FUTURE FLEET PROJECT
WHAT CAN WE AFFORD?

National Security Perspective

Mark Lewellyn | Chris Wright | Rodney Yerger | Duy Nhan Bui

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

FUTURE FLEET PROJECT

What Can We Afford?

Mark Lewellyn

Chris Wright

Rodney Yerger

Duy Nhan Bui

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

NSAD-R-16-004

Contents

Figures

Image credits:

Figure 1. Department of the Navy, "FY 2017 President's Budget," Press Brief," February 9, 2016, http://www.secnav.navy.mil/fmc/fmb/Documents/17pres/DON_PRESS_BRIEF.pdf.

Figure 3. Congressional Budget Office, "An Analysis of the Navy's Fiscal Year 2016 Shipbuilding Plan," October 2015, https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/reports/50926-Shipbuilding_OneCol-2.pdf.

Figure 4. Congressional Budget Office, "An Analysis of the Navy's Fiscal Year 2016 Shipbuilding Plan," October 2015.

Tables

Table credits:

Table A-3. Congressional Budget Office, "An Analysis of the Navy's Fiscal Year 2016 Shipbuilding Plan," October 2015.

Summary

The shape of the Navy's future fleet will be affected greatly by two factors: the ships and aircraft it has in its inventory today and its long-term plans for recapitalizing the force. The size and makeup of the Navy's fleet of ships are frequent catalysts for debate. Complicating debates on fleet size is the fact that the capability of individual ships has changed over the years as the weapons and sensors on those ships have evolved.

According to a recent Congressional Budget Office analysis, the Navy spent an average of $15.8 billion in fiscal year (FY) 2015 constant dollars each year over the last thirty years for building new ships and refueling its nuclear-powered ships and submarines. This compares to an average projected cost of $20.2 billion ($FY15) per year needed to implement the Navy's planned modernization program over the next thirty years. Given the downward pressures on future Defense Department budgets, not to mention the federal budget as a whole, it will be difficult to accommodate this planned growth in the Navy's shipbuilding accounts. What are the alternatives for prioritizing this spending?

Both the former and current Chiefs of Naval Operation stated that the recapitalization of the nation's sea-based deterrent force—the *Ohio* Replacement Program (ORP)—is a priority. In addition, recent statements by combatant commanders emphasized the need to increase the number of deployable attack submarines. Congress further stipulated that the Navy maintain eleven aircraft carrier battle groups. Focusing only on these three goals over the next thirty years would deplete 70 percent or more of the average $15.8 billion ($FY15) per year dedicated to shipbuilding, leaving insufficient funds to fully modernize surface combatants, amphibious lift ships, logistics ships, and other vessels.

This study explores various alternatives the Navy might pursue to recapitalize and upgrade its fleet under various priorities and funding scenarios between now and FY 2030. It also illuminates the long-term consequences of these alternatives. We chose a fifteen-year period instead of the thirty years covered in the Navy's shipbuilding plans because we believe it is a more realistic period for planning. We consider a range of funding scenarios. At the high level, we assume spending on shipbuilding will average $19 billion ($FY15) per year—the amount needed to meet the goals for the next fifteen years specified in the Navy's thirty-year shipbuilding plans. At the low level, we assume shipbuilding will average $13 billion ($FY15) per year, roughly the amount allocated in the 1990s, which was the last time the United States achieved a balanced budget. We find that at average spending on shipbuilding below $15.8 billion ($FY15) per year, it will be difficult to fund the ORP, maintain eleven aircraft carrier battle groups, and sustain reasonably healthy programs for attack submarines, surface combatants, and amphibious ships without exploring less-expensive aircraft carrier designs than the current *Ford* class. Further, at funding levels below the $19 billion per year needed to execute the Navy's current plans, the size of the fleet will be reduced, leading to reductions in the numbers of ships that can be deployed to meet combatant commanders' demands.

Now is the time to make the case for increased shipbuilding funds by making clear what the future fleet might look like without such an increase. Simultaneously, we should develop plans for a fleet we can afford in the event only historical levels of funding are available, whether the result will be a smaller fleet of equally capable ships or a similarly sized fleet built around ships with less capability.

The shape of the future fleet will be affected greatly by the ships and aircraft the Navy has in its inventory today and its long-term plans for recapitalizing the force. The size and makeup of the Navy's fleet of ships are frequent catalysts for debate. Complicating debates on fleet size is the fact that the capability of individual ships has changed over the years as the weapons and sensors on those ships have evolved.

Concern about the relative size of US and Soviet fleets during the Cold War led to a push during the Reagan administration to achieve a fleet size of six hundred ships. Several decades later, post-9/11 concerns with the spread of terrorism led then-Chief of Naval Operations (CNO) Admiral Mike Mullen to call for a "one-thousand-ship Navy" built around increased cooperation between US and allied navies to secure the maritime "commons." Given the recent growth of a credible Chinese fleet and the reemergence of Russia as a military power, now is a good time to examine alternative ways the Navy's current fleet might evolve to address the emerging security environment at sea as well as the budget environment at home. This is particularly important given the downward pressures on resources that are affecting the funds available to recapitalize and operate the Navy's ships.

Planning for the Future Fleet

Plans for the future fleet are shaped by a number of factors, not all of which are controlled directly by the Navy.

What Shapes the Navy's Current Plans?

Congress expressed its interest in the size of the future fleet in Title 10 Section 231 of the US Code of Laws, which calls for the Navy to submit a thirty-year shipbuilding plan each year. The Congressional Budget Office (CBO) uses this report as a basis to evaluate the ability of the Navy to afford the fleet reflected in the plan based on projected levels of funding to buy and operate new ships. The Congressional Research Service also prepares periodic reports for Congress on potential oversight issues related to the Navy's ability to execute its plans.

The Navy's current fleet of ships includes 275 deployable battle force ships, of which roughly one-third are deployed at any given time. The Navy defines a specific set of ships that comprise "The Battle Force"—ships that are capable of deploying to contribute to overseas combat capability of the Navy.[1]

The shape of the future fleet will be affected greatly by the ships and aircraft the Navy has in its inventory today and its long-term plans for recapitalizing the force.

Recently, however, the percentage of deployed ships has been under pressure as the Navy recovers from shortfalls in readiness funding resulting from the sequestration of funds in fiscal year (FY) 2013.

The Navy's stated goal, developed in a 2014 update to its Force Structure Assessment (FSA), is a fleet of 308 ships.[2] CNO Richardson chartered a new FSA

[1] Procedures for defining the content of the battle force are stated in Secretary of the Navy Instruction 5030.8C, "General Guidance for the Classification of Naval Vessels and Battle Force Counting Procedures," June 14, 2016, www.nvr.navy.mil/5080.8C.pdf.

[2] The Navy's previous (2012) FSA developed a 306-ship requirement—slightly less than the 313 ships developed in its 2006 plan. The reduction reflected plans to forward base ballistic missile defense guided missile destroyers (DDGs) in Spain and changes in the total number of littoral combat ships (LCSs) planned for procurement. The LCS has faced particular scrutiny since its inception early in this century due to concerns about its modular design, survivability, and cost. Since the release of the FSA, Secretary of Defense Chuck Hagel directed the Navy to limit the procurement of LCSs to thirty-two ships and explore alternative small combatant designs. Following work by the Small Surface Combatant Task Force, the Navy recommended supplementing the twenty-four baseline LCSs with twenty new frigate-like ships based on an LCS hull with improved armor and armament. These twenty ships would be preceded by eight transitional LCS

to consider how the emergence of ISIS/ISIL in the Middle East and the reemergence of Russia will affect the Navy's stated goal. This new FSA will be informed by two efforts. The first is the Alternative Carrier Study undertaken at the request of the Senate Armed Services Committee whose chairman, Senator John McCain, is a critic of large, expensive carriers like the *Ford* class and wants the Navy to consider alternative designs. The second is the Fleet Architecture Study—an effort performed by three groups to examine alternatives for how the fleet is assembled.[3] The Navy's goal and the supporting FSAs reflect a number of judgments and planning factors (some of which the Navy receives from the Office of the Secretary of Defense), including but not limited to the following:

- US interests, the US role in the world, and the US military strategy for supporting those interests and that role
- Current and projected Navy missions in support of US military strategy, including both wartime operations and day-to-day forward-deployed operations
- Current and projected capabilities of potential adversaries, including their anti-access/area-denial capabilities
- Regional combatant commander (COCOM) requests for forward-deployed Navy forces
- The individual and networked capabilities of current and future Navy ships and aircraft
- Basing arrangements for Navy ships, including numbers and locations of ships home-ported in foreign countries
- Crewing concepts for Navy ships
- Maintenance and deployment cycles for Navy ships
- Fiscal constraints

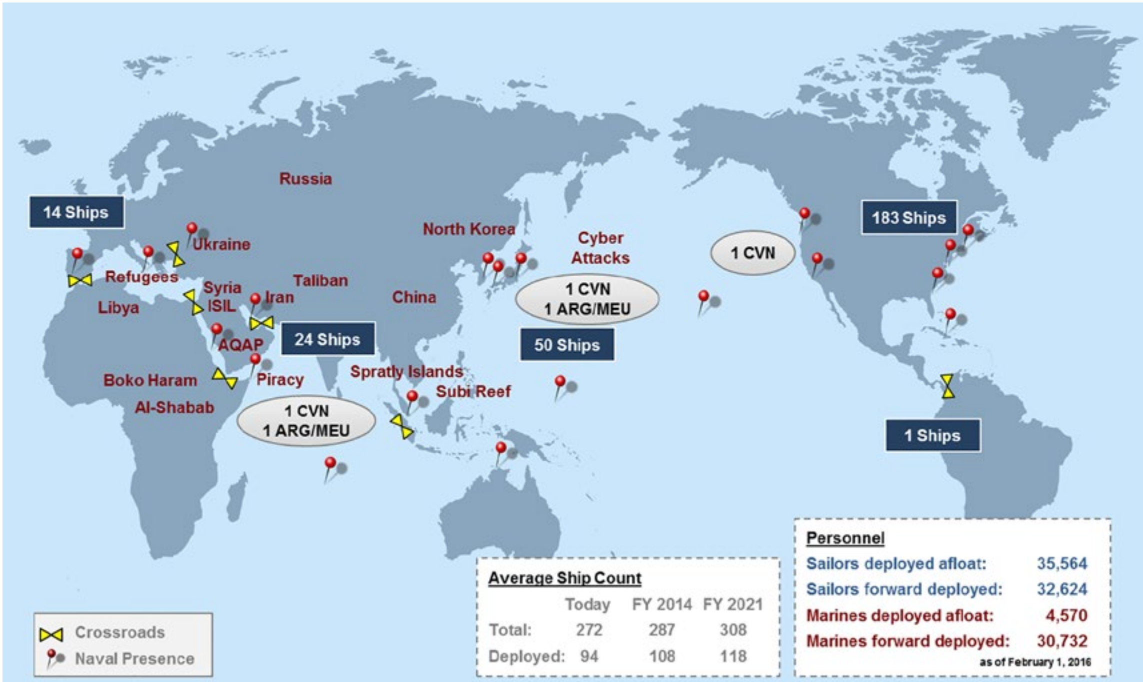
Of these factors, those affecting the number of ships deployed—the Navy's forward posture—are the most important because they reflect a portion of the demands the various COCOMs have for naval forces at any given time.[4]

Figure 1 displays the Navy's recent deployment trends and was included in its FY 2017 budget press briefing materials. The map shows various countries and areas of concern in red letters, the location of continental US and overseas naval presence with red "pins," geographical "choke points" or crossroads with yellow "bow ties," the average number of ships deployed overseas as well as those assigned to continental US bases in blue boxes, and the number of deployed nuclear-powered aircraft carriers (CVN) and amphibious ready groups/marine expeditionary units. In addition, Figure 1 summarizes the number

designs incorporating some but not all design modifications intended for the frigate, for a total of fifty-two ships in all. Also, in 2014, the Navy updated the 2012 FSA to account for both the 2012 Department of Defense Strategic Guidance and the 2014 Quadrennial Defense Review. The 2014 FSA added two ships: one additional amphibious ship (specifically, a 12th LPD-17 class amphibious ship) and one additional mobile landing platform/afloat forward staging base ship, increasing the requirement from 306 to 308 ships. More recently (December 2015), Secretary of Defense Ashton Carter ordered the Navy to trim its planned total buy of LCSs to forty and downselect to a single shipbuilder and design for the class as part of its FY 2017 budget. Under this plan, the Navy would have twenty-four of the baseline LCS designs, four "transitional" designs, and twelve frigate-like ships.

[3] Christopher P. Cavas, "Shaping the Fleet of the Future," *Defense News* (May 16, 2016), http://www.defensenews.com/story/defense-news/2016/05/08/navy-fleet-future-architecture-aircraft-carrier-cno-richardson-csba-bryan-clark-force-structure-mccain/84002628/.

[4] According to the transcript of a March 12, 2014, hearing before the House Armed Services Committee on the Department of the Navy's proposed FY 2015 budget, then-CNO Admiral Jonathan Greenert testified that a Navy of 450 ships would be required to fully meet COCOM requests for forward-deployed Navy forces. The difference between a fleet of 450 ships and the current goal for a fleet of 308 ships can be viewed as one measure of the operational risk associated with the goal of a fleet of 308 ships. A goal for a fleet of 450 ships might be viewed as a fiscally unconstrained goal. (See Ronald O'Rourke, "Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress," Congressional Research Service Report RL32665, August 1, 2014: 23, https://www.hsdl.org/?view&did=756733.)



ARG – amphibious ready group; MEU – marine expeditionary unit. Since February 2016, the Navy's total ship count has grown to 275 from the 272 shown on this figure.

Figure 1. Recent Navy Deployment Patterns (January 2016)

of sailors and marines both deployed afloat and forward-deployed as well as current and projected counts for active and deployed ships.

How Do the Navy's Plans Compare to Today's Fleet?

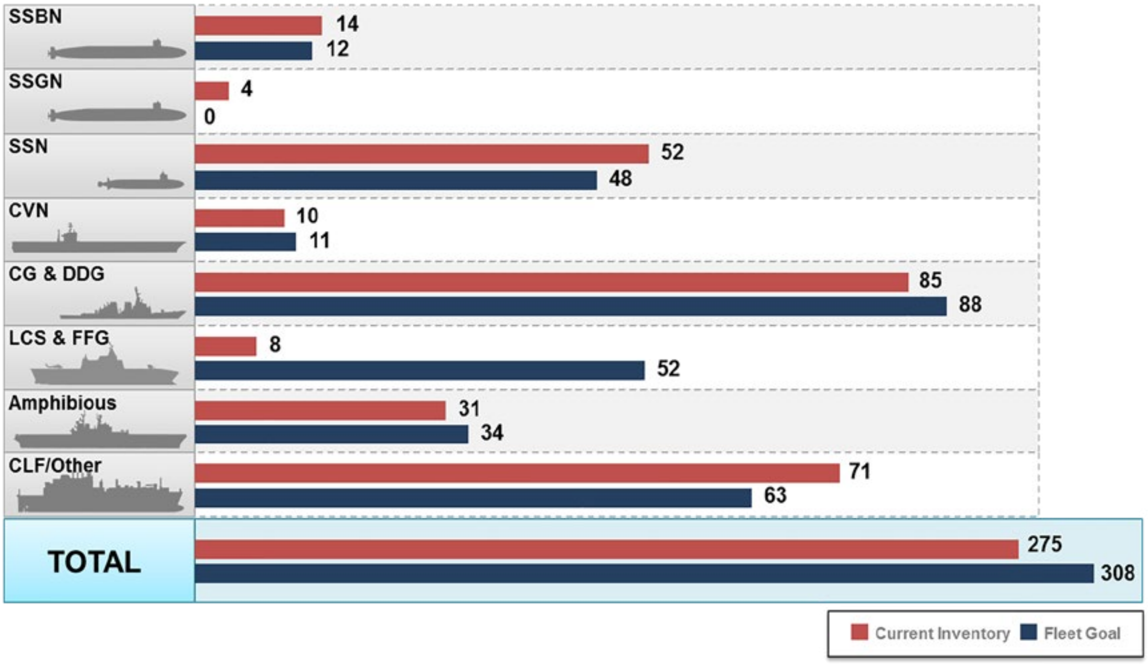
Figure 2 provides a comparison of the current fleet composition taken from the Naval Vessel Register[5] and the goal reflected in the 2014 FSA. One can see that a large amount of the growth in fleet size between the current Navy inventory and the planned future fleet represented by the FSA is due to the increase in the number of LCSs/frigates. This growth will be reduced by Secretary of Defense Carter's recent guidance to limit the number of new LCS/frigate procurements to forty. At this time, it is unclear whether subsequent FSAs will reduce the future fleet requirements to 296 ships or replace the "lost" LCS/frigates with new classes of ships. However, CNO Richardson observed that the missions covered by these LCSs have not gone away, and the new FSA he has chartered may have a goal greater than 308 ships. The Navy announced a set of revisions in its concept for the LCS/frigates in September 2016.[6] While retaining the capability to swap mission packages, individual ships typically will operate with one mission package installed on a long-term basis, aligned more closely with the new frigate design.[7]

We should note several other points of comparison between the Navy's current fleet and the goal reflected in the FSA. First, recapitalization of the sea-based

[5] Naval Sea Systems Command, "Naval Vessel Register," accessed September 30, 2016, http://www.nvr.navy.mil/INDEX.HTM.

[6] Department of the Navy, "Navy Adjusts LCS Class Crewing, Readiness, and Employment," Story Number NNS160908-10, September 8, 2016, http://www.navy.mil/submit/display.asp?story_id=96574.

[7] Justin Doubleday, "Navy Set to Brief Congress on Changes to LCS Program," *Inside the Navy*, August 26, 2016, https://insidedefense.com/inside-navy/navy-set-brief-congress-changes-lcs-program.



CG – guided missile cruiser; CLF – combat logistics force ships; FFG – frigate. The LCS and guided missile frigate fleet goal value represents the number of LCSs in the 2014 FSA. Secretary Carter's December 2015 guidance would reduce this number to forty. Note: in this chart and similar charts in this paper, the bars reflecting numbers of ships are not drawn to scale.

