fleet Platform Architecture and how it might be employed in 2030.

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Surface Combatant Force

Surface combatants, as the name implies, are warships designed to wage war from the surface of the water. The primary sea control missions of surface combatants are to eliminate adversary threat (ASuW), submarines (ASW), and aircraft and missiles (IAMD). Failure to successfully execute these missions puts not only the surface combatants themselves at risk, but also the high-value assets they have been assigned to protect.

The surface combatant force is sub-divided into two categories:

- **Large Surface Combatants.** For the purposes of this study, large surface combatants are defined as warships with a fully loaded displacement of 8,000 or more tons. The *Ticonderoga* class CG and *Arleigh Burke* class DDG both fall into the large surface combatant category. U.S. cruisers and destroyers are very capable platforms with significant VLS capacity that can be outfitted with missiles for ASuW, IAMD, and land attack. Most CGs and DDGs have a helicopter detachment, as well as onboard sonar systems, for ASW. CGs also act as air defense commanders for a CSG.
- **Small Surface Combatants.** The Request for Information released by the Small Surface Combatant Task Force, in April 2014, did not provide a specific definition for a small surface combatant [42]. For the purposes of this study, any warship smaller than 8,000 fully loaded tons and capable of sustained operations in the open ocean is considered a small surface combatant. This is consistent with the current use of “frigate” by other navies. The *Independence* and *Freedom* class Littoral Combat Ship (LCS) both fall into the small surface combatant category. LCS can be configured for ASuW, with an embarked MH-60R helicopter and MQ-8B Fire Scout Vertical Take-off unmanned aerial vehicle (UAV) as the Aviation Module for ASW or for Mine Countermeasures (MCM). The LCS mission module for ASuW is designed to counter small boat threats, not other surface combatants armed with ASCMs.¹ The LCS has no capability for area IAMD, so it cannot offer any IAMD protection to high value units. The ASW mission module and off-board systems deployed from the LCS do, however, provide capabilities to protect high value units by detecting and engaging submarines. A recently announced Frigate (FF) program is intended to improve upon the LCS in various design areas, including survivability.

Table 5 shows a deficit of 65 large and 6 small surface combatants with the revised defeat / hold scenario. The significant deficit in large surface combatants is primarily due to the lack of any IAMD capabilities in the current small surface combatant inventory, coupled with the dramatic rise of long-range missile threats to the naval force. It is highly unlikely that the U.S. Navy will be able to afford or have the capacity to build an additional 71 surface combatants by 2030. Since the Navy cannot build its way out of the problem, the primary issue that will be addressed in this section is how to improve the effectiveness of existing platforms in the IAMD mission and adjust the current shipbuilding plans to capitalize on the IAMD strategy described earlier.

¹ There are plans to evaluate the Naval Strike Missile for the LCS, which would give it a long-range ASuW weapon but the LCS does not have the onboard sensors to identify targets at range.

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Small Surface Combatant Recommendations

The LCS was designed to replace a variety of small surface combatants – patrol craft (PCs), mine countermeasure ships (MCMs), and frigates (FF). Under recent Congressional definition, the Navy's 13 PCs are no longer considered battle fleet assets, so the FY 17 fleet will legally have a total of only 25 small surface combatants consisting of 14 LCS and 11 MCM. By 2030, the planned fleet will consist of 40 small surface combatants (29 LCSs and 11 FFs). This change to the FY16 30-year plan, as directed in a December 14, 2015 memorandum from the Secretary of Defense, reduced the total number of small surface combatants from 52 to 40 [43].

Based on the IAMD strategy, the study recommends:

- **Terminating LCS production.** The LCS does not contribute to IAMD, does not have a Mark 45 gun, and cannot be retrofitted to accommodate one, so it cannot take advantage of the HVP innovation. It may be possible to design a major modification to as-yet unbuilt LCS ships to do so, but this is still a sub-optimal solution made more problematic given the structural, corrosion, and mechanical issues the Navy is currently experiencing with its LCS designs. The study recommends terminating LCS production in FY18. The cost of three LCSs is about \$1.5 billion and the cost of a DDG-51 Flight III is \$1.9 billion [44]. Producing an additional DDG-51, vice three LCSs, provides the capabilities that matter for high-end warfare.
- **Accelerating the transition to a future Frigate [FF(X)].** For an aircraft carrier to survive in the anticipated 2030 A2AD environment, the IAMD capabilities of the naval force must be significantly upgraded. The FF(X) design should accommodate the HVP innovation with either two 5" guns or both an EMRG and 5" gun for rapid fire IAMD support. The primary mission of the FF(X) will be IAMD, but the HVP also be employed for land attack and ASuW missions. The goal should be to license an existing frigate design, between 5,000 and 7,000 displacement tons, and incorporate:
 - *One EMRG and one 5" gun or two 5" guns.* The OTO-Melara 127 mm / 54 caliber deck gun is advertised as capable of handling the same munitions as the Mark 45, but has a rate of fire of 36 to 40 rounds per minute. At a minimum, doubling the size of the magazines to 1,200 rounds would be prudent, given the increased rate of fire and how the guns will be employed. An increase of this magnitude should be feasible due the lower weight of the HVP, as compared the current 5" round.
 - *VLS Launcher with Tomahawk Land Attack Missile.* All modern Navies are building FFs with VLS capabilities. Addition of some number of VLS cells with these land attack capabilities will give the SSC long-range Strike capabilities and contribute directly to Distributed Lethality across wide geographic areas and dispersed attack vectors.

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- *Multiple SeaRAM Anti-Ship Missile Defense Systems.* The small surface combatant envisioned will have a core mission to guard the high value unit. It will be part of a formation that will screen this platform and a SeaRAM system will help attrite ASCM that come over the horizon.
- *Nulka and other countermeasures / non-kinetic effects.* The small surface combatant will need electronic warfare systems to both aid in its survival against leakers and seduce missiles away from the high value unit.
- *Ability to stow, deploy, and retrieve unmanned surface vehicles (USVs).* USVs can be sent deployed as pickets to extend the sensor range of the FF(X) to detect surface ship or ASCM threats and, if appropriate, act as spotters for the 5" gun fire engaging these threats. The USVs can also be equipped with sensors to support ASW operations in the vicinity of the high value unit.
- *Helicopter lily pad.* The small surface combatant has the ability to re-fuel and re-arm helicopters that land on it, but does not have a hanger or helicopter detachment.
- *Cost-effective surface and air-search radar.* The FF(X) will operate in defense of a high value unit that will also have one or more CGs or DDGs operating SPY-1 or SPY-6 radars with CEC for long-range IAMD targeting. Accordingly, the FF(X) should have an appropriately scaled search and air search radar system and a low-latency data link that allows engage-on-remote targeting, using off-board sensors to direct fires from the FF(X)'s guns.

These FF(X) recommendations are intended to keep the design as simple as possible. The former *Garcia* class frigate had a full load displacement of 3,560 tons, two 5" guns, and sufficient space for the remainder of what is outlined above. Changes in design standards and increases in a ship's electrical demand preclude a ship of that displacement from filling this role today. However, ships smaller than the DDG-51 class should be capable of doing so. By example, Figure 8 shows the German Navy's *F125* class frigate, with a 7,200-ton full load displacement that may be adaptable to these recommendations and then constructed in the U.S. The *F125* class is currently fitted with a single Otobreda 127mm/64 (5") gun, 8 Harpoon ASCM and RAM missiles for point defense. A similar Italian frigate (*Bergamini* class) has 5" gun, 8 ASCM, and 16 VLS cells. Given the \$735 million/unit cost of the *F125* class frigate, the intent is to obtain a simple, relatively low-cost design that enables sufficient numbers to be produced to rapidly offset any A2AD disparities. If licensure of a foreign design is pursued, it is likely that the electrical system will require re-design to support installation of an EMRG.

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Figure 8. German Baden-Württemberg Frigate (Lead ship of F125 class)



Source: www.wikipedia.org

Large Surface Combatant Recommendations

Today, the U.S. Navy has 90 large surface combatants (66 DDG-51s, 2 DDG-1000s, and 22 CG-47s). The current 30-year shipbuilding plan builds two DDG-51s per year between 2016 and 2030. This rate of production is slightly ahead of the number that will be decommissioned, so the large surface combatant force will actually increase from 90 in FY16 to 95 in FY30. The Department of the Navy's Presidential Budget 2016 (FYDP) pursues a ten-ship, multi-year procurement of DDG-51 Flight III ships with AN/SPY-6 radars to partially replace the capability and capacity of decommissioned *Ticonderoga* class cruisers. The Navy will also execute a phased modernization plan to keep a minimum of 11 CG-47s in service at all times. The "2/4/6" plan places no more than two cruisers per year in phased modernization, makes each cruiser unavailable for no more than 4 years due to maintenance or modernization, and has no more than 6 cruisers of the 22 (CG-47 plus DDG-51 Flight IIIs) in this status during any given year. This process ensures at least one CG-47 is available for each deploying CSG.

Based on the IAMD and long-range strike imperative, the study recommends:

- **Increasing DDG-51 production at the expense of LCS.** As outlined earlier, producing an additional DDG-51, vice three LCSs, provides the capabilities that matter for high-end warfare.
- **Building a magazine ship [MG(X)] to augment existing large surface combatants.** Large surface combatants will have very capable SPY-1 and SPY-6 radar systems, but lack the magazine depth and are also very expensive. The Navy should build low-cost magazine ships to act as "wingmen" for large surface combatants. To keep the costs low, these ships would be based on either a commercial or civilian manned fleet oiler (T-AO) hull that can keep up with the surface combatant. The future T-AO (T-AO 205) is projected to cost roughly \$0.5 billion, and using the same basic hull should keep the magazine ship within the same price range, with some additional cost for increased speed to operate with CSG [44]. The goal should be to incorporate the following into the magazine ship:

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- *Two to four weapons sections.* A standard size section supports: 1) one EMRG turret with power and 1,000 round magazine or 2) 128 to 256 VLS cells for standard missiles or 3) 12 to 24 VLS cells for a Pershing 3-sized missile. The magazine ship is configured with the appropriate sections when built – no changes afterwards. One magazine ship might have two EMRGs and 24 Pershing 3s. Another might have 516 VLS cells for standard missiles and 48 VLS cells for Pershing 3s. These magazine ships can be tailored for specific roles or functions when built, each with different implications on the number and type of weapons needed to fully load them.
- *Multiple SeaRAM Anti-Ship Missile Defense Systems.* The magazine ship must have its own point defense system to defend itself and guard the high value unit from any ASCM that come over the horizon unexpectedly or leakers.
- *Nulka and other countermeasures and non-kinetic effects.* The magazine ship will need electronic warfare systems to both aid in its survival against leakers and seduce missiles away from the high value unit.
- *Cost-effective surface and air-search radar.* The magazine ship will operate in defense of a high value unit in conjunction with a CG or DDG operating SPY-1 or SPY-6 radars with CEC for long-range IAMD targeting. Accordingly, the magazine ship should have an appropriately scaled surface and air search radar system and a low-latency data link that allows engage-on-remote targeting.
- **Using the DDG-1000 class destroyers as command ships.** The Navy plans to build only three *Zumwalt* class destroyers. These destroyers have a fairly extensive area that can support operational-level C2 functions. The study recommends that DDG-1000 ships be used as replacements for the current command ships (LCCs) when the LCCs reach the end of their service life in 2039. In the interim, DDG-1000 can be employed as a command ship, as needed, based on emerging operational needs.
- **Building future large surface combatants with a 10,000-ton full load displacement to accommodate two guns and VLS system.** Future large surface combatant should be based around EMRG with the HVP to the extent practicable.

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Surface Combatant Shipbuilding

Table 7 summarizes the current planned surface combatant shipbuilding plan with the study recommendations.

Table 7. Recommended 15-year Shipbuilding Plan for Surface Combatants

Year	Navy Plan ¹			Study Recommendation				
	LCS	DDG-51	FFX	LCS	DDG-51	FFX	MGX	ROM ² (\$ billion)
FY16	3	2		3	2			\$5.5
FY17	3	2		3	2			\$5.5
FY18	3	2		0	3			\$6
FY19	3	2		0	3			\$6
FY20	3	2		0	3			\$6
FY21	3	2		0	3			\$6
FY22	3	2		0	3			\$6
FY23	3	2		0	3			\$6
FY24	3	2		0	3			\$6
FY25	3	2		0	2	1	1	\$5.75
FY26		2			1	2	2	\$5.5
FY27		2			1	2	2	\$5.5
FY28		2			1	2	2	\$5.5
FY29		2			1	2	2	\$5.5
FY30		2	1		1	2	2	\$5.5
Total	30	30	1	6	32	11	11	-

1. Ronald O'Rourke, *Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress*, Congressional Research Service, 8 January 2016.

2. Assuming ship costs of \$0.5 billion for LCS, \$2 billion for DDG-51, \$1 billion of FFX, and \$0.75 billion for MG(X).

Carrier Force

The CVWs, delivered by aircraft carriers, are the centerpiece of naval power projection. Table 8 summarizes how the size and composition of the CVW has changed over the last several decades. The trend has been a reduction in the number of total fighter and attack aircraft since the Cold War. The Navy also elected to invest in shorter range aircraft, with greater reliability and sortie generation rate, optimized for lower-end conflict scenarios in littoral regions. These decisions, which occurred over decades, have resulted in CVWs with reduced:

- **Combat range of attack and fighter aircraft.** In 1956, the average striking range of CVW aircraft was 1,210 nautical miles using only internal gas. These ranges were, in part, driven by the requirement for long-range nuclear strike. The fully loaded combat ranges for the A-6 and F/A-18 E/F are 880 and 500 nautical miles, respectively. The air intercept ranges for the F-14D and F/A-18 E/F are 1,065 and 500 nautical miles, respectively. [45]
- **Organic tanking capacity.** During the Vietnam War, a single KA-3 with about 29,000 lbs. of fuel could extend the striking distance of twelve A-4s, A-6s, or A-7s out to about 1,800 nautical miles. Today, the CVW has to dedicate five to six F/A-18 E/Fs for organic tanking, which reduces the number of aircraft for combat missions. A single F/A-18 E/F with 8,772 lbs. of fuel can extend the striking distance of four F/A-18 E/Fs to roughly 1,000 nautical miles. [45]

Consequently, an aircraft carrier is currently at risk from long-range ASCM or ASBM attack well before its CVW can be employed in strike missions.

Table 8. Evolution of the U.S. Carrier Air Wing

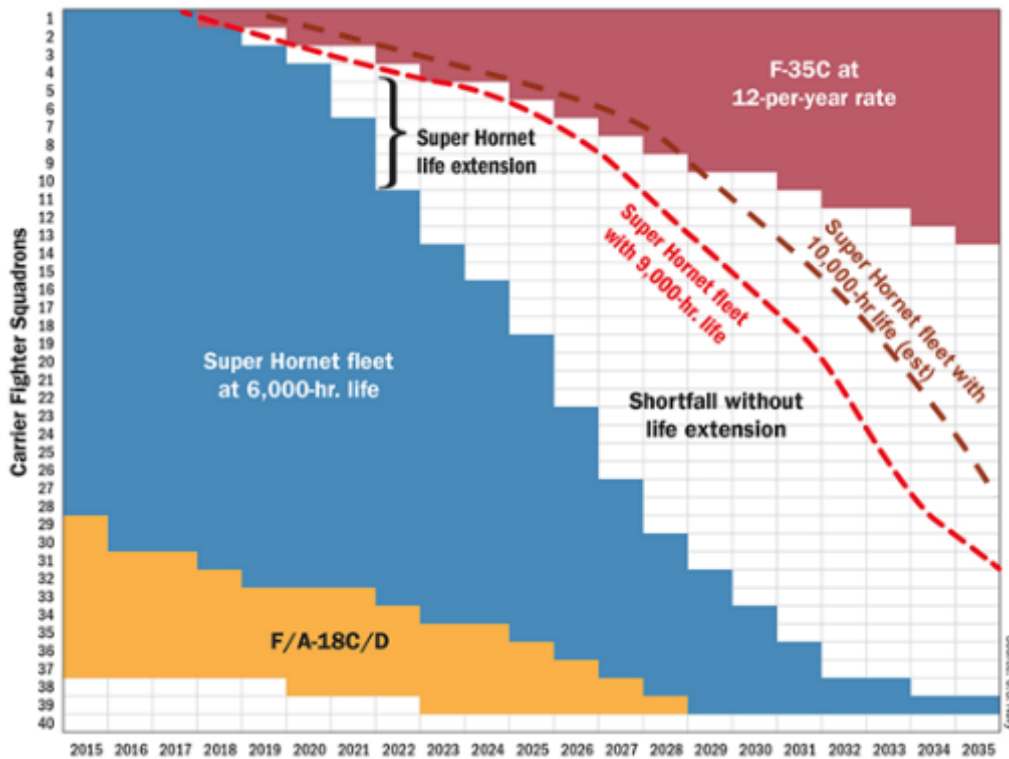
Type of Aircraft	Number of CVW Aircraft ¹		
	1980s	1990s	Today
Fighter (F-14)	24	24	-
Attack (A-6/A-7)	36	10	-
Fighter / Attack (F/A-18)	-	24	44
Airborne Early Warning (E-2)	5	5	5
Electronic Attack (EA-6B / EA-18G)	4	5	5
Anti-Submarine Warfare (S-3)	10	8	-
Helicopter	6	6	19
Total	~85	~84	73

1. https://en.wikipedia.org/wiki/Carrier_air_wing

Number of Carrier Air Wings

The purpose of an aircraft carrier is to carry a CVW, so the number of available CVWs drives the number of carriers needed to host them. Delays in F-35C production, coupled with the increase in per unit cost, has put naval aviation in a precarious position. In 2030, as shown in Figure 9, under the current plan, the Navy will have 15 fighter squadrons (six F/A-18 E/F squadrons and nine F-35C squadrons). With 40 fighter squadrons needed for the ten CVWs, this represents a shortfall of roughly 25 fighter squadrons. The Navy currently has ten operational CVWs, but plans to retire one CVW in 2017 [46]. The retirement of a CVW helps in two respects. Reducing the total number of fighter squadrons is reduced to 36 correspondingly reduces the 2030 shortfall to 21 fighter squadrons. If the Navy cannot make up this deficit in fighter aircraft squadrons, the number of operational CVWs will fall, as will the need for aircraft carriers to host them.

Figure 9. Naval Aviation Fighter Squadron Shortfall



Conserving the flight hours in the F/A-18 E/F fleet preserves aircraft for operations in 2030 and beyond, albeit with some operational risks. The CNA recently completed an organic refueling study for the CVWs. Roughly 5 to 6 F/A-18 E/Fs per CVW are currently dedicated to return and mission tanking missions. The CNA estimated that obtaining another aircraft for the organic tanking mission (starting immediately in 2015, which CNA admits is an unreasonable assumption) results in less flight hours on 50 to 60 F/A-18 E/F airframes, which translated into about 100 more F/A-18 E/F airframes available in 2030 [47]. This basic formula can be used to assess options to mitigate the shortfall in fighter squadrons:

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- **Reducing F/A-18 E/F squadrons to 10 aircraft in 2017.** Reducing the number of aircraft in each F/A-18 E/F squadron to ten² pulls an additional 36 airframes out of the squadrons. Using the same assumptions as above, reducing the squadron size translates into roughly 60 more F/A-18 E/F airframes in 2030.
- **Fielding a dedicated organic tanking platform.** As was mentioned earlier, each CVW dedicates five to six F/A-18 E/Fs for return and mission tanking. The Navy is considering procuring KV-22s, re-activating KS-3Bs, and procuring a tanking unmanned aerial system. Each option has advantages and disadvantages. However, the sooner the Navy can field an organic tanking aircraft, more flight hours on the F/A-18 E/Fs can be preserved to close the gap. If an organic tanker is not fully deployed until FY22, then that translates into about 50 more F/A-18 E/F airframes³ in 2030.

Implementing these recommendations results in an additional 110 F/A-18 E/Fs airframes – or 5.5 squadrons⁴ – available in 2030. Despite these efforts, the Navy still faces a deficit of roughly 15.5 attack fighter squadrons. Furthermore, and perhaps more important, the effect of extending time of service for the F/A-18 E/F fleet simply pushes the expected gap to the right by a few years. Without service life extension or procurement of additional aircraft, much of the F/A-18 E/F fleet in 2030 will be close to the end of their service life.