Figure 2. A Comparison of the Current Fleet Inventory and Fleet Goal

strategic deterrent (SSBN) force is a priority for the CNO and many other defense leaders. Plans call for the current force of fourteen *Ohio*-class SSBNs to be replaced by twelve new SSBNs—recently named the *Columbia* class—as part of the *Ohio* Replacement Program (ORP). This smaller number of SSBNs will be able to maintain current patrol coverage with acceptable increase in risk, although some risk will be incurred during the recapitalization process as force levels fall to ten SSBNs for several years in the 2030s and early 2040s.

The converted *Ohio*-class cruise missile submarines (SSGNs) will not be replaced as part of the ORP. Instead, the Navy will incorporate the *Virginia* Payload Module providing added payload volume in future new construction attack submarines (SSNs). The Navy's number of SSNs will decrease from the current inventory of fifty-four to an objective level of forty-eight in part to accommodate the need to build ORP submarines. Demand for SSNs remains high among COCOMs, however, and it is possible that the Navy's new FSA may revisit the requirement for SSNs.

At reduced levels of funding, the remaining classes of ships will be the "bill payers."

Congress legislated a requirement for eleven aircraft carriers via Title 10 Section 5062 of the US Code of Laws. [The Navy received a waiver to reduce its carrier force to ten due the gap between the retirement of the USS *Enterprise* (CVN-65) and the commissioning of the USS *Gerald R. Ford* (CVN-78).] However, in 2009, Secretary of Defense Robert Gates, following an extensive review of cost growth in defense programs led by the Office of Cost Assessment and Program Evaluation, announced a decision to shift procurement of carriers to five-year intervals to put carrier procurement on a more fiscally sustainable path.[8] This implies an eventual sustained force level of ten CVNs, assuming a fifty-year service life for large aircraft carriers.

In the balance of this paper, we will explore the impact of various levels of annual shipbuilding and conversion Navy (SCN) funding on the number and types of ships the Navy will be able to afford. In developing these numbers, we will focus on the priorities to fully fund ORP, sustain the numbers of SSNs, and maintain eleven aircraft carriers first. This means that at reduced levels of funding, the remaining classes of ships will be the "bill payers."

What Constrained the Navy's Ability to Realize Its Plans?

The Budget Control Act (BCA) of 2011 limited growth in funds allotted for new procurement. Further, as noted, the implementation of sequestration to enforce BCA spending caps in FY 2013 constrained funding available to maintain the readiness of the fleet. The reduction in readiness spending coupled with continuing demands from COCOMs for assets eroded the number of ships in ready-to-deploy status.

Additionally, the cost growth for new ship programs designed to recapitalize the fleet to the 308-ship level will lead in most cases to ships that are more expensive (and more capable) than those they will replace. As a result, it will be impossible to build the needed numbers of ships to reach the 308 goal if funds allotted to Navy shipbuilding accounts are not increased significantly above the average observed over the past thirty years.

[8] Ronald O'Rourke, "Navy Ford (CVN-78) Class Aircraft Carrier Program: Background and Issues for Congress," Congressional Research Service Report RS20643, April 19, 2010, http://www.dtic.mil/dtic/tr/fulltext/u2/a520782.pdf. Secretary Gates's statement concerning the decision on aircraft carrier force planning can be found in http://archive.defense.gov/Speeches/Speech.aspx?SpeechID=1341.

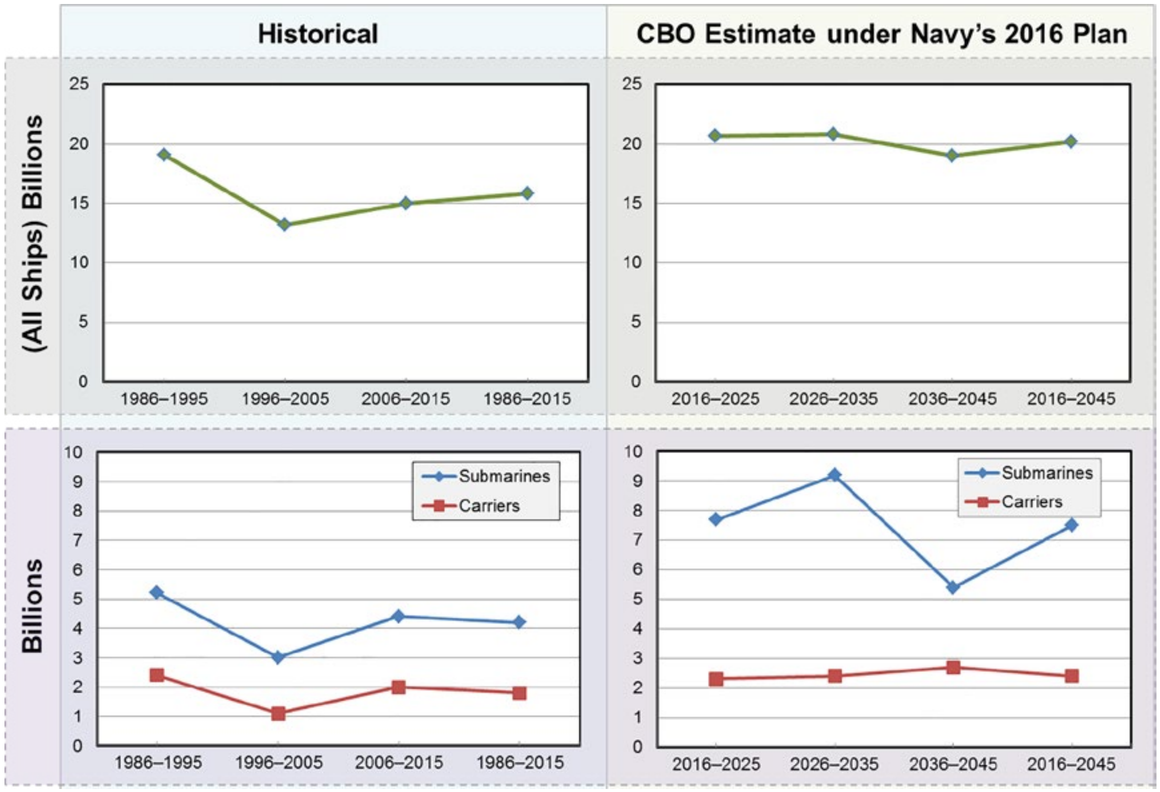
Figure 3 provides a historical comparison of past annual average shipbuilding costs with those projected under the Navy's 2015 thirty-year shipbuilding plan prepared by the CBO. (Details of the Navy's current shipbuilding plan are provided in Appendix A.)

The reduction in readiness spending coupled with continuing demands from COCOMs for assets eroded the number of ships in ready-to-deploy status.

CBO's estimate of $20.2 billion per year for the full cost of the Navy's 2016 shipbuilding plan is 28 percent higher than the $15.8 billion the Navy spent on average per year for all items in its shipbuilding accounts over the past thirty years. If the Navy's future funding for shipbuilding is in line with its past funding, the Navy will need to substantially reduce its new-ship purchases relative to the number called for in its 2016 plan.

For example, if the average annual funding for aircraft carriers and submarines held constant for the period 2026–2035 at $2.4 and $9.2 billion, respectively, as shown in Figure 3, along with $1 billion for refueling nuclear submarines and carriers, only about $3.2 billion per year on average would be left to procure all other ship classes, assuming the historical average of $15.8 billion is available.

To illustrate how much smaller the fleet of battle force ships would be under a reduction in new ship purchases, CBO constructed an alternative shipbuilding plan to meet the two criteria of sustaining funding for aircraft carriers and ballistic missile submarines. The key components of this plan are graphically depicted in Figure 4. (The CBO example sustains carrier force levels at ten, not eleven as reflected in existing law.) In this plan, the purchase of specific types of ships would be reduced relative to the 2016 plan in rough proportion, with the exception



Details provided in Appendix A.

Figure 3. Total Shipbuilding Costs by Major Category 1986–2045 (Constant FY 2015 Dollars)

of ballistic missile submarines and aircraft carriers. The CBO's cost estimates also reflect its independent projections of future ship acquisition costs, which are somewhat higher than those projected currently by the Navy.

With the nearly proportional reduction in purchases of other types of ships, the distribution of the fleet in 2045 among types of ships would be about the same as that specified in the 2016 plan, although the number of ships of each type would be smaller. Spending would be fairly similar (in inflation-adjusted dollars) during the near-term, midterm, and far-term periods.

The CBO's alternative plan is not a recommendation but simply an illustration of the possible consequences of continuing funding for shipbuilding at its historical average amount rather than increasing it, as would be required under the Navy's 2016 plan.

Purchases under that alternative plan would number 192 ships, compared to 264 in the Navy's plan. Figure 4 shows a comparison of the ships by type procured by the Navy and CBO alternative and the impact the procurements on the resulting inventory of ships in 2045 at the end of thirty years—a difference of almost seventy ships.[9]

It is unlikely that reductions in planned shipbuilding would occur proportionally, as in the CBO illustration. In addition to its priority on a sea-based deterrent and funding a force of twelve SSBNs while maintaining its plans for carrier force levels, the Navy will work hard to maintain a credible force of attack submarines. The Navy maintains a significant advantage in submarine capability, which will be

[9] Dr. Eric Labs, the principal author of CBO's analysis of the 2016 shipbuilding plan, explored the consequences of fiscal pressure on the Navy's plans in a recent article in the Naval Institute's *Proceedings*. [See Eric J. Labs, "A Fiscal Pearl Harbor," *Proceedings* 142, no. 2 (2016), http://www.usni.org/magazines/proceedings/2016-02/fiscal-pearl-harbor.]

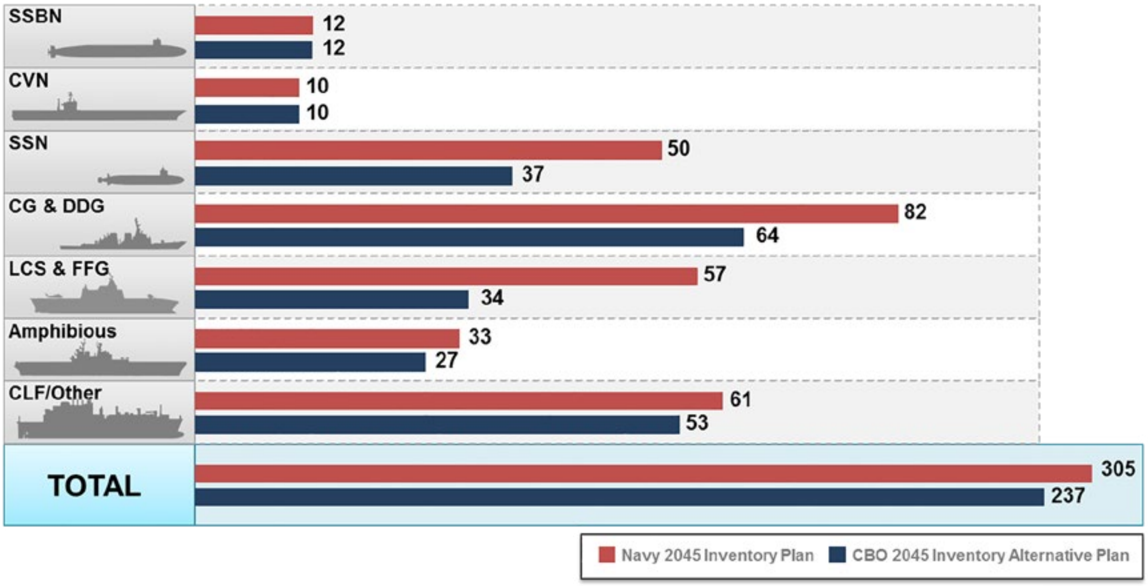


Figure 4. Comparison of Procurements and Inventories in the Navy (Red) and CBO (Blue) Alternative Thirty-Year Plans

important in countering threats posed by emerging peer competitors.

However, the most important consideration in the long term could be the reduction in total fleet ships that would occur barring significant increases in SCN funding above historical averages. As noted, for the case of CBO's alternative plan summarized in Figure 4, the reduction amounted to almost seventy ships. This reduction in total ships, in turn, would reduce the number of forward-deployed ships by fourteen or more, based on current deployment arithmetic, depending on the force management options employed.[10]

What Factors Determine Fleet Requirements?

Figure 5 shows a simple, idealized relation among the factors that shape naval force architectures. These factors can be characterized at any given point in time. However, the challenge for Navy planners is that the strategic and fiscal guidelines and associated threat projections that shape naval force architectures change more rapidly than the anticipated thirty- to fifty-year service lives of the ships that comprise those architectures. As a consequence, Navy planners look to changes in the sensors and weapon systems that are integrated in ships, for example, radars, communication systems, aircraft, missile launchers, and guns, and the ways ships are based, deployed, and crewed to respond to shorter-term changes in the strategic environment.

The Navy's forward posture, in turn, is based on demands from COCOMs and, in the Office of the Chief of Naval Operations, calculations using campaign-, mission-, and spreadsheet-level

[10] To allow sufficient time for crew training, ship maintenance, and transit, from four to seven ships are needed in the inventory to keep one forward deployed in the Western Pacific or Central Command (CENTCOM) using rotational deployment from US-based ports. With forward basing, fewer ships are needed to provide the same presence. For example, original Navy plans called for use of a "3-2-1" deployment plan for LCSs, maintaining three crews for every two LCSs and keeping one of those two LCSs continuously underway. The Navy's newly announced LCS plan adopts a simpler multicrewing concept similar to the two-crew blue and gold concept used by the ballistic missile submarine force. While the resulting plan would provide two crews for each ship in the deployment pool, compared to three crews for two under the original plan, the new plan also would remove ten ships from the rotational pool to serve in training and test support roles. Those ten ships could be deployed if needed under extraordinary circumstances.

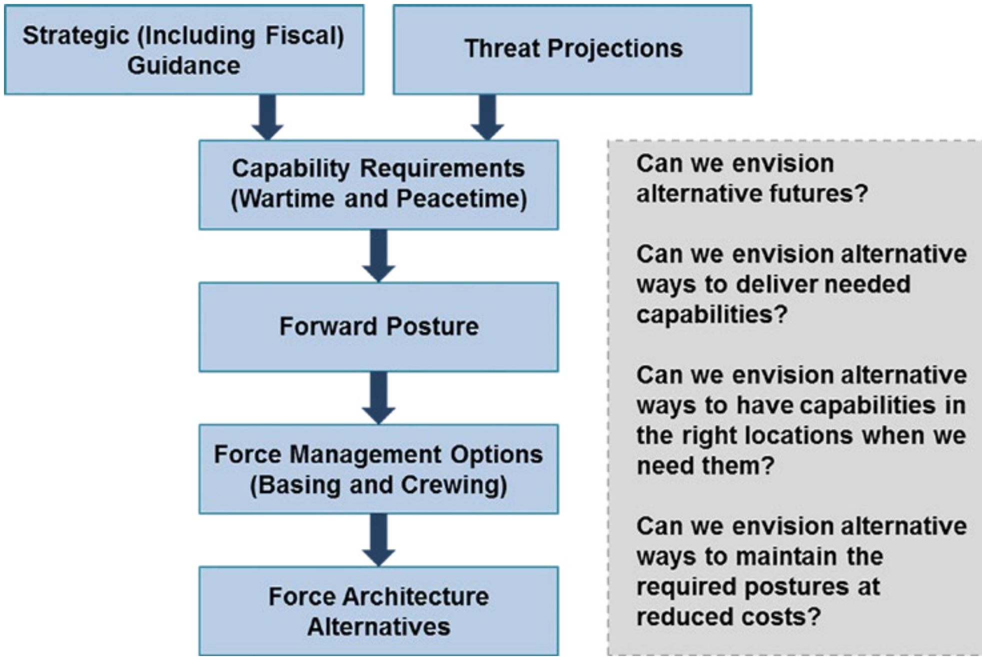


Figure 5. Flow Chart for Developing Force Structure Alternatives

models of the number and types of ships, aircraft, and weapons (capability requirements) needed to maintain adequate peacetime presence and/or prevail against potential threats characterized by operational plans for each theater. These calculations are informed by the projected capability of threat forces and strategic guidance on the employment of US forces. This guidance includes factors such as the amount of warning—can forces from other theaters move to support the theater of concern before hostilities begin?—and the goals of US forces, for example, halting the advance of enemy forces, winning decisively.

Alternative Future Fleets

The questions along the right side of Figure 5 reflect issues we need to consider in this effort, which will focus on developing options to shape the future fleet. The first question concerns the alternative futures the Navy must consider in shaping the fleet, and these futures are driven by strategic guidance reflected in documents such as the "National Security Strategy of the United States,"[11] the "Defense Strategic Guidance,"[12] and service-specific guidance such as the revised "Cooperative Strategy for 21st Century Seapower."[13] Fiscal guidance is another important factor affecting alternative futures. In particular, the BCA of 2011 provides specific guidance on future funding for both defense and nondefense discretionary spending and includes a sequestration mechanism to enforce these limits. Our primary consideration will be how alternative fiscal futures may shape the Navy's decision space for developing this fleet, and these futures will be affected directly by the BCA. Final elements shaping alternative futures are intelligence community projections on

[11] President of the United States, "National Security Strategy," February 2015, https://www.whitehouse.gov/sites/default/files/docs/2015_national_security_strategy.pdf.

[12] Department of Defense, "Sustaining U.S. Global Leadership: Priorities for 21st Century Defense," January 2012, http://archive.defense.gov/news/Defense_Strategic_Guidance.pdf.

[13] Department of the Navy, "A Cooperative Strategy for 21st Century Seapower," March 2015, https://www.uscg.mil/seniorleadership/DOCS/CS21R_Final.pdf.

the capabilities that existing and potential threats can bring to bear in the maritime environment.

Today's fleet is the result of a range of disparate answers to the questions posed in Figure 5. Further, the answers were developed over a long period of time as the nation's focus shifted from World War II to the Cold War, Vietnam, the post-Cold War "peace dividend," the first and second Gulf Wars, and today's refocus toward the Pacific and the challenges posed by a rising China. During this time, there have been few coordinated efforts to develop a naval force architecture responsive to a range of alternative futures. We have noted the current fleet architecture that will shape the Navy's new FSA.