Since accelerating F-35C production does not appear to be a viable option, the Navy has only two options to address this shortfall are:

- **Extending the service life of the F/A-18 E/Fs.** Implementing a service life extension program (SLEP) will extend the limit on the F/A-18 E/F from 6,000 to 9,000 flight hours, at a cost of about \$30 million per airframe.
- **Procuring additional F/A-18 E/Fs or Advanced Super Hornets.** The F/A-18 E/F production line is planned to close in 2017, although that may change given Canada's recent interest in procuring F/A-18 E/Fs instead of F-35As [48]. The fly away cost of an F/A-18 E/F is roughly \$62 million.

Procuring a new F/A-18, with 6,000 flight hours, is operationally comparable in the short-term to implementing a SLEP on two F/A-18s to get an additional 3,000 flight hours each. However, both of the aircraft that underwent a SLEP will still reach end of service life at roughly the same time, so the crisis has been delayed but not averted. Implementing a large-scale SLEP for F/A-18 E/Fs pushes the cliff out by several years, but does not address the problem if the F-35C procurement rate cannot cover the gap. As was pointed out by the Congressional Budget Office, the only way to close the gap is to procure additional F/A-18s and either defer or reduce the F-35C procurement [49].

² A similar measure was implemented with the F/A-18 C/D squadrons, which currently have only 10 aircraft.

³ Given the later implementation of an alternative aircraft for the tanking mission, it was assumed that only half of the airframes would be available in 2030. A more rigorous calculation is required to validate this assumption.

⁴ The U.S. Navy acquired roughly 500 F/A-18 E/Fs to put 240 aircraft in 20 squadrons. This suggests that for every two airframes, one can be in a squadron.

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Aircraft Carrier Recommendations

Assuming the Navy will be able to sustain nine CVWs, the study recommends:

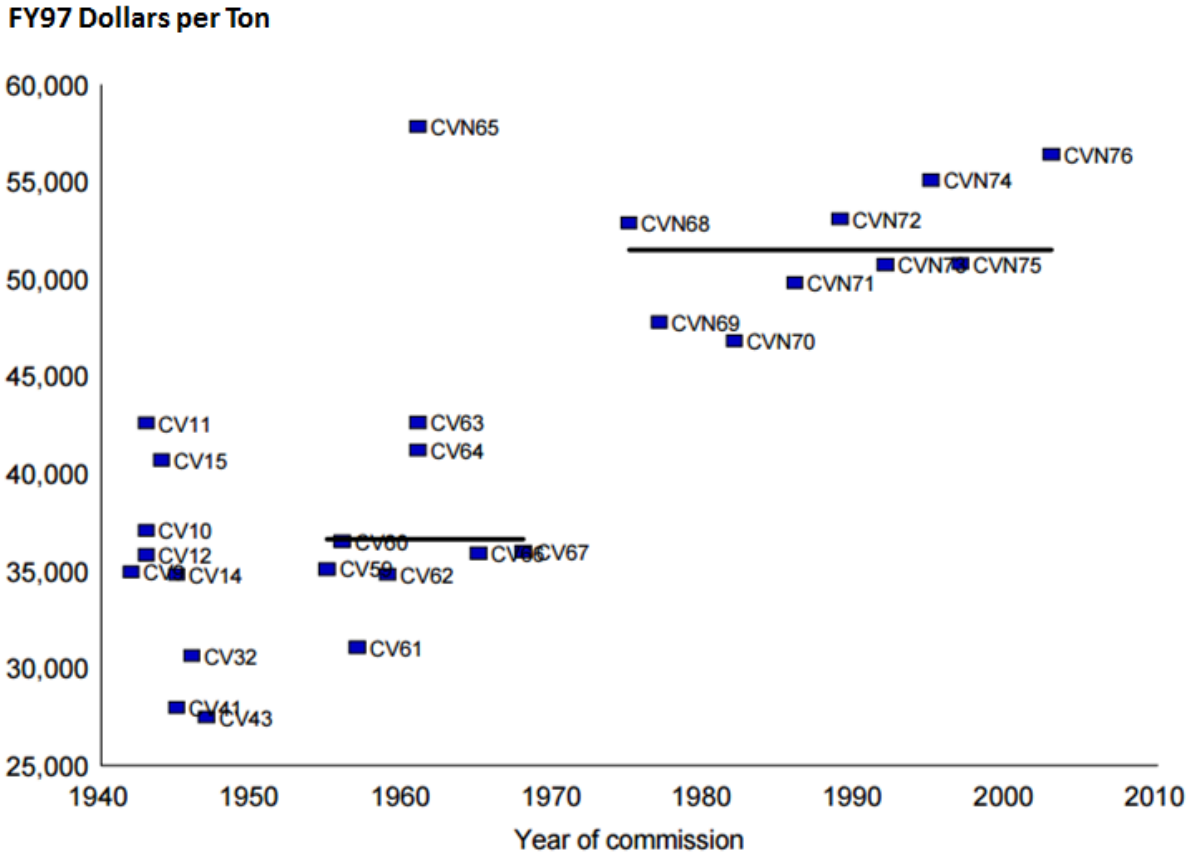
- **Slowing the production of the current *Ford* class aircraft carriers.** Aligns the number of aircraft carriers with the likely number of CVWs that would be available. Reducing the production rate of CVN79 aircraft carrier frees up SCN funds that can be used for other shipbuilding priorities or to address aircraft and weapon procurement shortfalls. If the Navy does not address the carrier aviation shortfall, the number of aircraft carriers built could face further reductions.
- **Reduce the cost of aircraft carriers.** The *Ford* class aircraft carrier is estimated to cost between \$12.9 and \$13.2 billion [29]. As a point of comparison, the Navy estimates the procurement cost of a *Nimitz* class aircraft carrier at about \$9.0 billion [50] and the Government Accountability Office estimated the cost of a conventional aircraft carrier at about \$3.1 billion [51], when adjusted to FY16 dollars. The Navy needs to rein in the cost of the fleet aircraft carriers or it will not be able to sustain the required number of them. This study recommends the Navy pursue the following options in parallel:
 - *Reduce the cost of the existing Ford class design.* At a minimum, the Navy needs to get the cost of each ship to under \$11 billion.
 - *Design of a conventional aircraft carrier based on the hull of the Ford class.* Nuclear aircraft carriers have a number of advantages, but are more expensive to build and operate [51]. The Navy should assess a re-design of the *Ford* class with conventional power, but roughly the same displacement and an emphasis on containing costs now that some of the Nuclear Propulsion Program requirements no longer apply (see Figure 10). Conventional power options include gas turbines, gas turbine generators with all-electric ship, and diesels/diesel generators. This option was not considered as part of the recent RAND study on alternative aircraft carrier designs and has the benefit of leveraging the existing shipbuilding production line.
 - *Design of a conventional aircraft carrier based around the hull of the America class amphibious assault ship.* A Short TakeOff Vertical Landing (STOVL) variant of the *America* class was considered by the Naval Sea Systems Command. The *America* class has a full load displacement of 45,693 tons, which is comparable to the *Midway* class aircraft carriers, when it was first built. The USS *Midway* underwent a modernization program in 1966 (SCB-101.66) – to increase the size of its flight deck, add steam catapults, etc. – resulting in a displacement of about 65,000 tons, so there is a precedent for modifying an existing flight deck design. The objectives for this new *America* design should be to add 2 to 4 catapults, add an angled flight deck, increase the power plant to support speeds up to 30 knots, and support 40 to 80 aircraft (no well deck required) while keeping the total cost to about \$6 billion, as opposed to the current \$3.8 billion procurement cost.

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The intent is to choose the most cost effective of these three alternatives for the follow-on to CVN79, using either the existing shipbuilding capacity for the *Ford* or *America* class hull. With the approach outlined above, the Navy could also elect to pursue a high-low aircraft carrier force composed of a mixture of supercarriers and smaller fleet or light carriers.

Figure 10. Procurement Cost per Ton for Conventional and Nuclear Aircraft Carriers



Source: GAO Report GAO/NSIAD-98-1, Navy Aircraft Carriers: Cost-Effectiveness of Conventionally and Nuclear-Powered Carriers, August 1998.

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Aircraft Carrier Shipbuilding

Table 9 summarizes the current aircraft carrier plan with the study recommendation.

Table 9. Recommended 15-year Shipbuilding Plan for Aircraft Carriers

Year	Navy Plan		Study Recommendation		
	CVN Built ¹	CVN Inventory	CVN Built	CVN Inventory	ROM ⁴ (\$ billion)
FY16		11		10	\$2.6
FY17		11		10	\$2.6
FY18	1	11	1	11	\$2.6
FY19		11		11	\$2.2
FY20		11		11	\$2.2
FY21		11		11	\$2.2
FY22		11		11	\$2.2
FY23	1	12		11	\$2.2
FY24		12	1	12	\$2.2
FY25		11		11 ²	\$2
FY26		11		11	\$2
FY27		11		10 ³	\$2
FY28	1	11		10	\$2
FY29		11	1	11	\$2
FY30		11		11	\$2
Total	3	-	3	-	-

1. Ronald O'Rourke, *Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress*, Congressional Research Service, 8 January 2016.

2. USS *Nimitz* was commissioned in May 1975 and is de-commissioned in 2025.

3. USS *Dwight D. Eisenhower* was commissioned in Oct 1977 and is de-commissioned in 2027.

4. Assuming ship costs of \$13 billion for CVN. First ship is split over 5 years, but subsequent ships are over 6 years. Also assumes a \$1 billion cost reduction on 3rd ship. Assumes a \$10 billion CV/CVN design starting in 2025.

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Submarine Force

Submarines are stealthy warships designed to wage war from underneath the sea. As mentioned earlier, the sole mission of SSBNs is strategic deterrence and is not considered part of this study. The missions / roles of the rest of the submarine force are to: 1) ASuW; 2) ASW; 3) power projection ashore with TLAMs and Special Operation Forces (SOF); 4) Intelligence, Surveillance, and Reconnaissance (ISR) missions; and 5) engage in mine warfare (MIW). Submarines – by virtue of their inherent stealth – provide persistent, undetected, assured access anywhere, anytime.

At the peak of the Cold War in the 1980's, the Navy had an attack submarine force structure requirement for more than 100 SSNs. Today, the current number of SSNs in the fleet is 48, which was set in 2006 based on the assumption that the Navy would not face a peer adversary in the near future. Ironically, a Defense Science Board (DSB) study, *Submarine of the Future*, in 1998 stated that a force structure of 50 SSNs⁵ was inadequate given long-term trends favoring submarine stealth and firepower, while also failing to prepare for the rise of a peer competitor.

Today, the Navy now faces two increasingly sophisticated peer competitors:

- **China.** China is in the midst of a major quantitative and qualitative buildup of its naval forces, including both conventional and nuclear-powered attack submarines. Over the past two decades China has added more than 40 new submarines and is currently building four improved variants of the *Shang* class SSN. The Office of Naval Intelligence reports that China's submarine force likely will grow from its present fleet of 62 submarines – 5 SSNs, 4 SSBNs, and 53 diesel-powered attack and air-independent propulsion submarines (SS/SSP) – to between 69 and 78 submarines by 2020. China continues to expand its undersea reach as evidenced by the deployment of a Chinese nuclear submarine to the Indian Ocean in 2015.
- **Russia.** Russia's submarine fleet is by far the most capable component of its naval forces and has been operating further afield than its surface fleet in the last several years. Recently, Russian attack submarines were reported to be reconnoitering the international undersea cable lines that are critical to both our commercial and military communications. Russian submarines have begun much more aggressive patrolling in the Atlantic, Mediterranean and Pacific. In the next two years, Russia will begin construction on nine submarines. Russia has already commissioned two *Borei* class SSNs and plans to build six more. This new submarine is a notable threat carrying sixteen SS-NX-32 Bulava intercontinental ballistic missiles (ICBMs) and six SS-N-15 cruise missiles. In addition, the Russian navy plans to add seven *Severodvinsk* class nuclear attack submarines by 2020 with intentions for reaching a total of sixteen.

⁵ Recommended in the 1997 Quadrennial Defense Review (QDR)

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Attack Submarines

The attack submarine force is sub-divided into three types of submarine platforms, all of which are nuclear powered:

- **Los Angeles class.** Considered the backbone of the submarine force, these submarines were designed with improved sound quieting, a larger propulsion plant than previous classes, and armed with 4 torpedo tubes and 12 VLSs, on the newer variants which comprise most of the force, for TLAMs. A total of 62 *Los Angeles* class SSNs were built between 1972 to 1996, with 39 still in commission today. Of the 23 *Los Angeles*-class submarines that have already been retired, 14 were decommissioned prematurely for cost savings purposes approximately half way through their projected service life of 33 years. The Navy expects to decommission 15 more by the end of the FYDP, with the remaining 24 ships of the class expected to retire across the 2020s.
- **Sea Wolf class.** Originally intended as the blue water successor to the *Los Angeles* class SSNs, this class was cancelled after just three ships due to the end of the Cold War and the Navy's desire to build a next century SSN at a reduced cost. *Sea Wolf* class SSNs were designed to be larger, faster, and significantly quieter than the *Los Angeles* class SSNs. They were also built for greater firepower and are armed with 8 torpedo tubes and 50 VLSs for TLAMs. This unique class of SSNs will remain in service across the 2030s.
- **Virginia class.** The Navy's newest class of attack submarines was designed as an advanced stealth multi-mission platform for a broad range of open-ocean and littoral missions. Smaller than a *Seawolf* but larger than a *Los Angeles* class SSN, Virginia class submarines incorporate a variety of advanced innovations and features including a photonics mast, pump-jet propulsor for quieter operations, and a fly-by-wire ship control system. For the first 13 years of the program, the Navy procured one hull per year with the lead ship entering service in 2004. After reducing unit cost to \$2 billion, the Navy received authorization to build 2 ships per year starting in FY11. To date, 12 *Virginia* class submarines have been delivered to the Navy with 16 more in the procurement and construction pipeline. Current Navy plans call for Multi Year Procurement (MYP) of 10 more hulls in FY19, dubbed Block V, and up to 10 more thereafter, for an overall fleet size of up to 51 *Virginia* class submarines.

Although the Navy currently has 53 SSNs in its inventory, the SSN force will steadily decline over the next 13 years to a low water mark of 41 in 2029. The reduction in the force is unsurprising given that the Navy only procured two SSNs per year from 1991 to 1998 and then only one SSN per year from 1998 to 2010. Consequently, today's operational demand for submarines exceeds what Navy's submarine force structure, both now and into the foreseeable future, can deliver [52].

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Guided Missile Submarines

Four *Ohio* Class SSBNs were repurposed into Guided Missile Submarines (SSGNs) between 2002 and 2008 to increase the Navy's undersea conventional strike capacity, as directed by the 1994 Quadrennial Defense Review (QDR). Each SSGN is capable of carrying up to 154 TLAMs, loaded in seven-shot Multiple-All-Up-Round Canisters (MACs) in 22 missile tubes. SSGNs also have the capacity to host up to 66 SOF personnel and their specialized equipment. These four submarines represent more than half of the submarine force's VLS capacity and are in high demand by the combatant commanders. However, they are scheduled to retire from service by 2028.

The Navy plans to add Virginia Payload Modules (VPMs) to *Virginia* class submarines to make up for this significant loss of conventional strike capacity with the retirement of the SSGNs. VPM will include a 70' hull insert amidships to add four 87-inch diameter missile tubes, each capable of launching seven TLAMs utilizing the same MAC canisters currently in service on SSGNs. These 28 missiles combined with two six-round Virginia Payload Tubes (VPT) in the bow would increase the total number of TLAMs per boat to 40. The VPMs will have the added flexibility to accommodate a variety of other payloads. If VPM fielding starts with the *Virginia* class Block V construction in 2019, the 60-percent shortfall in conventional strike capacity with SSGNs retirement by 2028 will be reduced to a 40-percent shortfall. As VPMs continue to be fielded, the loss of undersea conventional strike capacity will eventually be eliminated, albeit many years later.

Undersea Enablers

Unmanned Underwater Vehicles

Unmanned underwater vehicles (UUVs) potentially provide alternative ways for submarines to increase their sensor reach, expand their payload capacity, or deliver payloads into areas that are too risky or constrained for an expensive, manned submarine to reach. A number of different types of UUVs are either in use today or under development:

- **Long-endurance sea gliders.** Sea gliders control forward motion with differences in buoyancy, which trades off speed for long endurance. These UUVs can remain on station for extended periods and are typically employed to collect data on the underwater environment. For example, the Teledyne Slocum 2 sea glider has over 400 units that have been deployed, have been used on missions lasting 25 to 365 days, support depths up to 1,000 meters, and speeds of up to 0.68 knots. [53][54]
- **Large Displacement Unmanned Underwater Vehicle (LDUUV).** A capable UUV developed by the ONR to support ISR/acoustic surveillance, ASW, MCM, and offensive operations. An unmanned undersea vehicle designed to offload 'dull, dirty, dangerous' missions from manned platforms to mitigate the submarine gap beginning in 2022. LDUUV can be launched from both surface ships and submarines.

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- **Prototypes.** In addition to the Navy's LDUUV, Boeing Phantom Works has developed Echo Voyager, a completely autonomous 51' hybrid diesel, which can run for months and submerge to a depth of 11,000 feet on batteries

Figure 11 shows the Slocum sea glider (on the left) and LDUUV (on the right). The challenge is to acquire these UUVs in numbers that matter for warfighting. For example, the Navy will have procured only 30 LDUUVs by 2030. Concepts for how they would be employed to augment or support manned submarines also need to be developed.

Figure 11. Slocum Glider and Large Displacement Unmanned Underwater Vehicle



Undersea Networks

- **Undersea Constellation.** “Networked undersea forces will act as a key to unlock the door for decisive force to enter the fight and seize and maintain the initiative.” [55] To achieve this end, the capability to connect submarines, autonomous unmanned vehicles, distributed sensor networks, undersea cables, and a variety of other systems is a critical enabler for not only building and sharing a comprehensive understanding of the undersea environment, but maintaining a comparative advantage in the undersea domain. See the classified annex for additional information.
- **Maritime Surveillance Systems.** The global proliferation of stealthy submarines with advanced capabilities and the growing threat that these undersea forces pose necessitates that the Navy must sustain and recapitalize its fixed, mobile, and deployable acoustic arrays that provide vital tactical cueing to anti-submarine warfare (ASW) forces.

Submarine Recommendations

Based on the current submarine force shortfall and long-range power projection imperative, this study recommends:

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- **Continue building two *Virginia* class SSNs per year.** Demand for SSNs is rapidly exceeding supply, retirements are outpacing construction, and the submarine industrial base is already stretched thin. Continue efforts to reap savings through Multi Year Procurement (MYP) contracts, advance procurement authorities for cross-class procurement between SSN and SSBN programs, shortened construction timelines through improved technologies and upgraded infrastructure, and innovative contracting and acquisition strategies to find synergy and additional cost savings. Sustaining the rate of procurement concurrently with *Ohio* Replacement Program (ORP) construction will be challenging.
- **Include the VPM in all *Virginia* class SSN procurements beyond 2019.** The submarine forces need sufficient capacity to support long-range power projection with conventional cruise missiles. Current Navy plans call for building 20 *Virginia* class SSNs through 2033, but only 15 will be built with the VPM. Building each *Virginia* class SSN with the VPM will increase undersea strike capacity while also creating production line efficiencies to reduce VPM per unit cost.
- **Develop supersonic alternative for the TLAM.** The inherent covertness of the submarine force enables it to operate within the A2AD environment, so a conventional strike does not require range as much as speed and lethality. The Navy should develop a supersonic, maneuvering missile that can be launched from a submarine VLS, but with a shorter range than a TLAM. The current quiver of torpedoes and cruise missiles does not have the punch for a 21st century fight.
- **Field UUVs to augment the submarine force in sufficient numbers to matter.** UUVs can provide alternative ways for submarines to increase their sensor reach, expand their payload capacity, or deliver payloads into areas that are too risky or constrained for an expensive, manned submarine to reach. This will require increased resources and a focused effort on developing autonomous systems that can perform complex military missions in dynamic environments.
- **Build conventional diesel submarines to mitigate the growing shortfall in U.S. attack submarines.** Even with a *Virginia* class production rate of two per year and increasing the total buy does not address the impending shortfall in SSN inventory. Modern and highly capable conventional submarines now form a key component of more than 66 nations' order of battle; are suitable for littoral operations because of their low acoustic, magnetic, and thermal signatures; are smaller, stealthier and more maneuverable in tight spaces than nuclear submarines; and can now remain submerged for weeks at a time using modern propulsion technology. Conventional submarines are about \$400 to 500 million each and much quicker to build than a nuclear submarine. Our strongest allies and our most likely adversaries have all taken a high-low approach to their submarine force structure. The study recommends the either partnering with a foreign submarine manufacturer to produce submarines in a U.S. shipyard or license a design for production by a U.S. manufacturer.

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Submarine Shipbuilding

Table 10 compares the current submarine shipbuilding plan with the study's recommendations.