Final elements shaping alternative futures are intelligence community projections on the capabilities that existing and potential threats can bring to bear in the maritime environment.

In the FY 2004 Defense Authorization Bill, Congress chartered an examination of alternative naval force structures.[14] Three organizations, the Center for Naval Analyses (CNA), the Office of Force Transformation in the Office of the Secretary of Defense, and the Center for Strategic and Budgetary Assessments, provided proposed alternative force architectures, which differed markedly from one another. In particular, the architecture proposed by the Office of Force Transformation was a significant departure from current planning constructs used by the Navy. In contrast, the Navy's current planning constructs influenced many of the elements of the architecture proposed by CNA. The Center for Strategic and Budgetary Assessments architecture included many of the same ship designs currently planned by the Navy but also proposed some new designs and therefore reflected a change from the Navy's planning constructs, but not as significant a change as that of the Office of Force Transformation.

A more recent view of the planning constructs Navy leadership will need to consider in developing a range of force architectures responsive to alternative potential futures is presented in a Naval Institute *Proceedings* article on rethinking the future fleet.[15] The article suggests several design themes the Navy should consider in addressing the second question in Figure 5, "Can we envision alternative ways to deliver needed capabilities?":

- "The use of a common large aviation-ship hull for Navy sea-control/power-projection air wings and for Marine Corps vertical-raid/assault-air wings, reconfigurable between the two missions between the deployments
- Surface combatants with smaller vertical-launch magazines that can reload at sea from logistic ships or remotely fire weapons carried in supplementary magazines on logistic ships
- Separate classes of surface combatants optimized for air defense or antisubmarine warfare (ASW) within a common hull type that can self-defend in peacetime but aggregate to fight offensively in wartime
- Tactical-combat aircraft that are optimized for endurance and carriage of long-range weapons rather than for penetrating sophisticated defenses carrying short-range weapons
- Large shore-launched unmanned undersea vehicles that take the place of submarines for preprogrammed missions such as covert surveillance or mine-laying

[14] Ronald O'Rourke, "Navy Force Structure and Shipbuilding Plans: Background and Issues for Congress," Congressional Research Service Report RL32665, February 14, 2006, http://www.dtic.mil/dtic/tr/fulltext/u2/a472401.pdf.

[15] Arthur H. Barber, "Rethinking the Future Fleet," *Proceedings* 140, no. 5 (2014): 48–52, http://www.usni.org/magazines/proceedings/2014-05/rethinking-future-fleet.

- Use of a common hull type for all of the large noncombatant ship missions such as command ships, tenders, hospital ships, ground vehicle delivery, and logistics
- Elimination of support models that are based on wartime reliance on reach-back access to unclassified cyber networks connected by vulnerable communications satellites or to an indefensible global Internet"

In contrast, in this study, we consider alternative future fiscal environments the Navy may face and ask how these environments might shape the future fleet. If we adopt a goal to maintain the submarine force—both SSBN and SSN—then we need to focus on options for the rest of the force, to include alternative carrier designs that are more affordable than the current *Ford* class but compliant with the congressional requirement for eleven carrier strike groups, as well as alternative approaches to modernizing and managing surface combatants, amphibious assault capability, and support shipping.

We consider alternative future fiscal environments the Navy may face and ask how these environments might shape the future fleet.

In addition to the historical average funding level for shipbuilding ($15.8 billion FY 2015) that CBO considers, we consider lower (~$13 billion) and higher (~$17 billion) levels. (The low and high levels of historical SCN funding shown in Figure 3 are $13.2 and $19.1 billion, respectively. We chose a $13–$17 billion FY 2015 range to bracket potential lower levels of funding below the ~$19 billion level needed on average to fund the current Navy plan through FY 2030.) The lower levels of funding are of particular interest because they correspond to the 1990s—the last decade when the federal budget was balanced. As such, they constitute a useful reference point if concerns about the size of the federal budget deficit and long-term economic growth in the United States dominate deliberations about the size of the federal budget, making it harder to sustain average SCN spending of $15.8 billion (FY 2015) per year or more without significant changes in plans for taxing and/or spending.[16] Also, while Congress has been adding funding to shipbuilding accounts, most recently a $2 billion addition in FY 2016, even such substantial increases fall well short of the roughly $21 billion a year that the CBO projects would be needed during the 2020s and 2030s to fully fund the Navy's thirty-year shipbuilding plan.

With our range of potential SCN funding levels as a starting point for fiscal guidance, we consider alternative fleet architectures that might result, as well as the effects these architectures will have on the other steps in the decision process outlined in Figure 5. Our analysis focuses on decisions the Navy must make between now and FY 2030—a time period critical for shaping the Navy's future fleet architecture but less than the thirty-year range required by Congress. During these fifteen years, Navy leaders will need to decide the extent to which they will begin implementing changes such as those suggested in the aforementioned *Proceedings* article[17] on rethinking the future fleet.

We took a structured approach to develop alternative shipbuilding plans at each of our funding levels. We developed alternative plans focusing on ship procurement that maintained current plans for SSBN force modernization. Next, we considered approaches to maintain eleven carrier strike groups using both *Ford*-class designs as well as smaller, less-expensive, and less-capable carriers. With remaining funds, we focused on maintaining SSN levels as close to the current FSA goals as possible and reduced construction of surface combatant, amphibious

[16] See, for example, Congressional Budget Office, "The Budget and Economic Outlook: 2015 to 2025," January 2015, https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/reports/49892-Outlook2015.pdf.

[17] Barber, "Rethinking the Future Fleet."

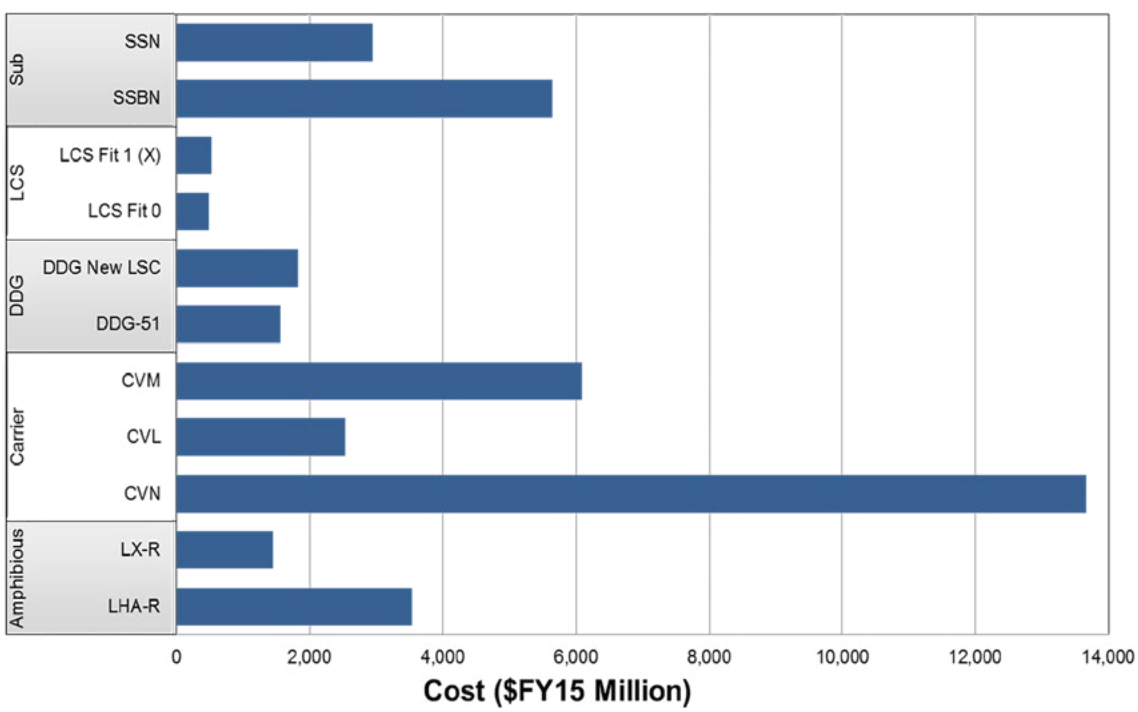
warfare, CLF, and other support ships to fit within the available funds. We also considered the need to maintain the industrial base for US shipyards building various classes of ships. At SCN levels lower than the historical average, the need to maintain the industrial base for surface ships could reduce the number of SSNs that can be built and hence overall submarine force levels.

In its aforementioned review of the Navy's thirty-year shipbuilding plan, the CBO provides shipbuilding cost estimates somewhat higher than the Navy's. In developing cost estimates for this analysis, we used CBO cost estimates along with extrapolations from the Navy president's budget submission and ship plan data, Congressional Research Service reports, and cost data for analogous platforms as a basis for our calculations. Our costs are in FY 2015 dollars ($FY15) unless otherwise specified. Figure 6 summarizes the unit costs that we used for this study. We provide more detail on our cost estimates in Appendix A.

In developing alternative fleets, we focused on the next fifteen years (through FY 2030). Our starting point was the baseline Navy shipbuilding plan for that period, displayed in Figure 7. Finally, Figure 8 shows the variation in annual SCN associated with this plan together with a red line displaying average annual SCN ($15.8 billion FY 2015) during the preceding thirty years.

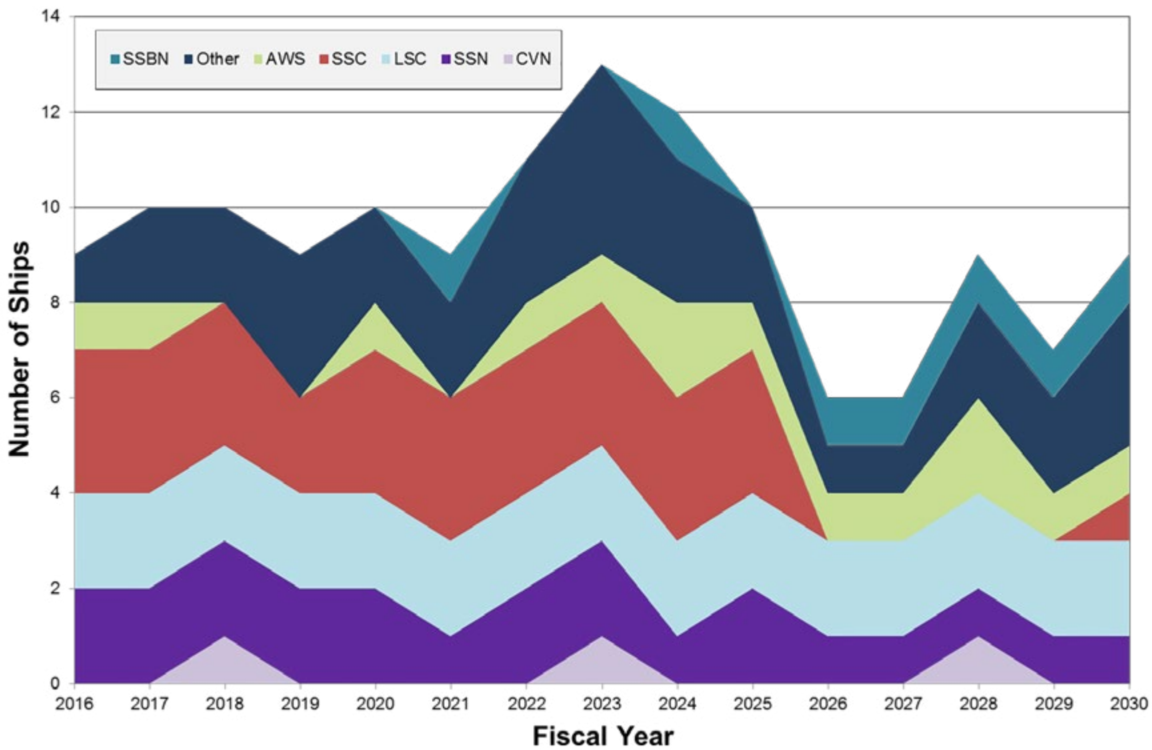
Figure 9 summarizes information on the baseline plan, as represented by the FY 2016 president's budget submitted in February 2015. These data show the planned force structure at the end of FY 2016 and its associated SCN budget, the fleet projected for the end of FY 2030, and the projected average SCN budget required for the FY 2016 to FY 2030 period to procure the planned fleet.

While the Navy's stated plan achieves almost all the force structure goals by ship type at the end of FY 2030, even at this higher-than-recent-average annual funding level, it falls noticeably short in the



CVL – small-sized aircraft carrier; CVM – medium-sized aircraft carrier; LHA-R – landing helicopter assault ship replacement; LSC – large surface combatant; LX-R – dock landing ship replacement

Figure 6. Ship Unit Cost Data



AWS – Amphibious ships; Others – CLF/support ships.

Figure 7. Baseline Construction Plan for Analysis (Average Year Cost = $18.9 Billion)

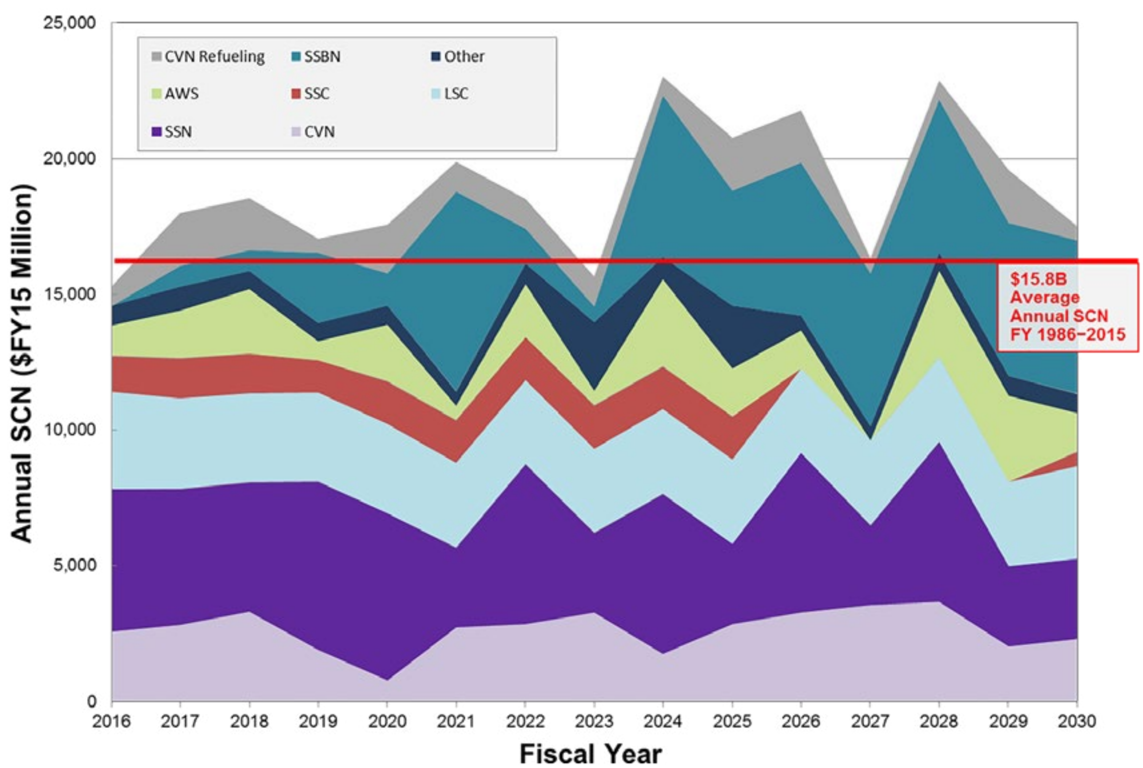


Figure 8. Baseline Funding Relative to Average Annual SCN ($FY15 Million)

number of SSNs. This shortfall reflects the impact of a prolonged period of comparatively low SSN production rates after the end of the Cold War. Only fourteen SSNs were authorized during the twenty years FY 1991 through FY 2010, before the current two ship per year construction rate commenced in FY 2011.[18]

Further, while current Navy plans show CVN force levels of eleven at the end of both FY 2016 and FY 2030, those force levels will drop to ten in FY 2040, consistent with Secretary of Defense Gates's previously mentioned 2009 decision to move CVNs to a five-year building cycle and the fifty-year service life projected for CVNs. Similarly, although the Navy's current goal for SSBNs is twelve ballistic missile submarines, the Navy's current shipbuilding plans result in a force of eleven submarines in FY 2030.

By selective reductions to the baseline plan, we developed alternative fleets consistent with reduced levels of funding. By using this approach, we can develop a range of alternative fleets for different funding levels. Our approach was to eliminate less-capable ships first, for example, remaining LCSs, before reducing more capable, multimission ships. Similarly, the new LX-R amphibious lift ships would be eliminated at lower budget levels, but three planned, large, multipurpose LHAs would be retained. In reality, changes to procurement plans for amphibious lift ships must be developed in concert with Marine Corps planners. Our present proposals do not consider impact on lift requirements for the Marines, helicopters, landing craft, vehicles, and supplies that these ships must support. Overall, this approach to procuring surface ships at reduced levels of funding favors capability at the expense of numbers even though some participants in debates about the size of the fleet have observed that "numbers have a quality all their own."

Our approach was to eliminate less-capable ships first, for example, remaining LCSs, before reducing more capable, multimission ships.