Table 10. Recommended 15-year Shipbuilding Plan for Submarine Force

Year	Navy Plan ¹		Study Recommendations			
	SSN	SSBN	SSN	SSBN	SSP	ROM ² (\$ billion)
FY16	2		2			\$6
FY17	2		2			\$6
FY18	2		2			\$6
FY19	2		2			\$6.6
FY20	2		2			\$6.6
FY21	1	1	1	1		\$3.3
FY22	2		2			\$6.6
FY23	2		2		1	\$7.4
FY24	1	1	1	1	1	\$4.1
FY25	2		2		2	\$8.1
FY26	1	1	2	1	2	\$8.1
FY27	1	1	2	1	2	\$8.1
FY28	1	1	2	1	2	\$8.1
FY29	1	1	2	1	2	\$8.1
FY30	1	1	2	1	2	\$8.1
Total	23	7	28	7	14	-

1. Ronald O'Rourke, *Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress*, Congressional Research Service, 8 January 2016.

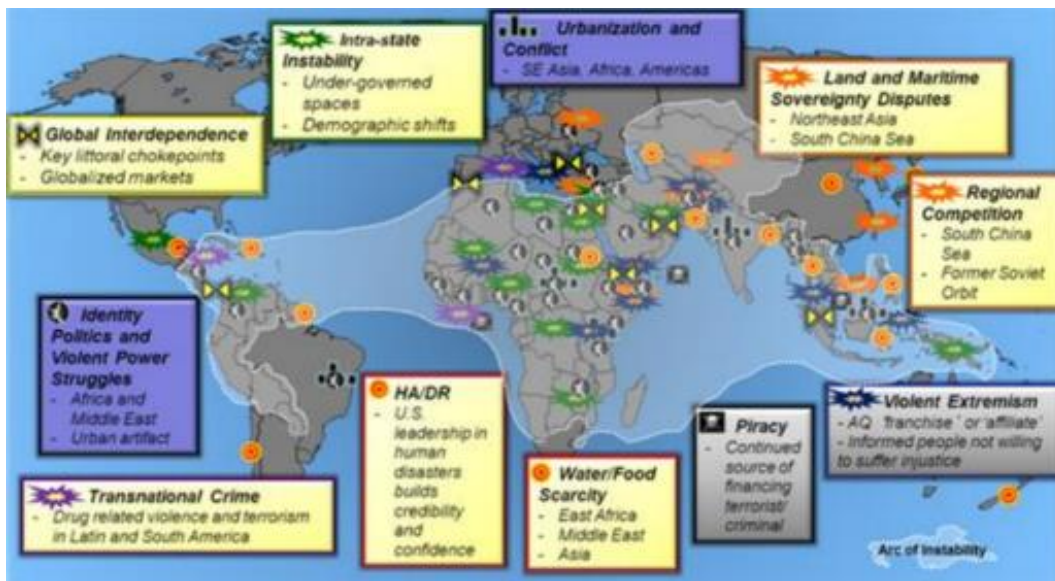
2. Assuming ship costs of \$3 billion for SSN without VPM, \$3.3 billion for SSN with VPM, and \$0.75 billion for SSP. SSBN costs are not included.

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Amphibious Force

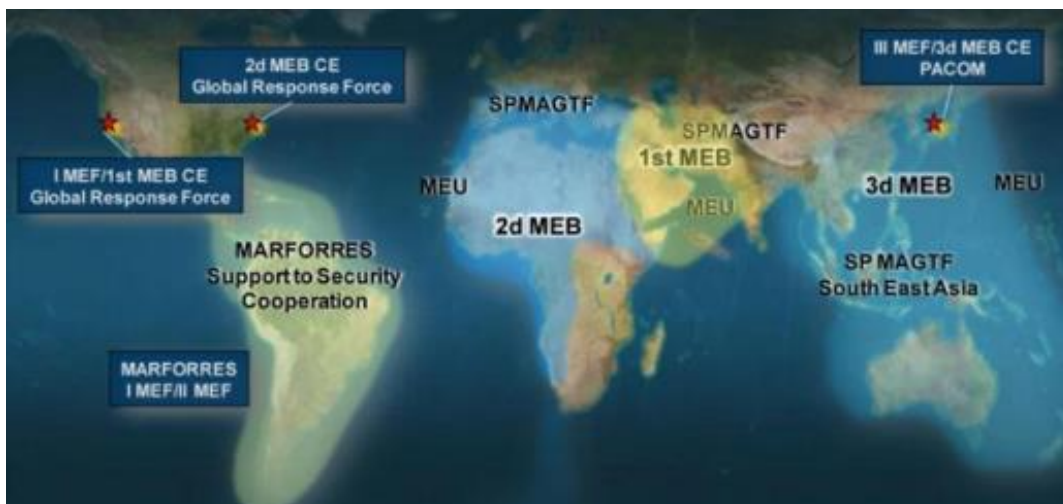
Amphibious forces operate forward to support allies, respond to crises, deter potential adversaries, and project sustainable power ashore. Amphibious forces provide the ability to rapidly and decisively respond to global crises without a permanent footprint ashore that would place unnecessary political or logistical burdens upon our allies or potential partners [56]. Figure 12 depicts areas of instability that may, at some point, require forcible entry by amphibious forces. The two drivers of amphibious ship requirement are: 1) the need to maintain persistent, forward presence and 2) delivering the assault echelons of Marine Expeditionary Brigades (MEB) for Joint forcible entry operations. Figure 13 shows the regional orientation of these forces, which is aligned with the regions of instability.

Figure 12. Overlap of Areas of Instability overlap with Key Littoral Regions



Source: United States Marine Corps, *Expeditionary Force 21*, March 2014

Figure 13. Regional Orientation of U.S. Marine Expeditionary Forces



Source: United States Marine Corps, *Expeditionary Force 21*, March 2014

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Amphibious Warships

The Chief of Naval Operations and Commandant of the Marine Corps jointly established an amphibious lift requirement of 38 amphibious ships, which has been fiscally constrained to 34 ships. A minimum of 30 operational ships is required, based on the footprint of a 2.0 MEB assault force and assuming the ships have a 90 percent operational availability. Thus, the minimum amphibious force consists of ten Amphibious Assault Ships (LHD and LHA), ten Amphibious Transport Docks (LPD), and ten Dock Landing Ships (LSD). The amphibious force consists of 32 ships (9 LHD and LHAs, 11 LPDs, and 12 LSDs) in 2017 and increases to 37 ships by the late 2020s.

These amphibious warships provide flexible means of delivering U.S. Marines, and their equipment, in packages optimized to achieve the strategic objectives of U.S. national policy:

- **Surface delivery.** A surface delivery capability – as articulated in the Seabasing Joint Integrated Concept – transports personnel, supplies and equipment from within the seabase to their objectives ashore. The current fleet of surface connectors, namely the Landing Craft Air-Cushion (LCAC) and the Landing Craft Utility (LCU), are reaching the end of their service lives and require modern replacements. Future surface connectors, with enhanced speed and range, will provide greater flexibility to operate in contested environments. These platforms are essential in connecting the combat power and logistical sustainment in the seabase to the expeditionary forces operating in the littorals or inland.
- **Air delivery.** The Aviation Combat Element (ACE) embarked on amphibious warships provides a force power projection capability and rotary-aircraft lift that can carry a marine assault force to their objective, which maybe hundreds of miles from the ships. For example, the U.S. Marine Corps successfully executed a vertical assault over 371 nautical miles inland from amphibious ships to seize Camp Rhino in Afghanistan, as part of Operation Enduring Freedom in 2001. The total mission package for the airfield seizure was six CH-53Es (carrying 2 fast attack vehicles and 161 combat-loaded marines), four AH-1Ws, three UH-1Hs, six KC-130s (two tanker, four cargo), a P-3 with a prepositioned 15th Marine Expeditionary Unit (Special Operations Capable) (MEU(SOC)) ACE pilot aboard, four AV-8Bs, and a command and control platform [57]. The vertical assault executed in Afghanistan illustrates how an expeditionary marine force can seize a lodgment – potentially a significant distance from the sea base – to support the flow of follow-on forces.

Self-Defense Capabilities

Amphibious warships have historically relied upon aircraft carriers and surface combatants for protection. Given the proliferation of advanced ASCM threats and the current capacity limits of the fleet, it is prudent for the Navy to improve the self-defense capabilities of amphibious warships. Some options to consider, some of which have implications for the ship's Combat System, include:

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- **More SeaRAM Anti-Ship Missile Defense Systems.** The *America* and *San Antonio* class could sacrifice some of their .50 caliber and 30 mm guns for improved missile-point defense capabilities.
- **Improved surveillance for ASCM threats.** Other navies have implemented helicopter-based airborne early warning (AEW) to detect ASCMs at ranges of 50 kilometers. These ranges still do not provide much warning for supersonic threats, but the U.S. Marine Corps could explore a similar capability on the MV-22 (which flies at higher altitudes to have a greater field of view and more payload capacity). Alternatively, the well deck of amphibious warships could also be used to support USVs to fulfill this function, which can operate at the horizon to provide warning to the amphibious warships as well as the surface combatants defending them.
- **Arm amphibious warships with HVP.** A Mark 45 5" gun or EMRG provides a capability to contribute to IAMD, ASuW, and – if it an EMRG – fire support for expeditionary forces.

Amphibious Ship Recommendations

The future Amphibious Ready Group (ARG) needs to be augmented for increased IAMD and ASuW capabilities for sea control.

- **Complete the planned *San Antonio* class LPD procurement through LPD28.** These LPDs have a well deck with amphibious landing craft and heavy equipment to support a traditional beach assault. They also support two MV-22s for vertical assault.
- **Continue *America* class LHA procurement, but consider the proposed *America* class aircraft carrier variant as an option for LHA9 and beyond.** LHA 8 will have a well deck to improved operational flexibility as well as a reduced island to increase flight deck space. An angled flight deck, as opposed to one optimized for STOVL, offers the potential for other types of fixed-wing or unmanned aircraft to be integrated into the ACE to provide more flexibility to address future threats or concepts of operations.
- **Consider some alternatives for the Amphibious Transport Replacement (LXR).** LXR is the replacement for the LSD, which start reaching the end of their service life in 2027. The Navy plans to have the first ship operational by FY25. The U.S. Marine Corps is also considering options for disaggregated or split operations as an alternative to the traditional ARG concept. LXR is the first opportunity to deliver a ship class that supports disaggregation to optimize for sub- MEU missions while increasing presence. Some options include:
 - *Continue with current plans to leverage the LPD17 hull.* Balances costs while delivering multi-mission warship capabilities, with current estimates between \$1.5 and \$1.9 billion per unit. Incorporating a gun – either Mark 45 or an EMRG – into this design makes sense. However, the cost per platform means a one-for-one replacement of LSD class ships.