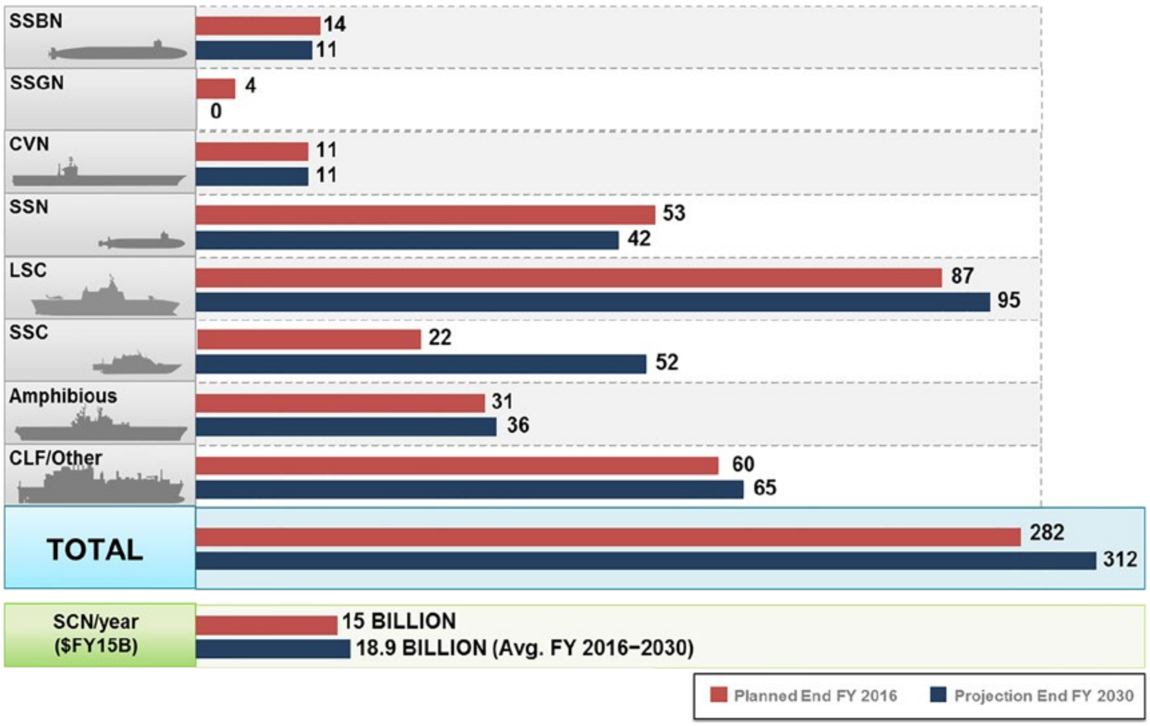
For the *Ford*-class CVNs, we took the opposite approach. The congressional language requiring eleven carriers does not specify the size or propulsion for these ships; therefore, we consider alternative designs for carriers that are smaller and less expensive than *Ford*-class CVNs.

On March 18, 2015, the Navy informed Congress that it was investigating alternative aircraft carrier designs to lower the cost of delivering sea-based aviation relative to the *Ford*-class CVNs in response to the aforementioned concern of Senator McCain. The Honorable Sean Stackley, Assistant Secretary of the Navy for Research, Development, and Acquisition, stated that the study will seek to determine: "is there a sweet spot, something different other than today's 100,000-ton carrier that would make sense to provide the power projection that we need that we get today from our aircraft carriers but at the same time put us in a more affordable position to provide that capability?"[19]

According to officials, configurations and acquisition plans for the first three *Ford*-class carriers, the USS *Ford* (CVN-78), USS *Kennedy* (CVN-79), and USS *Enterprise* (CVN-80) are not expected to change. However, the study could impact longer-term Navy plans for carrier designs and platforms. As noted, this

[18] The Navy is evaluating a variety of measures to reduce to a limited degree the impact of the SSN shortfall, which would not be overcome until the late 2030s under current shipbuilding plans. These measures include accelerating delivery of new ships and considering the possibility of some life extension for older vessels. See Statement of Rear Admiral Charles Richard and Rear Admiral Michael Jabaley on Naval Dominance in Undersea Warfare before the House Armed Services Committee, July 14, 2016, http://docs.house.gov/meetings/AS/AS28/20160714/105204/HHRG-114-AS28-Wstate-JabaleyUSNM-20160714.pdf.

[19] Sam LaGrone, "Navy Conducting Alternative Carrier Study," *USNI News*, March 23, 2015, https://news.usni.org/2015/03/23/navy-conducting-alternative-carrier-study.



In this and subsequent figures, we use LSC and small surface combatant (SSC) to represent larger (cruiser and destroyer) and smaller (LCS and frigate) combatant ships, respectively. The FY 2016 entry for SSCs includes eleven mine countermeasure ships, small, single-purpose ships that are intended to be replaced by the LCS before FY 2025.

Figure 9. Baseline Plans

study, along with the Force Architecture Study, will inform the Navy's new FSA.

In the late 1990s, the Future Aircraft Carrier (CVX) Analysis of Alternatives (AoA) considered a range of carrier designs featuring various sizes of flight decks and air wings and both conventional and nuclear power. The AoA was classified, but recent articles in the open literature detail the overall conclusions of the AoA:[20]

> At the center of the carrier debates in the late 1970s were the issues of carrier size and cost. The AoA looked again at these issues in detail. The options ranged from the existing large-deck *Nimitz*-class carriers (100,000 tons with approximately 75 aircraft) to small carriers (40,000–45,000 tons with 35–40 aircraft) such as France's *Charles DeGaulle*, with midsize carriers (70,000 tons with 55 aircraft) in between.
>
> The results were clear-cut: A large deck is considerably more cost-effective in generating sorties for combat missions. For example, small carriers cost about 3/4 as much to buy and operate as a comparable large carrier but carry 1/2 as many aircraft. A modern midsize carrier would cost about 90 percent as much to buy and operate as a comparable large carrier but carry only 3/4 as many aircraft. Moreover, once aircraft are allocated to essential defense and overhead functions, a large-deck carrier can generate more than half again as many strike sorties as a midsize carrier. In other words, there is a clear case

[20] J. Talbot Manvel Jr. and Dave Perin, "Christened by Champagne Challenged by Cost," *Proceedings* 140, no. 5 (2014), http://www.usni.org/magazines/proceedings/2014-05/christened-champagne-challenged-cost.

that large-deck carriers provide significantly more bang for the buck than comparable small or midsize carriers.

It is important to note that the ultimate unit cost for the *Ford*-class CVN is markedly greater than the AoA estimates due largely to the decision to include a greater number of new technologies in its design. It is unclear how the cost-per-sortie estimates summarized in these articles would change given this increase in construction costs.

For this study, we consider the impact of two alternative carrier designs as replacements for the CVN-80 and beyond. We made our choices to reduce carrier procurement cost, not to maximize the cost effectiveness of generating sorties. These smaller ship designs would have less capability than the ships they replace, with impact on operational capabilities:

- A CVM displacing approximately 65,000 tons with a conventional air wing. This design is a scaled-down variant of the existing CVN. We consider both gas turbine- and nuclear-powered versions similar to those considered in the CVX AoA. The SCN costs in Figure 6 reflect those for a gas turbine CVM.
- A CVL displacing approximately 30,000 tons with a short takeoff vertical landing (F-35B) and helicopter air wing similar to the LHA-6 as an aviation ship. This design assumed here is similar to that considered in the early 1980s for a vertical/short takeoff and landing support ship, a small aircraft carrier, but a somewhat larger design derived from the current LHA-type amphibious lift ship would also be possible. It will feature a cruiser/destroyer standard of passive protection.

As noted, the current Navy plan calls for a total of eleven CVNs in FY 2030, ten of which are deployable with their air wings as part of a carrier strike group at any given time.[21] Each of the ten air wings includes forty-four fighter/attack aircraft. In addition, there are two LHAs with expanded aviation capability (LHA-6/7) able to host up to about twenty short takeoff vertical landing F-35Bs, along with other large amphibious assault ships [LHAs/landing helicopter dock ship (LHDs)] with typical air wings, including six AV-8Bs or, in the future, F-35Bs.

It is important to note that the ultimate unit cost for the *Ford*-class CVN is markedly greater than the AoA estimates due largely to the decision to include a greater number of new technologies in its design.

We considered four alternative options for carriers in our future fleets:

- **Alternative 1.** Build CVN-80/81/82 to CVN-78 design as planned currently. These ships would deliver in FY 2027/32/37, respectively.
- **Alternative 2.** Cancel CVN-80 and subsequent *Ford*-class procurements. CVN-80 and subsequent ships are canceled and not replaced with smaller, less-expensive carriers with a subsequent reduction in sea-based aviation strike capability. This alternative would require change to the congressional requirement for eleven carriers. (CVN-80 is scheduled to be procured in FY 2018. The Navy's proposed FY 2017 budget estimates the ship's procurement cost at $12.9 billion then-year dollars. Our unit cost estimate is $13.7 billion FY 2015. The Navy wants to use advanced procurement funding for the ships in FY 2016 and FY 2017 and then fully fund

[21] The Navy's long-term operating plans are based on conducting lengthy CVN refueling overhauls in sequence with one ship following the next in a continuous series. The one ship in refueling overhaul is unavailable for deployment.

the ships in FY 2018–2023 using congressionally authorized six-year incremental funds.)[22]

- **Alternative 3.** Cancel CVN-80 and subsequent *Ford*-class procurements and replace them with CVMs.
- **Alternative 4.** Cancel CVN-80 and subsequent *Ford*-class procurements and replace them with small short takeoff vertical landing carriers (CVLs).

As noted in the aforementioned *Proceedings* article[23] on the CVX AoA, midsize and small carriers similar to our alternatives 3 and 4, respectively, would provide carriers with reduced sortie generation capability relative to the *Ford*-class carriers they would replace. Figure 10 shows estimates of the air wing totals for FY 2030 provided by each of our alternatives.

The smaller ships are assumed to be capable of embarking proportionally larger air wings than current CVNs. Current CVNs embark smaller air wings than during the Cold War but have capacity to accommodate more—typically air wings of seventy-five to eighty fixed-wing aircraft compared to the fifty-five to sixty embarked today. Sortie generation capability is dependent on a number of factors, including the number of embarked aircraft that are mission capable, the availability of pilots to fly the aircraft, and the availability of flight deck crews to ready the aircraft for flight and to launch and recover them. Experience during high-intensity flight operations as well as analyses performed by CNA have shown that people, not the machines they operate, limit flight deck capacity.[24] On the other hand, reduced numbers of catapults and deck space in the CVM, and elimination of catapults and much smaller size in the CVL, significantly reduce—or eliminate—the ability of the smaller ships to both launch large integrated strike aircraft packages and to sustain aircraft in combat areas at longer distances from the ship. Depending on threats and other circumstances, such capability reductions could have significant impact on strategic choices.[25]

In addition, if our smaller carriers, the CVM and CVL, are conventionally powered, building them instead of the *Ford*-class carriers could have an impact on the nuclear-powered shipbuilding industrial base. As noted, the CVX AoA considered a range of carrier sizes and propulsion concepts. One issue affecting the choice of propulsion concepts (nuclear or conventional) was the potential impact of the choice on both the nuclear and conventional industrial base. To inform this issue, analysts from the RAND Corporation's National Defense Research Institute analyzed the effects of this choice on the industrial base. RAND determined that:

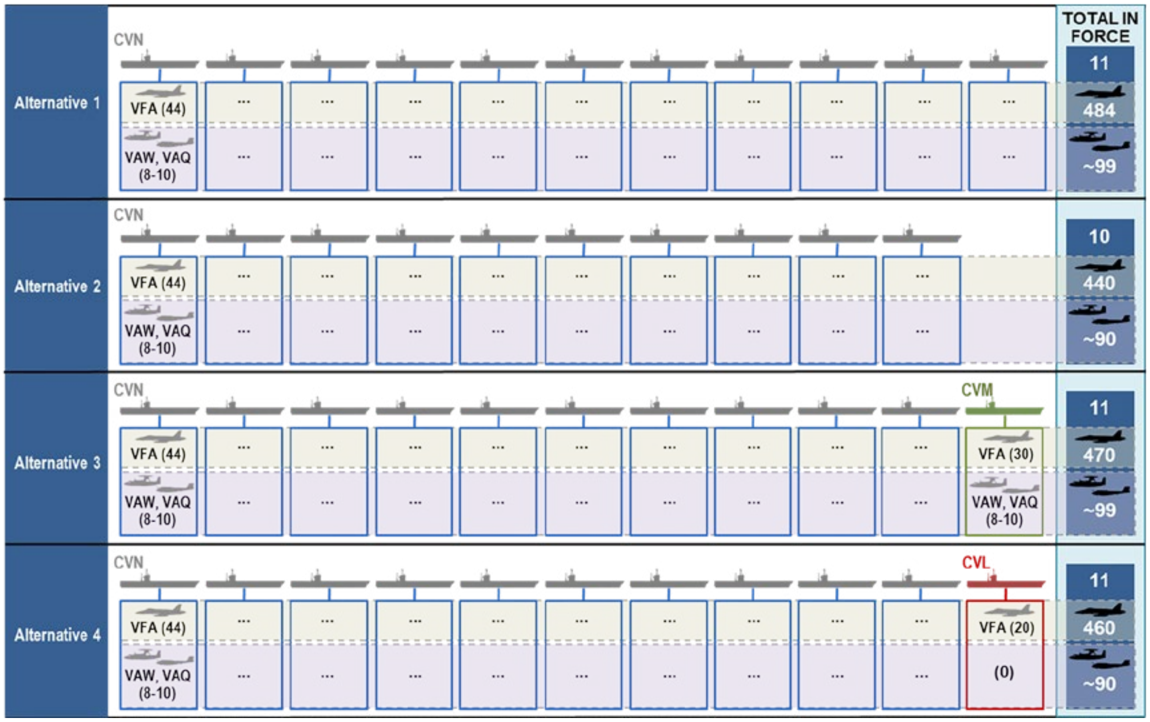
> Neither a nuclear CVX nor a non-nuclear CVX would affect the conventional propulsion

[22] Ronald O'Rourke, "Navy Force (CVN-78) Class Aircraft Carrier Program: Background and Issues for Congress," Congressional Research Service Report RS20643, April 5, 2016, https://www.fas.org/sgp/crs/weapons/RS20643.pdf.

[23] Barber, "Rethinking the Future Fleet."

[24] Angelyn Jewell, "Sortie Generation Capacity of Embarked Airwings," CNA Research Memorandum (CRM) 98-111, December 1998.

[25] A recent report by retired Navy Captain Jerry Hendrix raised concern about the decreasing combat range of carrier-based aircraft in current and planned air wings compared to older fighter and attack aircraft. (See Jerry Hendrix, "Retreat from Range: the Rise and Fall of Carrier Aviation," Center for a New American Security Report, October 2015, https://s3.amazonaws.com/files.cnas.org/documents/CNASReport-CarrierAirWing-151016.pdf.) This means that a greater portion of a carrier's air wing would need to support organic tanking in the event that enemy anti-access/anti-denial capability forces carriers to operate from greater standoff ranges against land-based targets. For carriers with smaller air wings, the need to provide organic tanking to support long-range strike operations significantly reduces strike capability. The F-35C promises a longer combat range compared to the F/A-18 E/F and will help to mitigate this problem. The initiative in the FY 2017 president's budget to restructure the Navy's Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS) program to a near-term focus on fielding a Carrier-Based Aerial Refueling System (CBARS) by the mid-2020s also will improve aircraft power projection capability. See Department of the Navy, "Highlights of the Department of the Navy FY 2017 Budget," 2016, 5-5.



Aircraft carrier and associated air wings for alternative forces as of the end of FY 2030. All ships, including CVNs in refueling overhaul status, are included. With no CVNs procured as planned in FY 2018, FY 2023, and FY 2028, the total number of CVNs would fall to nine in about FY 2032 and eight in about FY 2037. By the late 2030s, forces comprising eight CVNs and three CVMs could have a total of 442 VFA and about ninety-nine VAW/VAQ aircraft; forces having eight CVNs and three CVLs could have a total of 412 VFA and about eighty VAW/VAQ aircraft. Construction of smaller CVM- and CVL-type ships might proceed more quickly than CVNs.

Figure 10. Air Wings for Alternative Carrier Mixes

industrial base. The manufacturers in that area have robust markets in other Navy ships and/or in the commercial sector; the presence or absence of demand for a conventionally powered CVX would scarcely be felt. However, the nuclear industrial base may be affected by the demand for either a nuclear or nonnuclear CVX. If CVX were conventional, the cost of components for other Navy nuclear programs would increase. The cost of the heavy equipment and cores for the construction of nuclear submarines and the midlife refueling of carriers and submarines would increase by approximately $20 million to $35 million ($FY98) per year, or 5 to 7 percent of the cost of the nuclear components, depending on the program and the year. If CVX were nuclear, there is a potential schedule problem with the delivery of the heavy equipment components, suggesting that the CVX propulsion system decision must be made soon, and if nuclear, the reconstitution of production capability closely managed.[26]

We developed alternative fleets requiring average annual SCN funding levels between ~$13 billion and ~$17 billion per year in $FY15. The following

[26] John F. Schank, John Birkler, Eiichi Kamiya, Edward G. Keating, Michael G. Mattock, Malcolm MacKinnon and Denis Rushworth, *CVX Propulsion System Decision: Industrial Base Implications of Nuclear and Non-Nuclear Options* (Santa Monica, CA: RAND Corporation, 1998), http://www.rand.org/pubs/documented_briefings/DB272.html.

paragraphs provide a summary of our considerations in developing each alternative fleet:

- **Reduced funding alternative fleet baseline.** We set our reduced funding baseline at an average of ~$13 billion per year SCN. Developing a shipbuilding strategy at this level posed significant challenges given the need to maintain the ORP and SSN construction as a priority.

  Because the goal of some in Congress is to move toward a balanced federal budget without a significant increase in taxes, we felt it was appropriate to start at SCN levels close to those we last experienced with a balanced budget in the late 1990s. We considered two options to reach this level of SCN. Both affected the numbers of aircraft carriers in the proposed building plans, and both would be noncompliant in the long term with current legislation requiring the Navy to maintain eleven carriers. However, for both cases, we maintained SCN funding for refueling/maintaining the remaining CVN force. In the first option, we canceled all carrier procurements after CVN-79. We also canceled further SSC procurements, the joint high speed vessel replacement, and the LX-R. We reduced large surface combatant (LSC) procurement from thirty DDGs to fourteen and reduced procurement of several support ships. In the second option, we procured the CVN-80 but canceled CVN-81 and 82. To accommodate the addition of one CVN, we reduced the planned LSC buys from thirty DDGs to four. Figure 11 summarizes the composition of the fleet provided under this second option in FY 2030. However, while this option defers impact on the nuclear-powered shipbuilding industrial base, it might have unacceptable consequences for the surface shipbuilding industrial base. For this reason, we developed a reduced funding alternative that preserved the surface shipbuilding industrial base.