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- *Modify Spearhead class expeditionary fast transport (EPF).* These are 1,515 ton ships that cost roughly \$180 million per unit, so they are small and affordable. EPFs have a mission bay with 500-tons capacity, can support 312 embarked troops, and have a helicopter lily pad. Even with some modifications (e.g., adding SeaRAMs or 76 mm gun), the Navy could potentially buy 6 to 8 EPFs for the cost of the planned LXR. In the event of the LHA and LPD splitting off to handle different situations, the EPFs could be divided between them in a manner that best supports their respective objectives. An advantage of the EPFs is that they can deploy amphibious vehicles into the surface zone. However, it isn't as survivable, has challenges in high sea states, and does not currently have a helicopter hangar [58].
- *Modify Watson class large, medium-speed roll-on/roll-off ships (LMSR).* These are 29,000 ton, full-load displacement ships, as shown in Figure 14. About 2 to 4 of these ships could be bought for the cost of the planned LXR. Again, if the LHA and LPD were divided to address separate missions, the LMSRs could be split among them in a manner that best supports their respective objectives. An advantage of the LMSR is it balances survivability between the EPF and planned LXR. It has a tremendous cargo capacity to carry troops, vehicles, etc. It is also possible to put a variety of weapons – such as SeaRAM, a Mark 45 5” gun or, potentially, an EMRG – to give it more active defenses to make up for any survivability issues. It also has a hangar to support a helicopter or, potentially, an MV-22.

The Navy and U.S. Marine Corps need to decide on the best LXR option for fulfilling their future missions.

Figure 14. Watson class Large, Medium-speed Roll-on/Roll-off Ship



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Amphibious Ship Shipbuilding

Table 11 summarizes the current amphibious shipbuilding plan with the recommendation to maintain current plans. If the Navy and U.S. Marine Corps decide to pursue some of the alternatives that have been outlined, then the cost of the amphibious shipbuilding plan should not change appreciably, but the numbers of LXR ships and their capabilities will change.

Table 11. Recommended 15-year Shipbuilding Plan for Amphibious Force

Year	Navy Plan			Study Recommendation ¹			ROM ² (\$ billion)
	LHA	LPD	LXR	LHA	LPD	LXR	
FY16		1			1		\$2.4
FY17	1			1			\$2.4
FY18		1			1		\$1.2
FY19							\$1.2
FY20		1			1		\$1.2
FY21							\$0
FY22							\$1.3
FY23							\$1.3
FY24	1		1	1		1	\$2.8
FY25			1			1	\$1.5
FY26			1			1	\$2.8
FY27			1			1	\$2.8
FY28	1		1	1		1	\$2.8
FY29			1			1	\$2.8
FY30			1			1	\$2.8
Total	3	3	7	3	3	7	-

1. Ronald O'Rourke, *Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress*, Congressional Research Service, 8 January 2016.

2. Assuming ship costs of \$3.8 billion for LHA, \$2.3 billion for LPD17, and \$1.5 billion for LXR.

Other Key Architectural Elements

The analysis has emphasized the size and composition of the Navy's battle force. However, there are critical enablers that are needed to both keep this force at sea and combat effective: 1) the Combat Logistics Force (CLF) keeps the force supplied; 2) integrated kinetic effects, 3) integrated non-kinetic effects, and 4) unmanned systems. This section describes these key architectural elements in greater detail.

Combat Logistics Force

The CLF provides fuel, food, ordnance, spare parts, and other critical supplies that enable the fleet to remain at sea, on station, and combat ready for extended periods of time. The current CLF includes the *Kaiser* class oiler (T-AO), the *Lewis and Clark* class dry cargo ships (T-AKE), and the *Supply* class fast combat support ships (T-AOE) class. The future CLF is built around the *John Lewis* class oiler (T-AO 205) starting in 2016. The remaining nine planned, double-hulled T-AOs are procured at the rate of one-per year. Since this study has focused its analysis on the Navy's battle force and not had time to assess the CLF, no changes to the Navy's current CLF shipbuilding plan are recommended. Table 12 shows the Navy's shipbuilding plan, which maintains a 29-ship inventory through 2030 [59].

Table 12. Recommended 15-year Shipbuilding Plan for the Combat Logistics Force

Year	Navy Plan ¹	Study Recommendations	
	CLF	CLF	ROM ² (\$ billion)
FY16	1	1	\$0.5
FY17			
FY18	1	1	\$0.5
FY19	1	1	\$0.5
FY20	1	1	\$0.5
FY21	1	1	\$0.5
FY22	1	1	\$0.5
FY23	1	1	\$0.5
FY24	1	1	\$0.5
FY25	1	1	\$0.5
FY26	1	1	\$0.5
FY27	1	1	\$0.5
FY28	1	1	\$0.5
FY29	1	1	\$0.5
FY30	1	1	\$0.5
Total	14	14	-

1. Ronald O'Rourke, *Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress*, Congressional Research Service, 8 January 2016.

2. Assuming ship costs of \$0.5 billion for T-AOX ships.

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Integrated Kinetic Effects

This study has outlined a broad Navy strategy to defeat large ASCM and ASBM raids with a combination of long-range, mid-range, and point defense capabilities to protect the aircraft carrier until it can effectively project power. A great deal of time has been spent on ships and weapons but, obviously, a lot more is involved in the successful execution of this strategy:

- **Sensors.** A combination of SPY-1 and SPY-6 radars will be available on large surface combatants. Other platforms will have less capable systems, which can still contribute to the overall picture and need to be integrated with the more exquisite sensors. Furthermore, national sensors can also enrich what is known at the tactical level of war if the information can 1) get to the tactical force and 2) be integrated with the tactical sensors. This implies a challenge not only with the number/quality of sensors but also the rapid fusion of the sensor data into an actionable tactical picture. The ONR's Tactical Cloud Reference Implementation is currently developing cloud technologies that could be used to support the fusion of tactical and national sensor data for targeting and combat identification.
- **Data Links.** The aerial layer and surface combatants will utilize different sets of data links. The aerial layer will have some combination of Link 16, Tactical Targeting Network Technology (TTNT), and Multifunction Advanced Data Link (MADL). The surface force will have some combination of Link 16 and CEC. The individual data links need to have the capacity and scalability to support the IAMD fire control network that is envisioned. The ONR is developing technologies to improve the capacity / scalability of CEC via its Communications and Interoperability for Integrated Fires (CIIF) program. CIIF is also working on a Communications-as-a-Service function to enable fire messages to transit an ad hoc mesh of tactical data links within the appropriate latency guarantees.
- **Assured C2 systems.** A C2 system is required to assess readiness, support tactical planning across warfare areas, optimize the placement of forces, disseminate orders, and monitor the execution of assigned missions, functions, and tasks. Obviously, this implies a set of C2 applications that must run across the force, which requires some basic communications functions. In addition to the CIIF capabilities described earlier, the classified annex outlines some protected communications options and describes some basic C2 requirements.

Integrated Non-Kinetic Effects

Non-kinetic effects are also a critical enabler, but are typically classified and difficult to quantify. Clearly, the following broad categories of non-kinetic capabilities need to be a core component of the future force:

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- **Electromagnetic Maneuver Warfare.** The ability to control a ship's signature, create false targets, seduce adversary weapons away from ships, and perform similar functions are all key capabilities to create uncertainty within an adversary's kill chain and reduce their effectiveness. While this study mainly focuses on a range of kinetic capabilities and effects required by the fleet, non-kinetic effects are also needed to increase the survivability of the force. The ability to reduce adversary re-visit rates over the naval force or getting them to commit to the wrong area correspondingly reduces the number and, potentially, the size of raids the naval force must overcome. Also, no defense is perfect, so it is critical to have non-kinetic effects to defeat whatever missiles or platforms leak through the IAMD of the naval force.
- **Cyber.** The importance of cyber in future wars is described in the classified annex.

Unmanned Systems

Unmanned systems remain an area of rapid development and exploration for the Navy, for example: Fire Scout, Stingray, LDUUV, and ASW Continuous Trail Unmanned Vessel (ACTUV). The Navy should accelerate further exploration of unmanned systems operating in consort with manned platforms to understand the capabilities they could provide, as well as new operational concepts. The Navy should experiment with its initial cadre of unmanned systems to determine the appropriate operating concept for each: (1) as an extension of a manned platform and/or (2) as an autonomous vehicle, independent of a manned platform. The classified annex presents potential CONOPS for UAVs, UUVs, and USVs.

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Conclusions

The Navy faces many important challenges as it tries to balance its investments while managing operational risk in a complex, evolving national security environment. This study of future fleet architectures has several important findings:

- **Ubiquitous sensing will challenge the ability of surface naval forces to operate without their location being known to the adversary.**
- **Adversaries will target surface naval forces at long range to prevent U.S. naval forces from projecting power.**
- **IAMD capabilities are imperative for the survival of U.S. naval forces and long-range strike capabilities enable them to continue to project power.**
- **The per unit cost of high-end warships is dictating a force structure that does not result in sufficient numbers to address a revised defeat and hold scenario that is more representative of the current world situation.**
- **A balanced investment in high, medium, and low capability ships and submarines is necessary to free up funding to increase capacity.**
- **A deeper, and more diversified, fleet weapons magazine is required to pace these threats.**

To this end, the study makes the following recommendations for a more balanced and effective naval force:

- **Immediately cancel the Littoral Combat Ship production beyond FY18.**
- **Procure an additional DDG-51 per year, using funds available from LCS termination, until FF(X) is under construction.**
- **Augment existing CG-47s and DDG-51s with a magazine ship (MGX) to both augment their capacity and provide a long-range strike capability to the surface force.**
- **Fix the naval aviation shortfall by deferring or reducing the F-35C procurement for additional F/A-18 E/Fs.**
- **Develop an aerial layer for IAMD that is integrated with the corresponding IAMD platforms in the surface force.**
- **Delay the *Ford* class CVN79 procurement to align with the number of CVWs.**
- **Modify the *Ford* design or develop a conventional alternative to reduce cost to less than \$11 billion.**
- **Continue *America* class amphibious assault ship procurement but consider a small carrier option, with catapults for fixed-wing flight operations, as a potential alternative in the late 2020s.**
- **Do not procure any more *San Antonio* class LPDs beyond what is planned.**

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- Consider some near-term alternatives to the current plans for the LXR class of ships to support disaggregated expeditionary operations.
- Continue to build two *Virginia* class SSNs per year, each with VPMs after 2019.
- License and produce diesel submarines as lower cost platform to augment the SSN force.