- **Reduced funding alternative fleet baseline with adjustments to preserve industrial base.** Our intent in designing this force is to maintain full funding for the ORP within average annual SCN spending of ~$13 billion per year. We also want to maintain the industrial base for surface ships with limited impact on building plans for SSNs. We adjusted the procurement plan in an effort to preserve all the major existing private shipbuilding yards. Under our ~$13 billion case that preserved CVN-80, the elimination of most of the DDGs would be expected to close shipbuilding yards at Bath and possibly Pascagoula. To address this, we added some additional funding overall while also sacrificing two SSNs in order to add six DDGs, most allocated to Bath but some to Pascagoula as well. Without additional DDGs, Pascagoula could face unacceptable gaps between LHAs, which might be exacerbated with the cancellation of LX-R. There also would be an option in this case to shift LHAs to Newport News and let Pascagoula close, significantly reducing the industrial base for large, complex naval ships We did not attempt to offset impacts of LCS (SSC) cancellation on the comparatively small Austal USA and Marinette shipyards. The National Steel and Shipbuilding Company, given the continuous, sustained fleet replenishment oiler (T-AO) and submarine tender (AS) programs, might be sustainable at the ~$13 billion level, particularly if awarded long-term, block-buy contracts. Submarine yards are ensured work through priority to SSBN and SSN production. Figure 12 summarizes the composition of this fleet in FY 2030. Four of the six additional DDGs would deliver after FY 2030 and, therefore, are not reflected in Figure 12.

- **Reduced funding alternative fleet baseline with adjustments to preserve the industrial base and less-expensive aircraft carriers.** Our intent in designing this force is to substitute less-expensive (and less-capable) aircraft carriers—CVMs or CVLs—for *Ford*-Class CVNs in the force designed to preserve the industrial base. The average SCN cost per year would be lower for the fleet with CVL substitution than for one with CVMs. In the long term, the fleet would have fewer ships in the CVL case because the assumed service life for CVLs is forty years, as opposed to fifty years for CVMs. Figure 13 summarizes the composition of this fleet in FY 2030.

- **Reduced funding alternative fleet baseline with adjustments to preserve the industrial base, less-expensive aircraft carriers, and additional SSNs.** Our intent in designing this fleet is to use the money saved in buying less-expensive aircraft carriers to buy back the SSNs we gave up to preserve the industrial base for surface ships. For this case, we obtain an additional SSN by FY 2030 for a small increase in average SCN per year: $12.8 billion for CVL and $13.3 billion for CVM. Figure 14 summarizes the composition of this fleet in FY 2030.
- **Reduced funding alternative fleet baseline with adjustments to preserve the industrial base, less-expensive aircraft carriers, and additional SSNs and DDGs.** Our intent in designing this fleet is to add funding to the less-expensive carrier options to buy back additional LSCs (DDGs) in addition to smaller carriers and SSNs. For this case, we obtain six (with CVMs) to eleven (with CVLs) additional DDGs for another increase in average SCN per year: $13.5 billion for CVL and $14 billion for CVM. Figure 15 summarizes the composition of this fleet in FY 2030.
- **$15.8 billion per year fleet.** At a level of SCN equivalent to the average over the past thirty years, we procure the *Ford*-class CVNs to meet the carrier requirement and reduce the planned procurement of LSCs by thirteen, SSNs by one, and amphibious ships by six and cancel LCSs, limiting the number of SSCs to twenty-three. Figure 16 summarizes the composition of this fleet in FY 2030. Although contrasting this fleet to CBO's 2045 alternative fleet shown in Figure 4 involves something of an "apples and oranges" comparison, we can see the impact of an approach that seeks to preserve SSNs and maintain multimission LSCs at the expense of tailored mission SSCs instead of applying uniform reductions across all platforms other than SSBNs and aircraft carriers.
- **$17 billion per year fleet.** At this increased level of SCN, we can almost achieve the FY 2030 mix of major combatant ships called for in the FY 2016 program of record. For this case, we procure *Ford*-class CVNs to meet the carrier requirement and reduce the planned procurement of amphibious ships by six and cancel LCSs, limiting the number of SSCs to twenty-three. Figure 17 summarizes the composition of this fleet in FY 2030.

Figure 11 through Figure 17 show a range of fleet sizes from 248 to 264 ships by 2030. These fleets will deliver less presence than the 308 ships reflected in the Navy's current FSA. Figure 18 compares the number of ships each of the alternatives could deliver to each COCOM based on a deployment concept similar to that in Figure 1. We assume that all planned overseas homeports and multicrewing programs are continued at current levels, permitting higher relative deployed force totals for the smaller-fleet-force-structure options than if those deployment efficiencies were reduced in proportion to overall fleet size.

As we noted early in this paper, the number of deployed ships a fleet provides for use by COCOMs is the best measure of the relative immediately available combat capability it provides. Figure 18 shows that our alternative fleets will provide twenty to thirty fewer deployed ships in FY 2030 than the Navy's baseline. Most of these shortfalls are due to the smaller numbers of surface combatants and amphibious ships procured in our alternative fleets compared to the baseline plan. By design, each alternative fleet maintained aircraft carriers, SSBNs, and SSNs at levels as close to the baseline as practicable. Consequently, even our alternative fleets procured at SCN levels in the

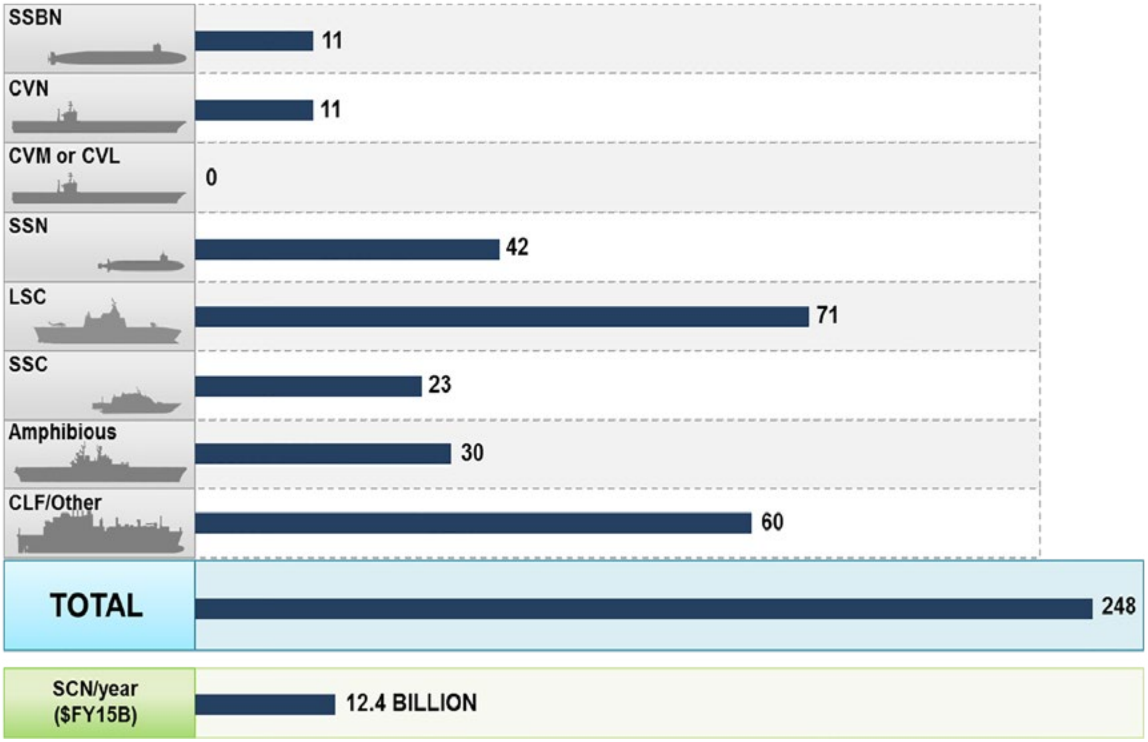


Figure 11. Reduced Funding Alternative Fleet Baseline

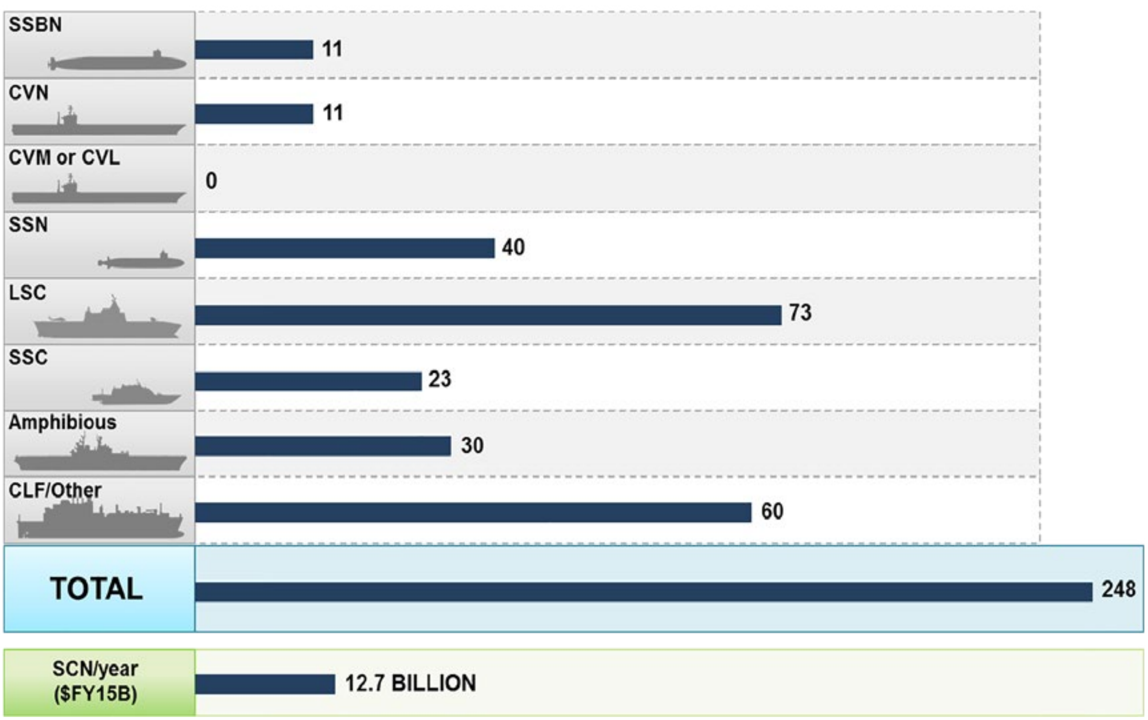


Figure 12. Reduced Funding Alternative Fleet Baseline with Adjustments to Preserve Industrial Base (FY 2030)

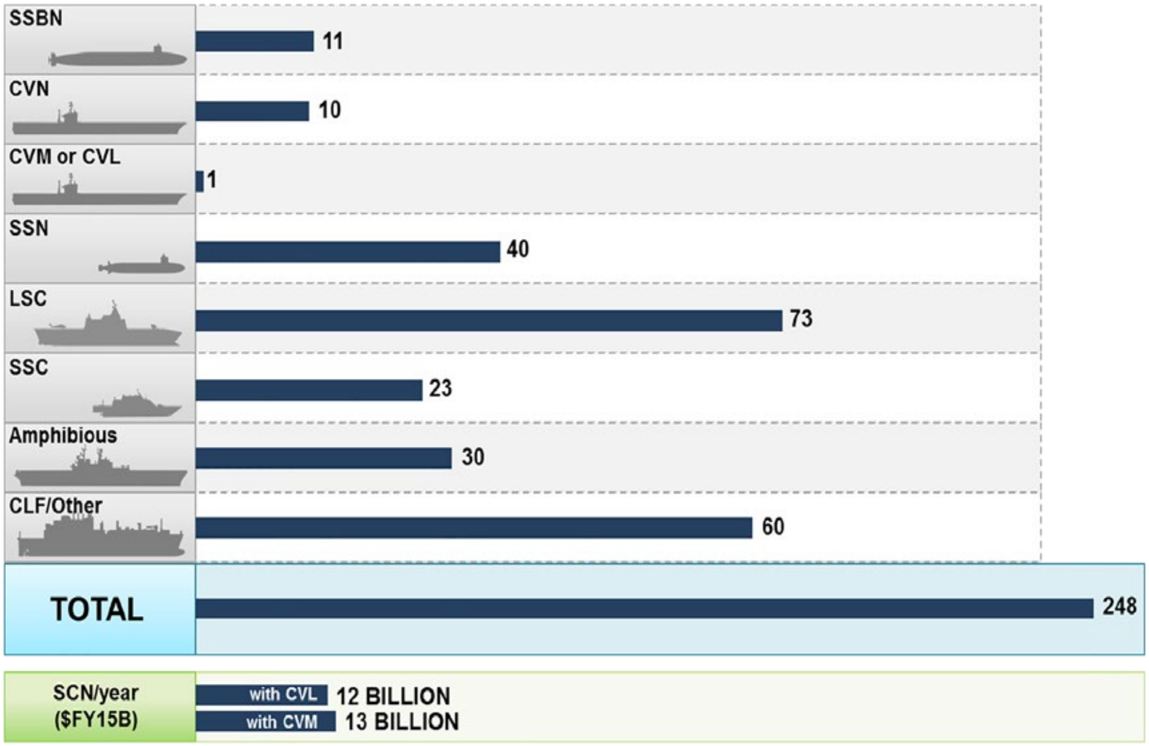


Figure 13. Reduced Funding Alternative Fleet Baseline with Adjustments to Preserve Industrial Base and Less-Expensive Aircraft Carriers (FY 2030)

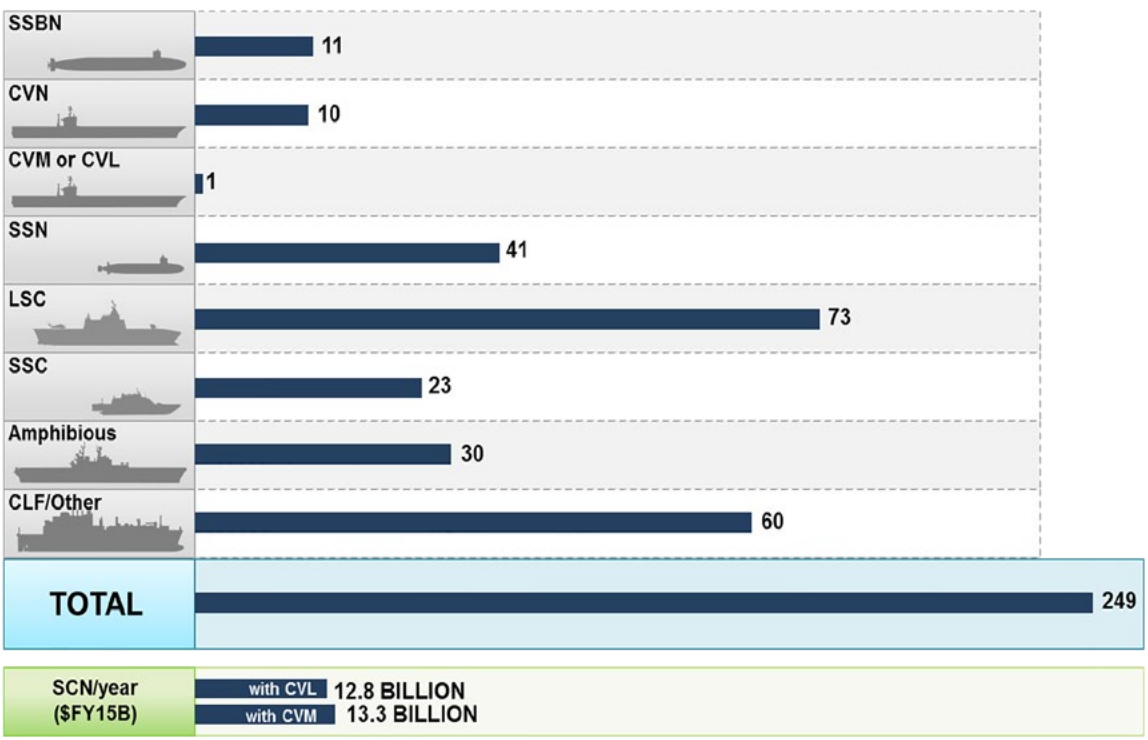


Figure 14. Reduced Funding Alternative Fleet Baseline with Adjustments to Preserve Industrial Base, Less-Expensive Aircraft Carriers, and Additional SSNs (FY 2030)

Figure 15. Reduced Funding Alternative Fleet Baseline with Adjustments to Preserve Industrial Base, Less-Expensive Aircraft Carriers, and Additional SSNs and DDGs (FY 2013)