Table 13 summarizes the recommended 15-year shipbuilding plan. The notable tradeoffs are: 1) more large surface combatants (LSCs) at the expense of small surface combatants (SSCs); 2) more attack submarines (SS); and 3) introduce lower cost ship concepts to pay for increased SS production. The total estimated cost for this battle force is about \$257 billion, which translates into an average shipbuilding budget of \$17.1 billion per year (not including support ships). Given the average Navy shipbuilding budget of \$16.9 billion between 2016 and 2025 (including support ships), the proposed shipbuilding plan is reasonable. It delivers 20 additional ships and a more capable force by 2030 within the existing shipbuilding budget, potentially with some moderate increases.

Table 13. Recommended 15-year Shipbuilding Plan for the Navy

Year	CVN	LSC	SSC	SS	AWS	CLF	ROM (\$ billion)
FY16		2	3	2	1	1	\$17
FY17		2	3	2	1		\$16.5
FY18	1	3		2	1	1	\$16.3
FY19		3		2		1	\$16.5
FY20		3		2	1	1	\$16.5
FY21		3		1		1	\$12
FY22		3		2		1	\$16.6
FY23		3		3		1	\$17.4
FY24	1	3		2	2	1	\$15.6
FY25		3	1	4	1	1	\$17.9
FY26		3	2	4	1	1	\$18.9
FY27		3	2	4	1	1	\$18.9
FY28		3	2	4	2	1	\$18.9
FY29		3	2	4	1	1	\$18.9
FY30	1	3	2	4	1	1	\$18.9
Total	3	43	17	42	13	14	\$257
Delta	0	+13	-14	+19	0	0	-

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Aircraft Procurement

The study recommends fixing the naval aviation shortfall by deferring or reducing the F-35C procurement for additional F/A-18 E/Fs. If the Navy purchased an additional 126 F/A-18 E/Fs, as examined by the Congressional Budget Office [60], then the estimated impact to the aviation procurement line is \$7.5 billion.⁶ Implementing a SLEP on an additional number of airframes, estimated at roughly \$30 million per unit, can help overcome the impending retirement of large number of tactical aircraft from the CVWs between 2030 and 2035. If we also assume an unmanned squadron in each CVW with a 2:1 tail-to-tooth ratio and \$40 million / unit, then an additional unmanned squadron, with 10 aircraft, per CVW is about \$7.2 billion. There are still some questions about how best to employ an unmanned squadron from an aircraft carrier. Some thoughts are offered in the classified annex on this topic.

Weapon Procurement

To improve the effectiveness of the naval force, the study made the following recommendations with implications for weapons procurement:

- **Pursue a Pershing 3 variant, to be launched from a large surface combatant, to provide a long-range offensive capability.** Recommended eleven MG(X) ships with some flexibility in configuration. If each has 24 VLS cells for this weapon, then 264 missiles are required to fill all of the launchers.
- **Pursue a MG(X) ship to augment the capacity of large surface combatants.** Recommended eleven MG(X) ships with some flexibility in configuration. If each has 256 VLS cells for standard missiles and is loaded out with Standard Missile 6, then an additional 2,728 are required to fill all of the launchers.
- **Pursue a missile variant for the aerial layer as part of an integrated IAMD strategy.** If tactical aircraft are going to fly combat air patrols with these missiles, then a large inventory of them is needed. Given the size of the Chinese inventory, if you assume that each aircraft carriers require 2,000 missiles, then a total of 20,000 missiles are required.
- **Procure primarily HVP to replace existing Mark 45 5" rounds by 2030.** While some unique, non-HVP rounds (e.g., flares) will still be required, the HVP should replace the majority of 5" rounds by 2030. Since the typical magazine of a surface combatant holds 600 rounds, the Navy needs to buy close to 100,000 rounds to completely replace the existing inventory and outfit the new classes of ship that are recommended.

Using these rough numbers and current cost estimates, a weapon procurement estimate for what has been outlined above is \$42 billion⁷ over 15 years. This is roughly a \$3 billion increase in the current weapon procurement budget, but required to ensure the force outlined in Table 13 is a credible – not hollow – force.

⁶ Assuming a F/A-18 E/F is roughly \$62 million / unit.

⁷ Assuming a Pershing missile variant, SM-6, aerial-layer missile, and HVP cost \$15 million / unit, \$3.5 million / unit, \$1.2 million / unit, and \$0.04 million / unit, respectively.

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Beyond 2030

The study makes the following recommendations for future platforms:

- **Future Large Surface Combatant (CGX).** The future large surface combatant should be large enough (on the order of 10,000 tons) to accommodate two guns, based around EMRG with the HVP to the extent practicable, and VLS cells.
- **Future Attack Submarine (SSNX).** The future attack submarine needs a design philosophy wedded to manned and unmanned platform integration. Consequently, it needs significantly improved payload capacity – both internal and external – to handle off-board vehicles and systems, decoys, and advanced weapons. Also, the Navy should consider alternatives, such as a non-metallic hull, to maintain covertness in future threat environments.
- **Future Aircraft Carrier (CVX).** The *Ford* class aircraft carrier is too expensive. If the costs cannot be contained, the study recommends either a new supercarrier class that is more affordable or transitioning to a mix of light and supercarriers to maintain needed capacity within the expected fiscal environment.
- **Future Unmanned Vehicles.** Procure additional UAVs, USVs, and UUVs for integrated experimentation and development, including use of UXV motherships, medium and large, and UAV carriers.
- **Future Command Ship (LCCX).** Defer future procurement and use DDG-1000 class as follow-on for current LCC class command ships.
- **Future Unmanned Carrier (CUVX).** As concepts for the employment of unmanned systems mature, the need for carrier to transport, deploy/retrieve, refuel/re-arm, and maintain unmanned systems in the field may be required. An EPF could be utilized as a demonstrator to experiment with squadrons of UUVs or unmanned surface vehicles. The proposed aircraft carrier variant of the *America* class hull could be used to support several unmanned squadrons of aircraft. There is tremendous potential for unmanned systems, but the Navy must work out how best to employ them to augment the capabilities of manned platforms.

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List of Acronyms

A2AD	Anti-Access/Area-Denial
ACE	Air Combat Element
ACTUV	ASW Continuous Trail Unmanned Vessel
AEW	Airborne Early Warning
AKE	Dry Cargo/Ammunition ship
ARG	Amphibious Ready Group
ASBM	Anti-Ship Ballistic Missile
ASCM	Anti-Ship Cruise Missile
ASuW	Anti-Surface Warfare
ASW	Anti-Submarine Warfare
AWS	Amphibious Warship
C2	Command and Control
C3	Command, Control, and Communications
CAP	Combat Air Patrol
CEC	Cooperative Engagement Capability
CG	Guided Missile Cruiser
CIIF	Communication and Interoperability for Integrated Forces
CLF	Combat Logistic Force
CNA	Center for Naval Analyses
COCOM	Combatant Commander
CRS	Congressional Research Service
CSG	Carrier Strike Group
CVW	Aircraft Carrier Air Wing
CVX	Small conventionally-powered aircraft carrier
DDG	Guided Missile Destroyer
DOD	Department of Defense
DSB	Defense Science Board
DSG	Defense Strategic Guidance
EF 21	Expeditionary Force 21
EAB	Expeditionary Advanced Basing
EMRG	Electromagnetic Railgun
EPF	Fast Expeditionary Transport

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ESB	Expeditionary Mobile Base
FF	Frigate
FFRDC	Federally Funded Research and Development Center
FF(X)	Future Frigate
GCE	Ground Combat Element
HVP	Hyper Velocity Projectile
IAMD	Integrated Air and Missile Defense
ICBM	Inter-Continental Ballistic Missile
INF	Intermediate-Range Nuclear Forces
ISR	Intelligence, Surveillance, and Reconnaissance
LCAC	Landing Craft Air Cushion
LCS	Littoral Combat Ship
LCU	Landing Craft, Utility
LDUUV	Large Displacement Unmanned Undersea Vehicle
LHA/LHD	Amphibious Assault Ship
LMSR	Large medium-speed roll on/roll off ship
LPD	Amphibious Transport Docks
LSC	Large Surface Combatant
LSD	Dock Landing Ship
LXR	Amphibious Transport Replacement
MAC	Multiple-All-Up-Round Canister
MCM	Mine Countermeasures
MEB	Marine Expeditionary Brigade
MEU	Marine Expeditionary Unit
MEU (SOC)	Marine Expeditionary Unit Special Operations Capable
MGX	Magazine Ship
MIW	Mine Warfare
MYP	Multi-Year Procurement
NATO	North Atlantic Treaty Organization
NSEC	National Security Engineering Center
ONR	Office of Naval Research
ORP	Ohio Replacement Program
PC	Patrol Craft
QDR	Quadrennial Defense Review

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R&D	Research and Development
SLEP	Service Life Extension Program
SOF	Special Operations Forces
SS	Conventionally powered submarine
SSBN	Ballistic Missile Submarine
SSC	Small Surface Combatant
SSP	Air independent propulsion submarine
STOVL	Short Takeoff, Vertical Landing
SWIFT	Society of Worldwide Interbank Financial Telecommunications
T-AO	Civilian manned fleet oiler
T-AOE	Civilian manned fast combat support ship
T-AO(X)	Future civilian manned fleet oiler
TLAM	Tomahawk Land Attack Missile
UAV	Unmanned Air Vehicle
USV	Undersea vehicle
USuV	Unmanned Surface Vehicle
UUV	Unmanned Undersea Vehicle
UXV	Unmanned Vehicle
VLS	Vertical Launch System
VPM	Virginia Payload Module
VPT	Virginia Payload Tubes

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Appendix A Terms of Reference

National Defense Authorization Act Section 1067

- (a) INDEPENDENT STUDIES. —
 - (1) IN GENERAL — The Secretary of Defense shall provide for the performance of three independent studies of alternative future fleet platform architectures for the Navy in the 2030 timeframe.
 - (2) SUBMISSION TO CONGRESS. — Not later than April 1, 2016, the Secretary shall submit the results of each study to the congressional defense committees.
 - (3) FORM. — Each such study shall be submitted in unclassified form, but may contain a classified annex as necessary.
- (b) ENTITIES TO PERFORM STUDIES. — The Secretary of Defense shall provide for the studies under subsection (a) to be performed as follows:
 - (1) One study shall be performed by the Department of the Navy and shall include participants from—
 - (A) the Office of Net Assessment within the Office of the Secretary of Defense; and
 - (B) the Naval Surface Warfare Center Dahlgren Division.
 - (2) The second study shall be performed by a federally funded research and development center.
 - (3) The final study shall be conducted by an independent, non-governmental institute which is described in section 501(c)(3) of the Internal Revenue Code of 1986, and exempt from tax under section 501(a) of such Code, and has recognized credentials and expertise in national security and military affairs.
- (c) PERFORMANCE OF STUDIES. —
 - (1) INDEPENDENT PERFORMANCE. — The Secretary of Defense shall require the three studies under this section to be conducted independently of each other.
 - (2) MATTERS TO BE CONSIDERED. — In performing a study under this section, the organization performing the study, while being aware of the current and projected fleet platform architectures, shall not be limited by the current or projected fleet platform architecture and shall consider the following matters:
 - (A) The National Security Strategy of the United States.
 - (B) Potential future threats to the United States and to United States naval forces in the 2030 timeframe.
 - (C) Traditional roles and missions of United States naval forces.
 - (D) Alternative roles and missions for United States naval forces.