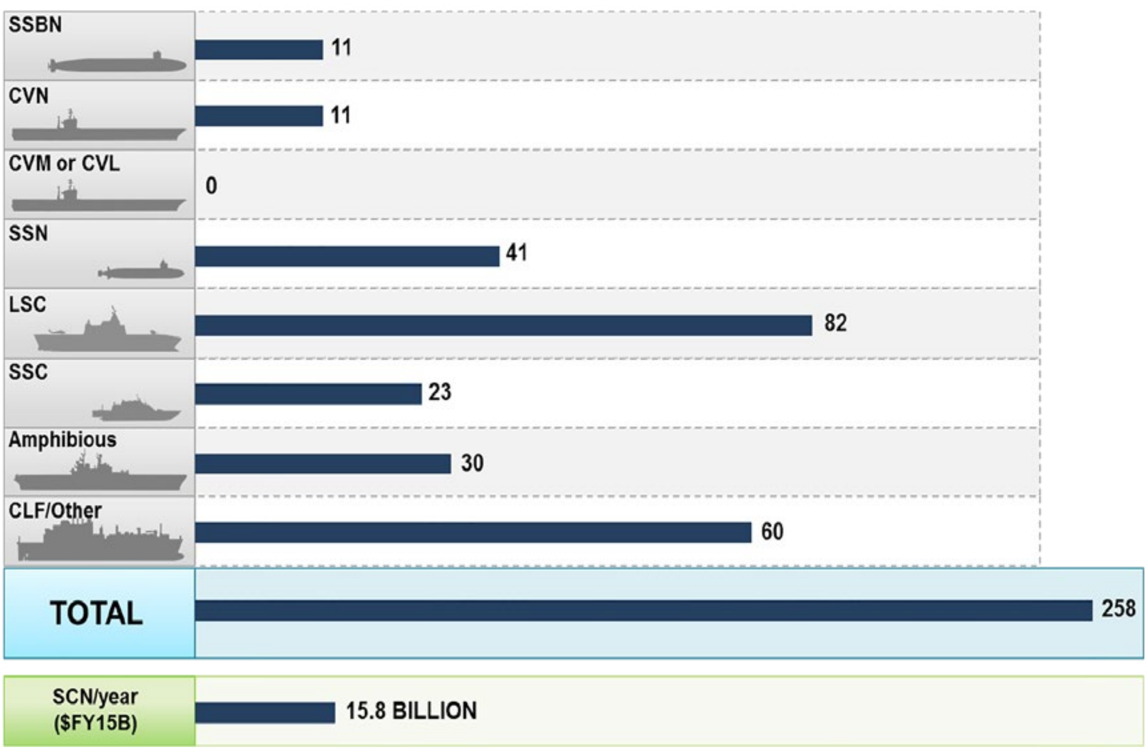


Figure 16. $15.8 Billion Per Year SCN Fleet

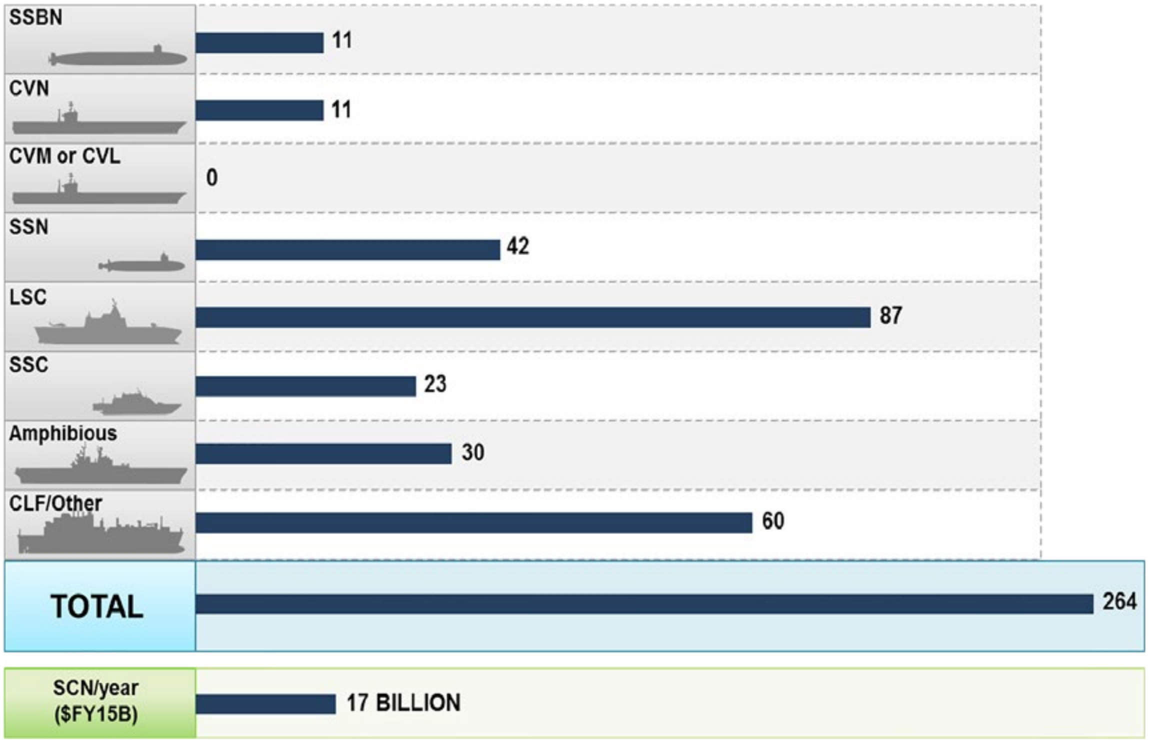


Figure 17. $17 Billion Per Year SCN Fleet

$15.8 to $17 billion FY 2015 average per year would provide presence slightly below that shown for today's fleet in Figure 1.

The smaller alternative fleets also would have reduced combat power in a conflict. The reduction in surface combatants would reduce the overall capacity to deliver strikes with weapons such as the Tomahawk cruise missile while also reducing defensive capacity provided by weapons such as the Standard Missile and ASW search and attack systems. A reduction from the planned baseline of eighty-eight large surface combatants would reduce the pool of ships that comprise the surface combatant element of an aircraft carrier strike or expeditionary strike group (CSG or ESG) as well as independent surface action groups. These reductions are significant because we maintain the number of aircraft carriers at eleven as mandated by Congress. In addition, a reduction in the numbers of CLF ships would reduce the ability of the fleet to provide prompt logistics support to CSGs, ESGs, and surface action groups.

Elimination of the LX-R amphibious lift ship program would reduce aggregate lift capability below planned levels. The Navy has stated that a force level of thirty-three amphibious lift ships represents "the limit of acceptable risk in meeting the thirty-eight-ship amphibious force lift requirements for the assault echelon in a two Marine Expeditionary Brigade forcible entry operation."[27] Reduction to thirty ships by end-FY 2030 (eleven LHAs/LHDs, twelve LPDs, and seven LSDs), as reflected in the lower-cost alternatives included here, would reduce the landing craft and aviation ship-to-shore lift available, lengthening the time needed to land Marines and their equipment in a conflict increasing risks further.

As noted, we focused on FY 2030 in characterizing our alternative fleets. Any reduction in shipbuilding during the FY 2016–2030 period has its greatest

[27] Office of the Chief of Naval Operations, Deputy Chief of Naval Operations (Integration of Capabilities and Resources) (N8), "Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for FY2015," June 2014, 24.

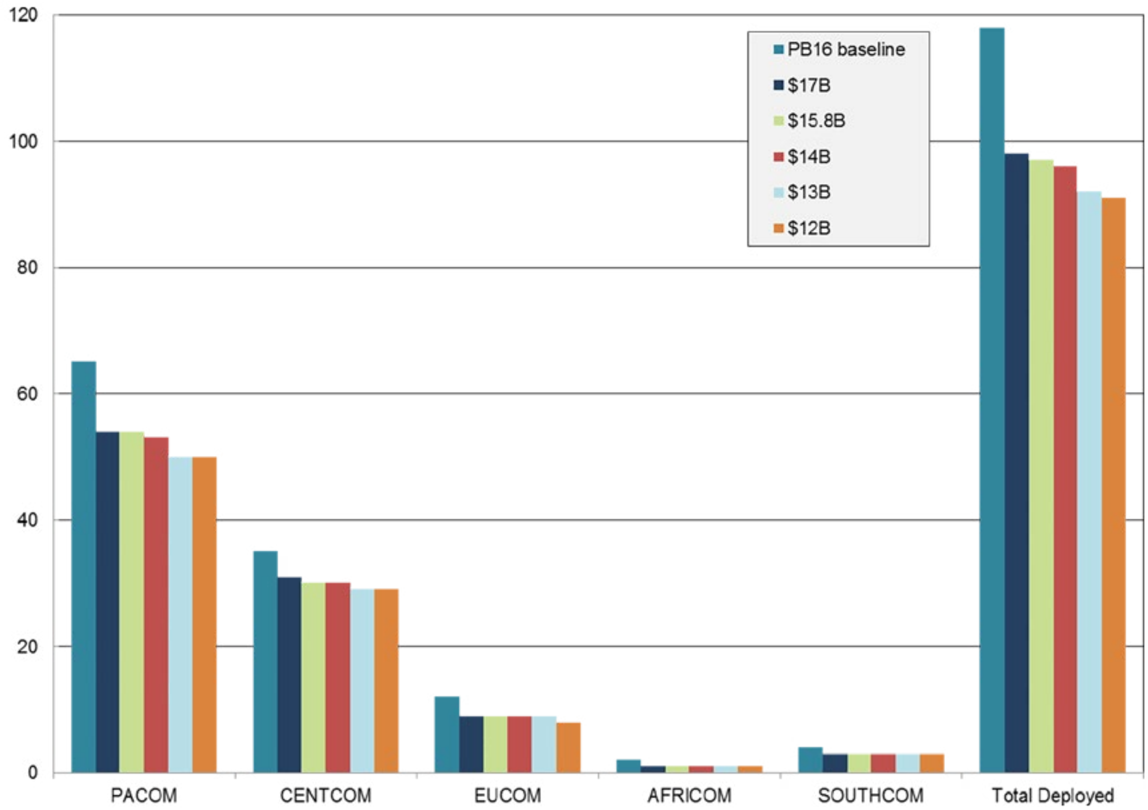


Figure 18. Projected Presence Provided by Alternative Fleets

impact after FY 2030. For example, options that terminate CVN-81/82 during the 2020s with no replacement eliminate ships that replace others (CVN-70 and 71) slated to retire during the 2030s. Reduction to one "hub"—one overseas carrier strike group station—would follow once carrier inventory fell to nine ships and below. The current ten-CVN force sustains two "hubs" but has gaps under current deployment policies.

In addition, the typical five-year construction period for large surface combatants places the impact of FY 2026–2030 procurement reductions beyond FY 2030. Alternative force management concepts could offset smaller fleet size. Figure 19 shows estimates of the implied long-term steady-state force levels for each of our alternatives.

In practice, fleet force size might not fall to the low levels shown in Figure 19. Past procurement rates for some categories of ships would keep their quantities at high levels until the 2050s. Further, once the ORP procurements are complete, funds would be available to buy larger numbers of less-expensive ships, increasing fleet size somewhat in the 2040s. Nevertheless, the impact of lower procurement rates during FY 2016–2030 would have a prolonged effect due to the projected service lives of ships and the increasing strategic significance of a smaller fleet as overall numbers decline.

Added overseas home-porting and increased use of multicrewing concepts can increase sustained forward presence. However, changes in deployment concepts could increase the amount of operations and support funding needed to maintain the readiness of each ship. The increased proportion of personnel stationed or deployed overseas could also add stress to personnel force management.

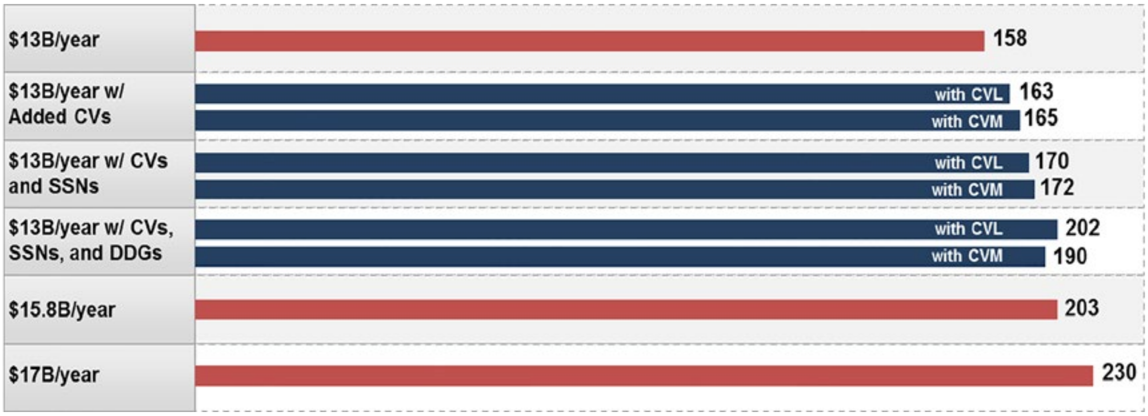


Figure 19. Implied Long-Term Steady-State Force

Dealing with the Challenge of a Smaller Fleet

One obvious solution to these difficulties would be to seek increased shipbuilding appropriations, either by an increase to the Navy's top line funding or by shifting funds within other accounts. However, such allocations on a sustained basis (over a decade or more) will be difficult in the current budget environment.

Changing the Ships We Buy

Alternatively, the Navy could build lower-cost ships to retain forward presence. This approach could include smaller, less-capable versions of expensive ships, for example, the use of CVMs and CVLs in place of CVNs at average SCN budgets below $15–16 billion per year. In many of our lower SCN fleet options, we reduce the number of procured large multimission surface combatants to ensure adequate funds for maintaining submarine and carrier capability. Therefore, to maintain the size of the surface force, the Navy could build more focused-mission combatants, such as undersea warfare-focused and air and missile defense-focused ships, which would reduce the weapon systems component of total ship costs. However, this could require changes to tactics and presence planning for some areas of responsibility without significantly increasing numbers of ships.

Alternatively, the Navy could accept the reality of a smaller fleet and increase the capability of its existing ships by upgrading their combat systems. The surface Navy's "distributed lethality" efforts are an example. In addition, the smaller number of ships could increase capability by a broader use of networks, such as Navy Integrated Fire Control – Counter Air. In addition, the Navy could build on successful Strategic Capabilities Office initiatives to repurpose existing weapons for new roles. The Navy could also augment capability with unmanned systems, such as the Defense Advanced Research Projects Agency's ASW Continuous Trail Unmanned Vessel, that extend the "reach" of existing platforms at a lower cost than buying additional ships. However, any initiatives that propose increasing the capability of existing ships by increasing investment in combat systems and sensors may be challenged by further use of sequestration to meet the funding limits specified in the BCA.

In addition to increasing the capability of existing ships, the Navy could build fewer, more-capable, but more-expensive ships with available funding to address growing threat capability.

Changing the Way We Operate

We have already discussed approaches to maintain forward presence with fewer numbers of ships by increased use of crew rotation and overseas home porting. Alternatively, the Navy could decide to reduce and refocus forward presence consistent with current force management practices for a smaller number of ships. Developing a modified strategy to engage potential threats, such as offshore balancing and/or deemphasizing maritime security operations, could accompany such efforts.

An issue for future fleet design is to determine which potential design architectures are able to meet the greatest range of potential future mission demands. As noted, the requirements in the FSA assume a specified concept of operations (CONOPs) for engaging threats in projected scenarios. For cases in which the projected budgets will not be adequate to fund shipbuilding at the FSA level, the Navy may need to consider alternative CONOPs. These CONOPs could, in turn, drive the Navy toward an acquisition plan that leads to a different fleet than that articulated in the current thirty-year plan.

An issue for future fleet design is to determine which potential design architectures are able to meet the greatest range of potential future mission demands.

Given the recent strategic guidance, the Navy has begun shifting the weight of its forward-deployed forces toward the Pacific. Today's plans call for roughly 60 percent of deployed ships (sixty out of one hundred) to operate in the Pacific. However, the need for ships to support ongoing operations in other theaters, for example, CENTCOM, or to address a resurgent Russian Navy continues and stresses the Navy's ability to maintain the 60 percent goal. With fewer ships or the wrong kinds of ships, the Navy will have less flexibility to address changing demands.

At the conclusion of the 2010 Quadrennial Defense Review, CNA released a report[28] describing five alternative futures for a global Navy. These alternatives emphasized various combinations of forward presence and credible combat capability. These options ranged from providing combat capability centered on carrier strike groups forward deployed at two hubs in the CENTCOM and US Pacific Command areas of responsibility with no/limited forces dedicated to "shaping operations" in other theaters to providing shaping capability only in multiple theaters with no/limited forces dedicated to providing significant strike capability. A default option—the shrinking status quo—would maintain current deployment patterns with a smaller number of ships and aircraft.

Increasing the number of ships that are forward based can increase the yield of forward posture one obtains from a fleet of a given size. Successful forward basing depends on securing appropriate cooperation from the host country and providing necessary levels of maintenance and logistics support to sustain combat readiness. Designing ships that can accommodate multicrewing concepts offers another way to improve this yield.

An issue for future fleet design is whether increasing the Navy's current forward basing is possible in light of future diplomatic developments and congressional preference to maintain current ship maintenance job positions in the United States. In addition, we need to consider how the design of the future fleet will increase our ability to employ multi-crewing concepts on a greater number of ships.

Alternative Design Concepts for Surface Combatants

As noted, surface ships—both combatants and amphibious lift ships—absorb the bulk of the cuts in our alternative fleets. Which alternatives exist to lessen the effect of these reductions? When thinking

[28] Daniel Whiteneck, Michael Price, Neil Jenkins, and Peter Swartz, "The Navy at a Tipping Point: Maritime Dominance at Stake?" Center for Naval Analyses Annotated Briefing CAB D0022262.A3, March 2010, https://www.cna.org/CNA_files/PDF/D0022262.A3.pdf.

about alternative ways to deliver capabilities, we need to consider upgrades to weapons and combat systems on existing ships and alternative CONOPs for employing them as much as the characteristics of new ships we may want to procure.

If average SCN funding falls below $15.8 billion FY 2015 for an extended period and the Navy focuses its available procurement funding on ORP, carriers, and SSN modernization, planners will need to focus on getting more out of the surface ships it does build. The Director of Surface Warfare recently chartered a capability-based assessment to guide preparation of an initial capabilities document (ICD) for future surface combatants. This ICD will, in turn, guide AoAs to determine appropriate designs for new ships. The aforementioned *Proceedings* article[29] on future fleet architectures highlighted some options for the future surface force. In addition, we identify several alternatives to consider in shaping this force, ranging from extending the life and utility of existing hulls to new concepts for ship design.

Upgrades to Weapons and Combat Systems on Existing Ships

All components of today's fleet are moving toward greater commonality and "open architectures" to ease the path of future upgrades. For example, Aegis Baseline 9 builds on commercial off-the-shelf hardware and open-architecture software—an approach similar to that used by the *Virginia*-class submarine program. This commonality will ensure that future software upgrades for major systems can be deployed more easily and affordably.

Another issue is the use of unmanned or autonomous systems to extend the "reach" of existing platforms, thereby increasing capability without procuring additional platforms. We have noted Defense Advanced Research Projects Agency's ASW Continuous Trail Unmanned Vessel program that is developing and testing a medium displacement unmanned surface vessel to assist in ASW, with the potential for larger unmanned surface vessels as follow-on designs. Similarly, deploying unmanned undersea vehicles from submarines could increase the range of effectiveness for undersea sensors and/or weapons. Also, launching unmanned strike aircraft from aircraft carriers could extend the range of strike operations in anti-access/anti-denial environments without putting pilots at risk. Alternatively, unmanned tankers can be used to offset the demand on F/A-18E/Fs to provide organic tanking capability to carrier air wings. The FY 2017 budget proposal to restructure the Navy's Unmanned Carrier Launched Airborne Surveillance and Strike program in the near term to a Carrier-Based Aerial Refueling System seeks to deliver that capability to the fleet by the mid-2020s.

All components of today's fleet are moving toward greater commonality and "open architectures" to ease the path of future upgrades.

A third issue concerns our ability to develop further efficiencies by improving networking among existing platforms. Cooperative Engagement Capability and Navy Integrated Fire Control – Counter Air increased the utility of a single sensor by linking it with other sensors, allowing the ability to fire or engage on remote. Are there additional sensors and weapons we can network to increase the efficiencies of engagement further? Recent discussions on "kill webs" address the potential for this approach.[30]

Developing Characteristics for New Surface Combatants

There are a variety of approaches for designing new surface combatants as part of a fleet architecture.

[29] Barber, "Rethinking the Future Fleet."

[30] Sam LaGrone and Megan Eckstein, "Navy Set to Deploy New Lethal Anti-Surface 'Tactical Cloud' Later This Year," *USNI News*, May 17, 2016, https://news.usni.org/2016/05/17/navy-set-to-deploy-new-lethal-anti-surface-tactical-cloud-later-this-year.

Many of these are highlighted in the aforementioned *Proceedings* article.[31] We review some of these in the following paragraphs and discuss issues that might impact SCN costs. However, we have not conducted any detailed design or cost analysis as part of this research effort.

Can we derive savings by using common hulls across different classes of ships? The search for commonality extends beyond weapons systems to hulls. By using a common hull design, ships in the fleet will benefit from learning in the construction process, which in turn will lower the costs to build ships over time. Because for large, complex combatants like the DDG-51 class, the hull, mechanical, and electrical component make up of about half the procurement cost of the ship, savings in the cost of building the noncombat-system components of the ship can have a significant impact on total ship costs.

In developing the *Ticonderoga* guided missile cruisers, the Navy used the *Spruance* destroyer hull as a baseline. Because the destroyer hull was not designed to accommodate the large Aegis radar, the cruisers suffered some stability issues, however. One of the options considered by the Surface Combatant for the "Twenty-First Century Cost and Operational Effectiveness Analysis (SC-21 COEA)"[32] included a common-hull approach for future destroyers and cruisers that reversed the design process used for the *Ticonderoga* and *Spruance*. The SC-21 COEA option began with a guided missile cruiser hull—the CG-21—designed to accommodate phased array radars with sufficient power to acquire and track projected threat cruise and ballistic missiles and used this hull as the basis for a new destroyer—the DD-21.

The DD-21 hull was large and expensive compared to the hulls of other destroyers. Eventually, a smaller hull design became the basis for the DD(X). The DD(X) was designed to be part of a new surface combatant family of ships, which included the CG(X) and LCS, and shared a common hull design. All three ships struggled with issues of affordability during the development process. The DD(X), renamed the DDG-1000, was truncated to a buy of three ships, and the CG(X) was canceled due to projected high procurement cost. After significant growth in its projected unit costs, the LCS program stabilized around two designs, which are both currently in production.

An issue for future fleet design is whether and to what extent the Navy can develop a common-hull concept that will yield significant savings, compared to concepts using a family of unique hull designs.

There are other opportunities to capitalize on a common hull. The alternative small carrier design we assess—the CVL—could use the same hull and design as large-deck amphibious ships in the event the Navy chooses to pursue a small carrier to reduce overall shipbuilding costs.

An issue for future fleet design is whether and to what extent the Navy can develop a common-hull concept that will yield significant savings, compared to concepts using a family of unique hull designs.

Are there savings opportunities in modular hulls? The LCS was designed on the concept of modularity. Each LCS consists of a basic hull, or sea frame, and one of three modular combat systems focused on ASW, mine countermeasure (MCM), and surface warfare (SuW), respectively. In addition, each LCS is equipped with hangar space for two SH-60 or MH-60 helicopters. Conceptually, mission modules could be "swapped out" in a few days at a port with the requisite equipment. However, the ability to do this will depend on the Navy's ability to procure more than one module per LCS and to be able to swap

[31] Barber, "Rethinking the Future Fleet."

[32] SC-21 COEA Study Team, "(U) SC-21 COEA Part II: Analysis of Alternatives Final Report," Center for Naval Analyses Report (CNR) 220, March 1998, Secret.

out crews trained in the operation of each module. (Each LCS will have two crews: one to operate the sea frame and a smaller detachment to operate the modular combat system. Current consideration of shifting the mix of sea frame and combat systems to fixed mission packages aligned more closely with a new frigate design may change this.[33]) As previously mentioned, the Navy announced revisions to the LCS operating concept in September 2016. While the ships will retain the capability to swap mission modules, normal operations will be based on individual ships retaining the same type of module on a long-term basis. Crew rotations also would be reduced with the ships—the "sea frames"—each having two crews, rather than rotating three crews among two ships. Apparently the Navy judged that volatility in personnel and equipment assignments was causing unacceptable degradation in operational availability and stated that further "iterative adjustments and improvements" would be made as appropriate.[34]

An issue for future fleet design is how the procurement and operating costs of a modular ship with interchangeable combat systems compare to the costs of a similar number of common hull ships with dedicated combat systems.

Are there potential savings in combining common hull and modular hull concepts? Former CNO Admiral Jonathan Greenert emphasized the need to consider modernizing the systems that ships host separately from their hulls. This makes sense because while hulls are designed to last thirty or more years, shipboard systems need to be upgraded more frequently. This is especially true for systems that rely on software and computational equipment to operate,[35] and we have noted that Aegis Baseline 9 builds on commercial off-the-shelf hardware and open-architecture software to ease the upgrade process. These developments have led some naval leaders to advocate for a fleet built around a set of common hulls or family of hulls designed to accommodate modular combat and propulsion systems built around the concept of open architectures. In theory, this approach would increase commonality across the fleet and facilitate upgrades and modernization of shipboard systems. This approach is similar to that developed for the MEKO family of warships. This family was developed by the German company Blohm & Voss, beginning in the late 1970s. MEKO is a registered trademark and stands for Mehrzweck-Kombination. It is a concept in modern naval shipbuilding based on modularity of armament, electronics, and other equipment, with the aim for ease of maintenance and cost reduction. MEKO ships include families of frigates, corvettes, and ocean-going patrol boats.[36] An issue for future fleet design is how the costs to acquire and operate a fleet based on a common hull-modular hybrid approach compare to those of a common hull, modular, and family of unique hull design approaches.

Can we increase the use of lower-cost, tailored-capability ships? An LCS with a mission module offers a tailored capability in ASW, MCM, or SuW. There are also nonmodular ships with tailored capability, such as MCM ships and patrol craft. Some consider larger ships such as the *Perry*-class frigates (all now retired) to offer tailored capability in that they provide only a subset of the capability offered by a multimission ship such as a DDG or CG.

[33] Doubleday, "Navy Set to Brief Congress on Changes to LCS Program."

[34] Department of the Navy, "Navy Adjusts LCS Class Crewing, Readiness, and Employment."

[35] Current interest in the Navy in the flexible warship concept reflects this concern. The goal is to introduce naval architectural features in future ship designs to greatly ease the process of making frequent, affordable capability improvements in installed combat systems. Modular designs typically have this feature, but the flexible warship idea is broader, encompassing not only possible swap-out of modules but also much simpler removal and replacement of fixed weapons, sensors, and supporting systems.

[36] "MEKO," *Wikipedia*, last modified May 23, 2016, http://en.wikipedia.org/wiki/MEKO.

Tailored-capability ships would feature in a future fleet with a bimodal or high-low mix design. An issue for future fleet design will be selecting the right mix of tailored-capability hulls to meet evolving fleet missions over the next thirty-plus years. Because tailored-capability ships are generally less expensive to procure and operate, they can be purchased in greater numbers for a fixed level of funding. In addition, because they have smaller crews than larger, multimission ships, they are more easily adapted to multicrewing employment, thereby yielding the possibility of increased forward presence for a given number of ships.

For example, if the cost of a multimission LSC, like the DDG, were split equally between combat systems and hull, mechanical, and electrical systems, it might be possible to procure two undersea warfare-focused and two air and missile defense-focused LSCs for the cost of three multimission LSCs, providing more ships for a set amount of funds. However, one would need to deploy one undersea warfare-focused ship with each air and missile defense-focused ship to achieve the same capability as one multimission LSC; therefore, six focused-mission ships would need to cost less than three multi-mission ships for the substitution to demonstrate an economic advantage. This level of cost reduction will be difficult to achieve.

Captain Wayne Hughes Jr., US Navy (Ret.), advocates an extreme example of a tailored-capability ship—an inexpensive single-purpose ship—in books and articles on coastal combat and fleet tactics.[37] He argues that single hits by modern antiship missiles are likely to incapacitate individual large as well as small surface combatants, and that accordingly it makes sense to build multiple numbers of smaller ships for the same cost. With such a larger number of ships, the overall force might be able to endure such attacks with a large enough number of surviving units to attain operational objectives. He observes that a hit on a single-purpose ship removes only one unit of capability, compared to the multiple capabilities lost when a multipurpose ship is removed. The principal challenge to this argument lies in the ability of naval architects to develop a small, capable combatant at a fraction of the cost of an LCS or a frigate.

Are there different ways to employ multimission ships to offset their greater unit cost? Multimission ships are capable but expensive, compared to tailored-capability ships, and fewer numbers can be procured and operated for the same level of funding. An issue for future fleet design concerns how to assign smaller numbers of multimission surface combatants to the range of missions anticipated for a campaign against a peer competitor. One option might be to assign attack submarines to fight the ASW campaign, allowing multimission surface combatants to focus on air and missile defense and strike missions while employing their ASW capability for self-defense only.

Today's fleet is an example of a "bimodal" or "high-low mix" fleet built around multimission and tailored-capability warships including large surface combatants (LSC), similar to DDGs and CGs, and small (SSC) surface combatants, similar to LCS. The Navy's current fleet architecture is designed to address the mix of high- and low-end missions envisioned in current planning. The Navy's Small Surface Combatant Task Force explored more survivable alternatives to the LCSs, such as a new frigate design using the LCS hull form.

The Navy's force of amphibious lift ships also represents a bimodal mix of ships with larger ships, such as LHAs and LHDs, capable of carrying more balanced proportions of a Marine Air-Ground Task Force (MAGTF) than other L-class ships, such as LSDs and LPDs. It is likely that the need for a bimodal amphibious force will remain to support future

[37] See for example, Wayne P. Hughes, Jr., *Fleet Tactics and Coastal Combat*, 2nd Edition (Annapolis, MD: Naval Institute Press, 2000), and Wayne P. Hughes, Jr., "Single-Purpose Ships for the Littorals," *Proceedings* 140, no. 6 (2014), http://www.usni.org/magazines/proceedings/2014-06/single-purpose-warships-littorals.

MAGTFs that demonstrate changing lift needs as the equipment and supplies need to support MAGTF operations changes.

An issue for future fleet design is how to determine the most affordable mix of tailored and multimission ships to address evolving threats in future fiscal environments.

A variation on the bimodal fleet is the concept of a "disaggregate hull." In the 1990s, the Navy and Defense Advanced Research Projects Agency explored the concept of an "arsenal ship." The arsenal ship design was based on a large, relatively inexpensive commercial hull operated by a small crew of approximately twenty personnel and capable of carrying over five hundred Tomahawk land attack cruise missiles. The arsenal ship did not demonstrate any organic capability to launch the missiles and depended on linking to a CG or DDG to accomplish its mission. The arsenal ship concept offered the potential for a multimission surface combatant to increase the size of its vertical-launch system magazine by a factor of five or more at a relatively modest cost.

The Maritime Prepositioning Force concept provides an analogous example for amphibious lift. This concept maintains supplies and equipment for MAGTFs in modified commercial lift ships, which can "marry up" with Marines who fly to an area of potential hostilities on military or commercial airlift. (In contrast, current Navy-crewed amphibious lift ships are designed to enable embarked marines to land with their organic equipment and be ready for combat ashore much more quickly.) The Maritime Prepositioning Force is organized, currently, into two squadrons.

An issue for future fleet design is whether the disaggregated hull concept demonstrates utility against future threats. For example, an arsenal ship carrying Standard Missile interceptors could increase the fleet's ability to engage large numbers of antiship missiles, provided there was sufficient radar capacity available to manage the engagement.

Conclusions/Implications for the Future Fleet

For a period of fifteen years (2020 to 2035), the ORP will consume about one-third of the historical thirty-year average of annual funds set aside for SCN expenses. Barring a significant (30-plus percent) increase in average annual SCN funds, the Navy will be unable to build all the ships needed to meet the requirements in its recent force structure assessments.

In this paper, we have explored some alternative approaches to shape the Navy's future fleet given the growing pressures on funding and the need to recapitalize critical and expensive capabilities such as the nation's sea-based strategic deterrent. We developed alternative fleets for funding levels both below and above the average annual SCN budgets for the past thirty years and compared these to the Navy's current thirty-year shipbuilding plan. At lower levels of funding, our alternative fleets provide fewer and, in some cases, less-capable ships than the Navy's thirty-year plan.

Barring a significant (30-plus percent) increase in average annual SCN funds, the Navy will be unable to build all the ships needed to meet the requirements in its recent force structure assessments.

Overall, military capabilities would be reduced, though we did not attempt to quantify the relative extent of the reduction in actual capabilities available to COCOMs, which would depend on the basing and crewing options employed by the fleet. We also examined the impact of smaller fleets on the Navy's ability to maintain presence in various theaters and suggested ways to mitigate the effect of these reductions.

Congress and future administrations could, of course, decide to fund Navy SCN at levels well above historical averages for the next fifteen to thirty years.

Now is the time to make the case for increased shipbuilding funds by making clear what the future fleet might look like without such an increase. Simultaneously, we should develop plans for a fleet we can afford in the event only historical levels of funding are available, whether the result will be a smaller fleet of equally capable ships or a similarly sized fleet built around ships with less capability.

Appendix A Ship Procurement Plans and Costs

This appendix provides details on the planning and cost data we used in our analysis. These data include the Navy's shipbuilding plans, the CBO assessments of the likely costs of these plans and how these investments compare to the Navy's historical expenditures for shipbuilding, sources for our own cost estimates for future ship procurements, and our estimates of the annual procurement costs associated with the next fifteen years of the Navy's plan.

Table A-1 shows the projected evolution of the fleet based on information in the Navy's current thirty-year shipbuilding plan, which it provides to Congress.[38] This plan uses numbers in the Navy's 2014 FSA as a goal.

Table A-2 shows planned ship construction to support this battle force inventory.

Table A-3 presents the detailed CBO cost data used to prepare Figure 3 in the main text.

Table A-4 provides information on the unit cost data we used to develop shipbuilding estimates for our alternative fleets. Table A-5 uses these data to develop cost estimates for the Navy's baseline shipbuilding plan.

Table A-6 provides ship and aircraft descriptions for the Navy's baseline shipbuilding plan.

[38] Office of the Chief of Naval Operations, Deputy Chief of Naval Operations (Integration of Capabilities and Resources) (N8), "Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for Fiscal Year 2016," March 2015.

Table A-1. Baseline Naval Battle Force Inventory in Navy's Thirty-Year Plan

FY	CVN	LSC	SSC	SSN	SSGN	SSBN	AWS	CLF	Supt	Total
2016	11	87	22	53	4	14	31	29	31	**282**
2017	11	90	26	50	4	14	32	29	28	**284**
2018	11	91	30	52	4	14	33	29	30	**294**
2019	11	94	33	50	4	14	33	29	32	**300**
2020	11	95	33	51	4	14	33	29	34	**304**
2021	11	96	34	51	4	14	33	29	34	**306**
2022	11	97	37	48	4	14	34	29	34	**309**
2023	12	98	36	49	4	14	34	29	34	**310**
2024	12	98	40	48	4	14	35	29	35	**315**
2025	11	98	43	47	4	14	35	29	36	**317**
2026	11	97	46	45	2	14	37	29	36	**317**
2027	11	99	49	44	1	13	37	29	36	**319**
2028	11	100	52	42		13	38	29	36	**321**
2029	11	98	52	41		12	37	29	36	**316**
2030	11	95	52	42		11	36	29	36	**312**
2031	11	91	52	43		11	36	29	35	**308**
2032	11	89	52	43		10	36	29	36	**306**
2033	11	88	52	44		10	37	29	36	**307**
2034	11	86	52	45		10	37	29	36	**306**
2035	11	88	52	46		10	36	29	37	**309**
2036	11	86	53	47		10	35	29	37	**308**
2037	11	85	53	48		10	35	29	36	**307**
2038	11	84	54	47		10	34	29	35	**304**
2039	11	85	56	47		10	34	29	32	**304**
2040	10	85	56	47		10	33	29	32	**302**
2041	10	85	54	47		11	34	29	32	**302**
2042	10	83	54	49		12	33	29	32	**302**
2043	10	83	54	49		12	32	29	32	**301**
2044	10	82	54	50		12	32	29	32	**301**
2045	10	82	57	50		12	33	29	32	**305**

Supt – support ships.