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- (E) Other government and non-government analyses that would contribute to the study through variations in study assumptions or potential scenarios.
 - (F) The role of evolving technology on future naval forces, including unmanned systems.
 - (G) Opportunities for reduced operation and sustainment costs.
 - (H) Current and projected capabilities of other United States armed forces that could affect force structure capability and capacity requirements of United States naval forces.
- (d) STUDY RESULTS. —The results of each study under this section shall—
- (1) present the alternative fleet platform architectures considered, with assumptions and possible scenarios identified for each;
 - (2) provide for presentation of minority views of study participants; and
 - (3) for the recommended architecture, provide—
 - (A) the numbers, kinds, and sizes of vessels, the numbers and types of associated manned and unmanned vehicles, and the basic capabilities of each of those platforms;
 - (B) other information needed to understand that architecture in basic form and the supporting analysis;
 - (C) deviations from the current Annual Long-Range Plan for Construction of Naval Vessels required under section 231 of title 10, United States Code;
 - (D) options to address ship classes that begin decommissioning prior to 2035; and
 - (E) implications for naval aviation, including the future carrier air wing and land-based aviation platforms.

N81 Terms of Reference

Purpose. This document provides guidance and promulgates the Terms of Reference (TOR) for the three independent studies of potential future Navy fleet architectures pursuant to Section 1067 of the National Defense Authorization Act for Fiscal Year 2016 (FY16 NDAA).

Background. The FY16 NDAA directs the Secretary of Defense (SECDEF) to commission three independent studies to recommend potential future Navy fleet architectures. The studies will be submitted to the congressional defense committees in unclassified form, with a classified annex if necessary, not later than April 1, 2016 (Note: this due date was extended by the congressional defense committees to July 1, 2016. An interim report was provided on 22 March, 2016). These studies will provide competing visions and alternatives for future fleet architectures in the 2030 timeframe.

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- One study will be performed by the Department of the Navy, with input from the Office of Net Assessment within the Office of the Secretary of Defense, and the Naval Surface Warfare Center Dahlgren Division.
- The second study will be performed by a federally funded research and development center (FFRDC). The MITRE Corporation was selected as the FFRDC to conduct the second independent study.
- The third study will be conducted by a qualified independent, non-governmental institute, as selected by SECDEF. SECDEF delegated authority to commission the qualified independent, non-governmental institute to the Secretary of the Navy, who subsequently delegated this authority to the Chief of Naval Operations (CNO).

CNO tasked Director, Assessment Division (N81) as the study coordinator for this effort.

Scope. The organizations performing the studies of fleet platform architectures for the Navy shall conduct work independently of each other.

The studies will conform to FY16 NDAA guidance:

- Optimize fleet architecture for the 2030 timeframe.
- While being aware of the current and projected fleet platform architecture, findings shall not be limited by current or projected fleet platform architecture.
- Consider the following matters:
 - The National Security Strategy of the United States.
 - Potential future threats to the United States and to United States naval forces in the 2030 timeframe.
 - Traditional roles and missions of United States naval forces.
 - Alternative roles and missions for United States naval forces.
 - Other government and non-government analyses that would contribute to the study through variations in study assumptions or potential scenarios.
 - The role of evolving technology on future naval forces, including unmanned systems.
 - Opportunities for reduced operation and sustainment costs.
 - Current and projected capabilities of other United States armed forces that could affect force structure capability and capacity requirements of United States naval forces.

Additionally, the studies will consider the impacts on the following:

- Industrial base capability and capacity
- Ship deployment cycles and maintenance requirements
- Basing, maintenance and shore infrastructure including overseas footprints
- Manpower requirements

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- Logistics support, ashore and at sea, including ancillary support equipment
- Weapons and payload inventories and maintenance requirements
- Command and control
- Communications and networks
- Current and alternative concept of operations
- Interdependence / reliance on Joint and coalition partners

Reporting Requirements. A report of each study shall be submitted to N81, in unclassified form, with a classified annex if necessary, not later than April 1, 2016. The study plan shall be provided to N81 by 05 February 2016, and an in-progress review to N81 and the Fleet Architecture Studies Oversight Board by 04 Mar. Final reports will include an annotated briefing and written report.

The results of each study under this section shall conform to FY16 NDAA guidance:

- Present the alternative fleet platform architectures considered, with assumptions and possible scenarios identified for each
- Provide for presentation of minority views of study participants; and
- For the recommended architecture, provide:
 - The numbers, kinds, and sizes of vessels, the numbers and types of associated manned and unmanned vehicles, and the basic capabilities of each of those platforms;
 - Other information needed to understand that architecture in basic form and the supporting analysis;
 - Deviations from the current Annual Long-Range Plan for Construction of Naval Vessels required under section 231 of title 10, United States Code;
 - Options to address ship classes that begin decommissioning prior to 2035; and
 - Implications for naval aviation, including the future carrier air wing and land-based aviation platforms.

Additionally, the results of each study under this section shall describe:

- Assumptions
- Expected threat and demand for Naval forces
- Operational concepts tied to the fleet architecture, such as:
 - Air-Sea Battle
 - Electromagnetic Maneuver Warfare
 - Distributed Lethality
 - Expeditionary Force 21
- Navy's employment cycle including forward presence provided

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- Implications to traditional naval missions
- Overseas basing and footprint
- Logistics concept of operations
- New or projected capabilities enabling the fleet architecture:
 - Cyber
 - Directed Energy
 - Unmanned systems and autonomy
- The resulting industrial base (not limited to shipyards)
- Navy shore infrastructure, communications and data networks, and weapons inventory and maintenance requirements
- Navy manpower requirements
- Weapons and payloads inventories and maintenance requirements needed

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Appendix B Prior MITRE Studies

MITRE's National Security Analysis Group (NSAG) is responsible for a collective body of work that has served to inform DoD leaders on strategic investment decisions. We used these analyses to help inform and illuminate this study by providing relevant and insightful analysis on factors that have potential to directly, or indirectly, influence naval force structure, architecture, and its associated capability and readiness.

All of these NSAG studies are classified SECRET or above. The excerpts below are included for brief context. For further detail and review, complete versions at the appropriate level of classification are also available upon request.

National Security Framework: An overarching body of work to provide DoD leadership a collective piece for strategic thought considerations and decision making. Highlights of the study addressed individual factors and the collective effects of: geo-political conditions, threat developments, existing and emerging technologies, existing and emerging CONOPs, and national budgets. These collective effects led to defining critical problems for specific warfare areas with associated recommendations. Follow-on studies included Future Ground Forces, Future Aerospace Forces, Future Maritime Forces, and special topics.

- Future Ground Forces: Framed the current and projected state of ground forces, evaluated against future threats and national budgets. Specific shortfalls and capability gaps were developed with specific courses of action and recommendations for future development of ground and amphibious forces.
- Future Aerospace Forces: Framed the current and projected state of Aerospace forces (primarily addressing U.S. Air Force and Navy assets), evaluated against future threats and national budgets. Specific shortfalls and capability gaps were developed with courses of action and recommendations for future baseline budget investments, platform attributes (manned and unmanned), weapons and sensors.
- Future Maritime Forces: Framed the current and projected state of maritime forces, evaluated against future threats and national budgets. Specific shortfalls and capability gaps were developed with courses of action and recommendations for baseline budget investments, platform attributes (manned and unmanned), weapons and sensors.

Defense Science Board (DSB) Missile Defense: A collective review of current and future ballistic and cruise missile threats, prepared and prioritized by short and long term strategies. Specific shortfalls and capability gaps were developed with courses of action and recommendations for cross/multi domain (Service/Agency) solutions.

Next Generation Air Dominance (NGAD): A threat-based analysis that examines how best to execute missions with identified alternatives that recapitalize capabilities and capacity lost as aircraft retire (reach material service life limits) while mitigating the capability gaps resulting from the evolution of the threat. Generation of viable alternatives will address the range of Performance, Affordability and Effectiveness trade space for senior leadership to select Next Generation Air Dominance capabilities. The proper selection of the "family of capabilities" will require well vetted alternatives to inform senior DoD leadership and

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decision makers. This is an outcome that will inform a wider USN / DoD audience on best alternatives, and the effectiveness of those alternatives for Next Generation Air Dominance.

Littoral Combat Ship Quick Look: A focused analysis that identified options for LCS that would make the ships and their payloads more relevant in high-end warfare.

Assured Command, Control, and Communications (AC3) Study: Assessed the Navy's current or programmed communications capabilities and a number of possible enhancements or mitigations, on their ability to support Fleet Forces Command vetted requirements, in the face of emerging Anti-Access/Area Denial (A2AD) threats. These mitigations ranged from current Navy or Joint programs of record to science and technology research projects. The study results evaluated each mitigation's capabilities and limitations on range, throughput, and others metrics, as well as providing a rough order of magnitude cost to implement in the Fleet.

Operations in a Contested Environment (OCE) Study: Evaluated the impact of emerging A2AD threats to U.S. Navy communications in a specific, classified operational scenario and assessed the utility of proposed mitigations.

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