Table A-2. Long-Range Battle Force Construction Plan Associated with Thirty-Year Plan

FY	CVN	LSC	SSC	SSN	SSBN	AWS	CLF/Supt	Total
2016		2	3	2		1	1	**9**
2017		2	3	2		1	2	**10**
2018	1	2	3	2			2	**10**
2019		2	2	2			3	**9**
2020		2	3	2		1	2	**10**
2021		2	3	1	1		2	**9**
2022		2	3	2		1	3	**11**
2023	1	2	3	2		1	4	**13**
2024		2	3	1	1	2	3	**12**
2025		2	3	2		1	2	**10**
2026		2		1	1	1	1	**6**
2027		2		1	1	1	1	**6**
2028	1	2		1	1	2	2	**9**
2029		2		1	1	1	2	**7**
2030		2	1	1	1	1	3	**9**
2031		2		1	1	1	3	**8**
2032		2	1	1	1	1	3	**9**
2033	1	2	1	1	1		3	**9**
2034		2	1	1	1		1	**6**
2035		2	2	1	1			**6**
2036		2	2	2		1		**7**
2037		2	2	2				**6**
2038	1	3	3	2				**9**
2039		3	4	2				**9**
2040		3	4	1		2		**10**
2041		2	4	2				**8**
2042		3	4	1		1		**9**
2043	1	2	4	2			1	**10**
2044		3	2	1		2		**8**
2045		2	3	2		1	2	**10**

Table A-3. Historical and Projected Costs for Navy Shipbuilding

	Historical				CBO Estimates Under the Navy's 2016 Plan			
	1986–1995	1996–2005	2006–2015	1986–2015	2016–2025	2026–2035	2036–2045	2016–2045
	Average Annual Costs (Billions of 2015 Dollars)							
New ship construction								
Aircraft carriers	2.4	1.1	2.0	1.8	2.3	2.4	2.7	2.4
Submarines	5.2	3.0	4.4	4.2	7.7	9.2	5.4	7.5
Surface combatants	7.1	4.8	4.2	5.4	5.4	5.0	7.1	5.8
Amphibious ships	1.3	1.7	1.6	1.6	1.7	1.9	2.3	2.0
Logistics and support ships	1.5	0.5	0.7	0.9	1.1	0.7	0.3	0.7
Subtotal	**17.6**	**11.1**	**12.9**	**13.9**	**18.2**	**19.2**	**19.0**	**18.4**
Carrier and submarine refueling	0.4	1.0	1.3	0.9	1.4	1.0	0.7	1.0
Other items	1.1	1.2	0.7	1.0	1.2	0.6	0.6	0.8
Total	**19.1**	**13.2**	**15.0**	**15.8**	**20.7**	**20.8**	**19.0**	**20.2**

Table A-4. Ship Unit Cost Data

Ship Type	Ship Class	Unit Cost ($FY15 Million)	Source	Reference	Notes
Amphibious	LHA-R	3,535	PB16	B	Crosscheck with Navy's estimate in CBO Report ($3.7B)
Amphibious	LPD-17	N/A	PB16	B	No unit cost, tocompletion only
Amphibious	LX-R	1,450	2016 Navy's Ship Plan/ Navy LX-R CRS Report September 2015	F, G	Crosscheck with Navy's estimate in CBO Report ($1.4B)
Amphibious	New Ship-Shore Connector	49	PB16	B	
Amphibious	Service Craft	8	PB16	B	
Amphibious	SC-X (LCU replacement)	5	Analogous LCU - 1625 unit cost	K	
CVN	CVN-78	13,661	PB16/CVN-78 AC Program CRS Report, March 2015	B, D	
CVL	CVL	2,535	Analogous LHA-R/CVN	L, M, N	
CVM	CVM	6,084	Analogous LHA-R/CVN	L, M, N	
DDG	DDG-1000	N/A	PB16	B	No unit cost, to completion only
DDG	DDG-51	1,560	PB16	B	Crosscheck with Navy's estimate in CBO Report ($1.4B Flight 2, $1.6B Flight 3)
DDG	New LSC	1,825	Navy's estimate in CBO Report ($1.8B)	A	
LCS	LCS Flight 0	479	PB16	B	Crosscheck with Navy's estimate in CBO Report ($464M)
LCS	LCS Flight 1/LCS (X)	524	PB16	B	
LCS	LCS Mission Package - MCM	101	2015 CRS Report	E	
LCS	LCS Mission Package - SuW	30	2015 CRS Report	E	
LCS	LCS Mission Package - ASW	30	PB16 OPN	B	
Modernization	CG modernization - Combat System	43	PB16/2010 CRS Report	B, C	
Modernization	CG modernization - HM&E	180	PB16/2010 CRS Report	B, C	
Modernization	CVN Refueling Overhaul	5,091	PB16	B	
Modernization	DDG modernization - Combat System	170	PB16/2010 CRS Report	B, C	PB16 - $150M, CRS - $188M (both with $50M install each)
Modernization	DDG modernization - HM&E	89	PB16/2010 CRS Report	B, C	PB16 - $85M, CRS - $92M (both with $25M install each)
Modernization	LCAC SLEP	19	PB16	B	
Others	AFSB	N/A	PB16	B	No unit cost, to completion only

Table A-4. Ship Unit Cost Data (Continued)

Ship Type	Ship Class	Unit Cost ($FY15 Million)	Source	Reference	Notes
Others	AS (submarine tenders)	1,777	Analogous LPD-17 average unit cost, December 2014 SAR	I	
Others	JHSV	193	PB16/AUC of Army and Navy's SAR report, December 2012	B, J	
Others	T-AGOS	145	The Naval Institute Guide to the Ships and Aircraft of the US Fleet	H	
Others	T-AOX	547	PB16	B	Crosscheck with Navy's estimate in CBO report ($.5B)
Others	T-ATF-X	68	2016 Navy Ship Plan	G	
SSBNs	ORP	5,641	2016 Navy Ship Plan	G	Crosscheck with Navy's estimate in CBO report ($6.6B average cost)
SSNs	SSN-774	2,938	PB16	B	Crosscheck with Navy's estimate in CBO report ($2.8B)

AFSB – afloat forward staging base; AUC – annual unit cost; CRS – congressional research service; HM&E – hull, mechanical & electrical; JHSV – joint high speed vessel; LCAC – landing craft air cushion; LCU – landing craft, utility; MCM – mine countermeasures; OPN – other procurement, Navy; PB – president's budget; SAR – selected acquisition report; SLEP – service life extension program; SuW – surface warfare

A – Congressional Budget Office, "An Analysis of the Navy's Fiscal Year 2015 Shipbuilding Plan," December 2014.

B – Department of the Navy, "Department of the Navy Fiscal Year (FY) 2016 Budget Estimates: Justification of Estimates," February 2015.

C – Ronald O'Rourke, "Navy Aegis Cruiser and Destroyer Modernization: Background and Issues for Congress," Congressional Research Service Report RS22595, June 10, 2010, https://www.fas.org/sgp/crs/weapons/RS22595.pdf.

D – Ronald O'Rourke, "Navy *Ford* (CVN-78) Class Aircraft Carrier Program: Background and Issues for Congress," Congressional Research Service Report RS20643, November 5, 2015, https://news.usni.org/wp-content/uploads/2015/12/RS20643.pdf.

E – Ronald O'Rourke, "Navy Littoral Combat Ship (LCS) Program: Background and Issues for Congress," Congressional Research Service Report RL33741, December 17, 2015, https://news.usni.org/wp-content/uploads/2015/12/RL33741-1.pdf.

F – Ronald O'Rourke, "Navy's LX(R) Amphibious Ship Program: Background and Issues for Congress," Congressional Research Service Report R43543, June 12, 2015, https://news.usni.org/wp-content/uploads/2015/06/R43543_3.pdf.

G – N8, "Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessel for Fiscal Year 2016."

H – Norman Polmar, *The Naval Institute Guide to the Ships and Aircraft of the U.S. Fleet* 19th Edition (Annapolis: Naval Institute Press, March 20, 2013).

I – Analogous to LPD-17 unit cost. See Department of Defense, "Selected Acquisition Report (SAR): LPD-17 *San Antonio* Class Amphibious Transport Dock (LPD-17)," December 2014, http://www.dod.mil/pubs/foi/Reading_Room/Selected_Acquisition_Reports/15-F-0540_LPD%2017_SAR_Dec_2014.PDF.

J – Department of Defense, "Selected Acquisition Report (SAR): Joint High Speed Vessel (JHSV)," December 31, 2012, http://www.dod.mil/pubs/foi/Reading_Room/Selected_Acquisition_Reports/JHSV_December_2012_SAR.pdf.

K – Analogous to LCU-1625 unit cost. See *Marine Engineering* vol. 70 (New York, NY: Simmons Boardman Publishing Corporation, 1965).

L – Analogous to LHA-R. See N8, "Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessel for FY2015."

M – Analogous to CVN-77. See Department of the Navy, "Department of the Navy Fiscal Year (FY) 2005 Budget Estimates: Justification of Estimates," February 2004.

N – Analogous to CVN-78. See N8, "Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessel for FY2015."

Table A-5. Estimated Costs for Navy Baseline Shipbuilding Plan

FY	CVN	SSN	DDG	LCS	Amphibious	Other	SSBN	CVN Refueling	Grand Total
	Millions of FY Dollars								
2016	2,584	5,241	3,590	1,332	1,123	717	–	700	15,287
2017	2,844	4,990	3,363	1,454	1,760	882	749	1,949	17,990
2018	3,332	4,741	3,290	1,457	2,364	682	747	1,913	18,527
2019	1,921	6,192	3,279	1,178	715	669	2,564	530	17,048
20020	792	6,140	3,296	1,573	2,071	701	1,194	1,786	17,552
2021	2,736	2,938	3,120	1,573	533	531	7,345	1,102	19,878
2022	2,867	5,876	3,120	1,573	1,954	744	1,270	1,102	18,506
2023	3,282	2,938	3,120	1,573	546	2,521	564	1,102	15,646
2024	1,776	5,876	3,120	1,573	3,226	822	5,923	700	23,016
2025	2,869	2,938	3,120	1,573	1,768	2,308	4,230	1,949	20,755
2026	3,279	5,876	3,120	–	1,408	531	5,641	1,913	21,767
2027	3,552	2,938	3,120	–	–	531	5,641	530	16,311
2028	3,688	5,876	3,120	-	3,175	676	5,641	700	22,876
2029	2,049	2,938	3,120	–	3,175	718	5,641	1,949	19,589
2030	2,322	2,938	3,432	524	1,408	718	5,641	530	17,512

Table A-6. Ship and Aircraft Descriptions for Navy Baseline Shipbuilding Plan

Ship/Aircraft Type	Description
A-6	Intruder All-weather Attack Aircraft
AFSB	Afloat Forward Staging Base
CG	Guided Missile Cruiser
CLF	Combat Logistics Force Ships
CVL	Small-sized Aircraft Carrier
CVM	Medium-sized Aircraft Carrier
CVN	Nuclear Powered Aircraft Carrier
DDG	Guided Missile Destroyer
EA-6B	Prowler Electronic Warfare Aircraft
EA-18G	Growler Electronic Warfare Aircraft
E-2	Hawkeye Airborne Early Warning Aircraft
F-14	Tomcat Fighter Aircraft
F/A-18	Hornet Multirole Fighter Aircraft
FFG	Guided Missile Frigate
JHSV	Joint High Speed Vessel [Recently renamed Expeditionary Fast Transport (EFT)]
KA-6	Aerial Refueling Aircraft
LCAC	Landing Craft Air Cushion
LCS	Littoral Combat Ship
LCU	Landing Craft Utility
LHA-R	Landing Helicopter Assault Ship Replacement
LHD	Landing Helicopter Dock Ship
LSC	Large Surface Combatant
LSD	Dock Landing Ship
LPD	Amphibious Transport Dock
LX-R	Dock Landing Ship Replacement
MH-60	Seahawk Multimission Helicoptior
S-3	Seaking Anti Submarine Warfare Helicopter
SH-60	Seahawk Multimission Helicopter
SSBN	Ballistic Missile Nuclear Powered Submarine
SSC	Smal Surface Combatant
SSGN	Cruise Missile Nuclear Powered Submarine
SSN	Nuclear Powered Attack Submarine

Table A-6. Ship and Aircraft Descriptions for Navy Baseline Shipbuilding Plan (Continued)

Ship/Aircraft Type	Description
T-AGOS	Ocean Surveillance Ship
T-AOX	Fleet Replenishment Oiler
T-ATF-X	Fleet Ocean Tug Replacement
VAW	Carrier Airborne Early Warning Squadron Aircraft
VAQ	Electronic Attack Squadron Aircraft
VFA	Strike Fighter Squadron Aircraft

Appendix B Air Wings for Alternative Small Carriers

This appendix provides details on the assumptions we made concerning aircraft air wings embarked on alternative smaller future aircraft carriers. Our fundamental assumption is that aircraft air wings embarked on future ships could grow to the size, relative to ship deck area, of air wings embarked by US Navy aircraft carriers during the 1980s.[39] Today's carrier air wings are approximately 68 percent of the size, in terms of deck space occupied, of air wings embarked aboard comparable ships about thirty years ago. To some extent, the smaller size of current air wings reflects affordability limitations, both in terms of aircraft investment and judgments concerning the overall mix of air, sea, and undersea capabilities the Navy seeks to provide. Other factors also might affect future decisions, including the ability of the ship to berth large enough crews for larger air wings and the level of consumable stores (for example, fuel and munitions) desired for a given air wing composition. It should be noted, however, that the advent of Global Positioning System-aided weapons and other technical and operational advances make today's smaller air wings much more effective for many roles than those of the 1980s.

Table B-1 shows the comparative air wings embarked in a current-design CVN in the early 1980s and at present. Table B-2 and Table B-3 show the air wings foreseen for mid- and small-sized aircraft carriers in about 1980 for use as a baseline for estimating full capacity and the resultant potential future air wings for such smaller ships if modern aircraft were embarked.

Values for current and future air wings are illustrative. The Navy has stated an interest in increasing airborne early warning and electronic warfare units from four to five aircraft each, and the data assumed here are an average that represents a force in transition to a large complement. Similarly, the number of helicopters embarked in current air wings varies, and an approximate value is shown for illustrative purposes. Embarked aircraft also include carrier onboard delivery logistics aircraft, but these—typically one aircraft per ship—do not significantly increase deck loading. (The small CVL and vertical/short takeoff and landing support ship designs would employ helicopters for more limited carrier onboard delivery support.)

[39] Most historical data on aircraft carrier air wing composition is taken from Norman Friedman, *U.S. Aircraft Carriers: An Illustrated Design History* (Annapolis, MD: Naval Institute Press, April 1983). Deck spot factor data is taken from a variety of sources, including Eric S. Ryberg, "The Influence of Ship Configuration on the Design of the Joint Strike Fighter," Report #20020326 229, presented at Engineering the Total Ship Symposium 2002, Gaithersburg, MD, February 26, 2002; Robert L. Wilde, "A Comparative Analysis of a CV Helicopter and a JVX Tilt-Rotor Aircraft in an Aircraft-Carrier Based ASW Role," Thesis, Naval Postgraduate School, March 1985, http://hdl.handle.net/10945/21198; and Gary Warner, "PEO Ships Brief to NDIA," Presentation, 2004, http://proceedings.ndia.org/5860/5860_Warner.pdf.

Table B-1. Comparative Large Aircraft Carrier (CVN) Air Wings

	CVN Current (Illustrative)			CVN 1980s (Typical)		
	Type	**Quantity**	**Deck Spot Factor**	**Type**	**Quantity**	**Deck Spot Factor**
	F/A-18E/F	24	1.24	F-14A	24	1.31
	F/A-18C	20	1	A-6E	12	1.24
				A-7E	24	.85
Fighter/Attack subtotal		**44**			**60**	
	E-2C/D	4.5	1.7	E-2C	4	1.7
	EA-18G	4.5	1.24	EA-6B	4	1.24
	MH-60	16.5	.54	S-3A	10	1.26
				KA-6D	4	1.24
				SH-3	10	.94
Total deck spot loadout			**71.9**			**105.44**

Table B-2. Comparative Smaller Aircraft Carrier (~1980 Design) Air Wings

	CVV (~1978)			VSS		
	Type	**Quantity**	**Deck Spot Factor**	**Type**	**Quantity**	**Deck Spot Factor**
	F-14A	10	1.31	AV-8B	4	.82
	A-6E	12	1.24			
Fighter/Attack subtotal		**22**			**4**	
	E-2C	4	1.7	SH-53	16	1.43
	EA-6B	4	1.24	SH-60	6	.54
	S-3A	10	1.26			
	KA-6D	2	1.24			
	SH-60	8	.54			
Total deck spot loadout			**59.1**			**29.4**

Table B-3. Comparative Smaller Aircraft Carrier (CVM/CVL) Air Wings

	CVM			CVL		
	Type	**Quantity**	**Deck Spot Factor**	**Type**	**Quantity**	**Deck Spot Factor**
	F/A-18E/F	30	1.24	F-35B	20	1.1
Fighter/Attack subtotal		**30**			**20**	
	E-2C/D	4.5	1.7	MH-60	10	.54
	EA-18G	4.5	1.24			
	MH-60	12				
Total deck spot loadout			**56.3**			**27.4**

Acknowledgments

The authors thank their colleagues Christine Fox, Jeff Miers, Matt Schaffer, and Emmy Probasco for helpful reviews of this study. In addition, the authors thank a capable team of graphic artists and editors who helped prepare this report for production: Sue Pagan, Cathy Peacock, Heather Pontius, and Candece Seling.

About the Authors

Mark Lewellyn is the head of the National Security Analysis Department at the Johns Hopkins University Applied Physics Laboratory (JHU/APL). Prior to joining JHU/APL in 2011, Dr. Lewellyn worked for thirty-three years at the Center for Naval Analyses where he led or supported numerous acquisition and technology studies for the Navy and Marine Corps.

Chris Wright is an analyst in the National Security Studies Office within the National Security Analysis Department at the JHU/APL. Prior to joining JHU/APL in 2005, Mr. Wright worked for thirty-four years in the Office of the Secretary of Defense in what is now the Cost Assessment and Program Evaluation organization.

Rodney Yerger is the head of the Affordability Analysis and Assessments Section within the National Security Analysis Department at the JHU/APL. Prior to joining JHU/APL in 2010, Mr. Yerger served in the US Navy as both a surface warfare officer (uniformed service) and a supervisory program analyst (civil service).

Nhan Bui is a cost analyst in the Affordability Analysis and Assessments Section within the National Security Analysis Department at JHU/APL. His research and analysis efforts include the development of cost models for assessing cost effectiveness of mission critical systems. Prior to joining JHU/APL in 2013, Mr. Bui worked at MCR LLC supporting the Air Force and the Federal Aviation Administration through major program acquisition processes.

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY