Future
Aircraft
Aircraft
Options

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In executing its long-range shipbuilding plan, the U.S. Navy is facing financial challenges that require it to evaluate potential lower-cost options for its most-expensive platforms. We examine potential alternatives for replacing later Nimitz-class nuclear-powered aircraft carriers (CVNs) as they reach the end of their planned service lives in 2030 and beyond. Some in Congress, among others, have criticized the Gerald R. Ford-class nuclear aircraft carriers (USS Gerald R. Ford [CVN 78], USS John F. Kennedy [CVN 79], and USS Enterprise [CVN 80]), which are now in construction or early long-lead procurement, for high acquisition cost, and the Navy has been directed to consider lower-cost alternatives. The study reported here was an effort to consider those alternatives by asking what platform options should be considered, how different platforms would perform in various operational environments, and the costs of alternative platforms. This report provides an unclassified summary of a longer, restricted-distribution companion report.

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Sea-based tactical aviation is a key part of the U.S. Navy's concept of operations for power projection. An integrated carrier air wing (CVW) provides capability across the full range of military operations, from peacetime presence to highly stressing major combat operations. Although the CVW is the actual component delivering warfighting capability, the individual air wings require aviation support for launch and recovery at tactical distances, fuel and flight crew replenishment, maintenance, and other sustainment. This support is provided by the aircraft carrier and embarked crew. Upon delivery of USS *Gerald R. Ford* (CVN 78) in the summer of 2017, the Navy will have provided 11 nuclear-powered aircraft carriers (CVNs) to meet congressional requirements established in law. Ten of the 11 aircraft carriers are typically operational at any given time while the 11th undergoes mid-life nuclear refueling, overhaul, and modernization.

There is concern that continuing the *Ford*-class carrier program imposes high acquisition cost and might unduly affect the whole of the Navy shipbuilding budget. The Senate Armed Services Committee noted that alternatives could be developed for less cost and potentially with sufficient capability. This led to a request for the Navy to examine lower-cost alternatives. More specifically, the National Defense Authorization Act (NDAA) for Fiscal Year 2016 directed the Navy to do the following:

• Assess fleet sea-based tactical aviation capability requirements in probable scenarios.

- Establish alternative platforms that provide supported capabilities across a minimum of three platforms, whether nuclear or nonnuclear, whether a new or existing design, considering incorporation of unmanned aircraft into the future CVW.
- Perform a cost assessment of various alternatives.
- Develop a notional acquisition strategy for development and construction of the shipbuilding industrial base and expected Navy shipbuilding demands.¹

The Navy asked the RAND Corporation to assist in responding to these requests by providing procurement cost and effectiveness analysis comparing the current Ford-class program with alternatives, focused to examine a potential future transition to a lower-cost carrier replacement in long-range shipbuilding plans if the findings support further Navy or congressional actions to that end. In turn, consistent with the NDAA language, we conducted an analysis of four carrier variants and examined their capabilities against anticipated future warfighting requirements as part of the overall carrier fleet architecture. The alternatives represented reasonable and technically achievable variants that provided at least some part of required warfighting capability. We developed them in consultation with a Navy-led executive steering committee. We assumed no change in the overall requirement for tactical air forces. However, we did note when carrier limitations imposed cost or risk. Our research recommendations present an overview of potential alternatives on air wing operations and execution.

This report is a shorter version of a classified, restricted-distribution report provided to the Navy in July 2016. Neither report is of a formal analysis of alternatives or detailed engineering study, nor is either a requirement document. It is an exploration of possible alternatives for further consideration to potentially replace the legacy force as it begins reaching expected service life in decades to come. Some things might be—or appear to be—infeasible or difficult at the moment but do not necessarily represent major engineering leaps forward. The vari-

¹ Public Law 114-92, National Defense Authorization Act for Fiscal Year 2016, November 25, 2015, § 128.

ants are possible alternatives, not recommendations for a specific future course of action.

Alternatives Considered

We analyzed the feasibility of adopting four aircraft carrier concept variants as follow-ons to the *Ford*-class carrier following USS *Enterprise* (CVN 80) or the as-yet-unnamed CVN 81. Among these options are two large-deck carrier platforms that would retain the capability to launch and recover fixed-wing aircraft using an on-deck catapult and arresting gear system and two smaller carrier platforms capable of supporting only short takeoff and vertical landing (STVOL) aircraft. Specifically, the four concept variants are as follows:

- a follow-on variant continuing the current 100,000-ton *Ford*-class carrier but with two life-of-the-ship reactors and other equipment and system changes to reduce cost (we refer to this design concept as *CVN 8X*)
- a 70,000-ton USS *Forrestal*-size carrier with an updated flight deck and hybrid nuclear-powered integrated propulsion plant with capability to embark the current large integrated air wing but with reduced sortie generation capability, survivability, and endurance compared with the *Ford* class (we refer to this design concept as *CVN LX*)
- a 43,000-ton variant of the USS *America*-class, fossil fuel-powered and arranged to support only STOVL operations but at a higher tempo than the current LHA 6 (USS *America*) (we refer to this design concept as *CV LX*).² This variant would incorporate the larger ship's beam excursion the Navy examined in the LHA 8-class flight 1 studies.³

² We depart from the Navy's convention of using the *LH* designation for STOVL support platforms. We use CV to ensure that it is clear that these proposed variants are replacements for the current CVN force.

³ *Flight 1* refers to earliest versions of the class. The term is used when additional flights are expected.

• a 20,000-ton variant that will resemble escort carriers that some allied navies currently operate (we refer to this design concept as *CVEX*). Similar to the 43,000-ton variant, it will be conventionally powered and will operate STOVL aircraft.

These concept alternatives were consistent with language in the fiscal year 2016 NDAA.⁴ However, they also represent a wide range of characteristics that could reasonably be examined to lower cost and potentially meet future warfighting requirements. For each alternative, we evaluated both the operational effects and the rough comparative costs. The latter two options would require major changes in Navy concepts of operations for the Navy's carrier strike group (CSG), require changes in the Navy's aircraft procurement plans, and create capability shortfalls that would need to be supported elsewhere in the joint force.

Derived Requirements for the Nuclear-Powered Aircraft Carrier

Our analysis is based on an aircraft carrier being able to generate sufficient tactical air capability and the capacity to support a joint campaign in the most stressing scenario (which includes capability, a specific number of aircraft, and an ability to rearm and sustain these aircraft); support an integrated air wing, including airborne early warning (AEW) and electronic attack (EA); and operate at ranges where tactical air can carry out its missions. These requirements imply specific capabilities a carrier must possess, which will, in turn, drive equipment and design:

• the ability to support organic aircraft capable of providing AEW and EA, which currently are the Advanced Hawkeye (E-2D) and Growler (EA-18G). Both are fixed-wing aircraft requiring catapult-assisted takeoff and arresting gear. We consider aircraft vari-

⁴ Pub. L. 114-92, 2015, § 128.

ants (the CV LX and the CV EX) without this capability and note the resulting limitations.

- the ability to support current tactical air strike aircraft, principal among which is the Lightning II carrier variant (F-35C), which requires catapult launch and arresting gear recovery and a flight deck that is approximately 1,000 ft. long. Although the numbers of tactical aircraft required to support future operational scenarios are not expected to diminish, we analyze smaller carrier variants (the CV LX and the CV EX) that can support only the F-35B (STOVL-capable Lightning II) and rotary-wing aircraft. Again, these smaller alternatives depart from the Navy's current aviation program plans.
- The propulsion systems must be able to support speed requirements, provide redundant propulsion capability, and meet electrical power generation requirements, which could include the potential to support an electric, integrated propulsion system.
- Magazine size must be adequate to support sustained operations, with replenishment occurring not more frequently than every seven to ten days during combat operations. This capacity will be proportionate to the size of the aviation element embarked; a carrier with a smaller number of aircraft will not need the same size magazine as one with a larger complement.

Many trade-offs are available to the Navy in designing future carriers, such as decisions to forgo additional active defense on high-value units or to forgo organic AEW and EA. Some trade-offs, such as a reduction in number of Electromagnetic Aircraft Launch System or other measures that could affect sortie generation rate (SGR), do not measurably change concepts of operations, while others would impose fundamental changes in the nature of CSG operations or in the Navy's shipbuilding and aircraft procurement plans. Our analysis identifies ways in which the alternative carrier variants affect such outcomes.

Operational Impact

To assess operational feasibility, we used generalized threat scenarios resembling those that fleet commanders use in Joint Task Force Exercise certifications to assess CSG readiness for deployment but also identified where missions are likely to change in the future. One major operational key performance parameter for the *Ford*-class carrier is SGR, which is a measure that "includes the ability to launch, recover, service, load and prepare the aircraft in all ways for the succeeding mission."⁵ Accordingly, our initial assessment of operational impact was oriented toward impact of the alternative variants on force sortie generation in varying scenarios with varying force flows, while considering other relevant factors as well. We note, according to future planning scenarios, that an SGR consistent with the *Ford*-class key performance parameter might not be necessary given the anticipated longer sortie durations caused by increased standoff.

Our analyses of the carrier variants illuminated capability shortfalls in some instances. Our overall findings are as follows:

- The CVN 8X, the descoped *Ford*-class carrier, offers similar warfighting capability to that of the *Ford*-class carrier today. There might be opportunities to reduce costs by eliminating costly features that only marginally improve capability, but similar tradeoffs are likely to be made in the current program as well.
- The CVN LX concept variant offers an integrated, current air wing with capabilities near current levels but with less organic mission endurance for weapons and aviation fuel. It will not generate the same SGR as the *Ford*-class carrier, but this is not a significant limitation for stressing warfighting scenarios.⁶ It will be less survivable in some environments and have less redundancy than the *Ford* program-of-record ship, and these factors might

⁵ Director, Operational Test and Evaluation, Office of the Secretary of Defense, "FY15 Navy Programs: CVN 78 *Gerald R. Ford* Class Nuclear Aircraft Carrier," c. 2015.

⁶ Increased standoff distances, and hence longer sortie durations, are characteristic of future planning scenarios. As a result of longer sortie durations, a lower SGR is required, all else being equal.

drive different operation concepts. Although we do not characterize the impact of decreased survivability, this is an important limitation that will have to be weighed against the potential cost savings. The major means of reducing cost is through engineering redundancy, speed, and air wing fuel capacity, and these could affect mobility and theater closure.

- The concept variant CV LX, which is a version of the LHA 6 platforms, might be a low-risk, alternative pathway for the Navy to reduce carrier costs if such a variant were procured in greater numbers than the current carrier shipbuilding plan; our analysis suggests a two-to-one replacement. Over the long term, however, as the current carrier force is retired, the CV LX would not be a viable option for the eventual carrier force unless displaced capabilities were reassigned to new aircraft or platforms in the joint force, which would be costly. This platform would be feasible for a subset of carrier missions but, even for those missions, could require an increase in the number of platforms. This concept variant might, if procured in sufficient numbers, eventually enable the Navy to reduce the number of Ford-class carriers in the overall force structure, but more-extensive analysis of missions, operations, and basing of such a variant and the supported air combat element is required.
- The smallest concept variants reviewed, the CV EX 20,000-ton sea-based platforms, do not provide either a significant capacity or an integrated air wing and, thus, force reliance on other legacy platforms or land-based assets to provide key elements of capability—in particular, AEW. As a result, this concept variant is not really a replacement for current aircraft carrier capability and would require other platforms, aircraft, weapons, and capabilities in the joint force. These platforms would be a viable pathway only in broad fleet architecture transformation providing a narrow mission set, perhaps regionally, and would require extensive analysis. Given that such a concept variant is not a viable replacement for an aircraft carrier, such analysis would be required to see whether any adjustment on the current aircraft carrier program would be feasible.

Platform Cost Comparison

The cost assessment reflects a comparison between the alternative concept platforms and the current *Ford*-class program-of-record budget data based on weight changes but also includes the nonrecurring engineering expense incurred for new design, the cost associated with different equipment, the potential loss of learning resulting from new designs for a new lead ship, and, to the extent possible, any force structure changes needed to support new platforms (such as the need for more carriers or replacement ships).

The overall results of our cost comparison are as follows:

- The descoped *Ford*-class carrier, the CVN 8X, *might generate fewer sorties than the current key performance parameter values for the Ford class and might have only incremental reduction in overall platform cost.* The analysis examining cost reduction with transition to a life-of-the-ship reactor, such that being done on submarine programs, does not appear to be cost effective. Between the developmental costs and a reduced service life, there is little cost advantage in this variant.
- The CVN LX concept would allow considerable savings across the ship's service life and *appears to be a viable alternative to consider for further concept exploration*. Construction costs would be lower; design changes and life-cycle costs would reflect the lessons already applied in the *Ford* class. The reliance on hybrid drive with fewer mechanical parts than legacy platforms is likely to further reduce maintenance cost. However, CVN LX would be a new design that would require a significant investment in nonrecurring engineering in the near term to allow timely delivery in the 2030s.
- CV LX, although it requires a larger force structure to maintain air capabilities, might still reduce overall construction costs if large carrier numbers were reduced. But, as described in the report, *reducing carrier numbers with the resulting loss of capability should not be pursued without extensive further analysis* for all displaced missions in the joint force execution of warfighting sce-

narios and, potentially, regional basing and narrowly focused missions for these platforms. Any cost savings would likely be offset to an unknown degree by requirements for additional systems to mitigate loss of capability associated with this variant.

• CV EX, the smallest variant, is not a practical variant at all without considerable revision of the Navy warfighting concept of operations. Although the same is to a degree true with CV LX, the impact of an even larger number of low-sortie ships with small and limited air wings is even more pronounced with this variant. CV EX has all of the shortfalls of CV LX and will pose even greater issues of mutual support and logistics sustainment.

Conclusions

Our analysis points to potential options for replacing the Nimitz-class carrier as these ships reach expected service life that have lower procurement costs than the Ford-class carriers. However, most of these options come with reduced capability that might require changes in the concept of operations to deliver sea-based aircraft capability comparable to that of carriers in the fleet today. If a new platform is introduced in the mid-2030s, the Navy's force structure will still contain a large legacy force of Nimitz- and Ford-class carriers, at least until the mid-2050 time frame, which might lower the risks of introducing a new carrier for some period of time. But, ultimately, if a new carrier variant is selected, it will define the carrier force and constitute the supported capability available to the Navy. Capability shortfalls can be mitigated, to some degree, with changes in operational concepts or by adding additional platforms to the force structure-which introduces additional cost that might offset anticipated cost savings. In addition, if the Navy stops procuring large-deck nuclear carriers, the ability to reconstitute the industrial base at some time in the future comes with substantial risk.

Although SGR was a central variable in comparing the carrier variants, our analysis suggests that there is room to make trade-offs in aircraft sortie rate capacity between the *Ford*-class carrier and a

lower-cost platform. However, it is important to consider that, whatever threats complicate carrier operations, they might even more significantly affect land-based tactical air operations. Carriers can move; have defensive support from escorts; can readily replenish; and might, in fact, be more survivable than their land-based counterparts. This is an important factor for Congress and the Department of Defense to consider before a trade-off is made to give up the supported air wing sortie generation capacity in the overall sea-based force. We wish to thank the sponsor, the Office of the Chief of Naval Operations, Assessment Division, and, in particular, LtCol Jason W. Heuer, U.S. Marine Corps. Additionally, we received exceptional support from Naval Sea Systems Command and the Program Executive Office, Aircraft Carriers, and support coordinated through the sponsor's office. We also wish to thank our reviewers, Paul DeLuca, Michael Nixon, and Robert Murphy, as well as Christopher A. Mouton and Cynthia R. Cook for their support in the review process in this unclassified and the previously published classified study.

1 + 15 75 minute (type of operational cycle) AEW airborne early warning AoA analysis of alternatives ASW anti-submarine warfare C2 command and control CSG carrier strike group variant of current aircraft carriers CV EX CV LX variant of USS America-class carrier CVN nuclear-powered aircraft carrier variant of USS Gerald R. Ford-class carrier CVN 8X variant of USS Forrestal-size carrier CVN LX CVW carrier air wing DCA defensive counterair DDG guided-missile destroyer defense planning scenario DPS ΕA electronic attack EMALS Electromagnetic Aircraft Launch System

EOH	engineered overhaul
F/A-XX	next-generation sea-based strike fighter after the $\ensuremath{F-35C}$
FF	forward funding
FY	fiscal year
GAO	U.S. General Accounting Office
GTG	gas turbine generator
IPS	integrated propulsion system
JTFEX	Joint Task Force Exercise
KPP	key performance parameter
LHA	general-purpose amphibious assault ship
METL	mission-essential task list
MTG	main turbine generator
n/a	not applicable
NAVSEA	Naval Sea Systems Command
NDAA	National Defense Authorization Act
NRE	nonrecurring engineering
NTA	Navy tactical task
OFRP	optimized fleet response plan
OPNAV	Office of the Chief of Naval Operations
PB	president's budget
POR	program of record
RCOH	refueling complex overhaul
SAR	search and rescue
SCN	shipbuilding and conversion, Navy

- SGR sortie generation rate
- STOVL short takeoff and vertical landing
- TACAIR tactical aircraft
- UNREP underway replenishment

Background

Sea-based tactical aviation is a key part of the U.S. Navy's concept of operations for power projection. An integrated carrier air wing (CVW) provides capability across the full range of military operations, from peacetime presence to highly stressing major combat operations. Although the CVW is the component actually delivering capability, CVWs do require aviation support for launch and recovery at tactical distances, replenishment, maintenance, and sustainment. For these purposes, the Navy provides 11 nuclear-powered aircraft carriers (CVNs), with ten carriers normally being operational at any given time. The 11th carrier is generally in a mid-life refueling, overhaul, and modernization period and is not available for fleet operations.

The Navy's current 30-year shipbuilding plan, from which Figure 1.1 is projected forward, details the current CVN force structure and its evolution, including commissioning and decommissioning dates and refueling complex overhauls (RCOHs).¹ The RCOH is an approximately 40-month-long mid-life overhaul and modernization period for the aircraft carrier during which the ships reactors are refueled at the shipbuilders' yard in Newport News, Virginia. During the RCOH period, the carrier is out of the fleet and not available for operations. Under the Navy's current 30-year shipbuilding plan, the number

¹ Deputy Chief of Naval Operations for Integration of Capabilities and Resources, *Report* to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for Fiscal Year 2017, Washington, D.C.: Office of the Chief of Naval Operations, July 12, 2016.

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SOURCES: Deputy Chief of Naval Operations for Integration of Capabilities and Resources, 2016; authors' projections.

NOTE: CVN 65 = USS Enterprise. CVN 68 = USS Nimitz. CVN 69 = USS Dwight D. Eisenhower. CVN 70 = USS Carl Vinson. CVN 71 = USS Theodore Roosevelt. CVN 72 = USS Abraham Lincoln. CVN 73 = USS George Washington. CVN 74 = USS John C. Stennis. CVN 75 = Harry S. Truman. CVN 76 = USS Ronald Reagan. CVN 77 = USS George H. W. Bush. CVN 78 = USS Gerald R. Ford. CVN 79 = USS John F. Kennedy. CVN 80 = USS Enterprise. CVN 81 through CVN 86 = as-yet-unnamed CVNs. Dark bars indicate production in progress. Light bars indicate production expected, with the leftmost point being when the keel is laid. Along the bottom are the possible snapshots of platforms in the fleet as of 2015 and in 2030, 2040, and 2050. RAND RR2006-1.1 of CVNs drops to ten near 2035. Any such reduction would require Congress to change the current law, and it should not be assumed, nor is it likely, that this reduction will actually occur.²

Aircraft carriers are currently divided into two classes: the *Nimitz* class (CVN 68 through CVN 77) and the *Ford* class (CVN 78 through CVN 80). These ships are nuclear powered; have 50-year service lives; and can support 80 tactical aircraft, which include a minimum of 44 strike aircraft. The carriers operate as part of a carrier strike group (CSG), which also includes surface combatants equipped with strike and air defense weapons, as well as the CVW. Of the *Ford*-class carriers, CVN 78 delivery was expected in mid-2017, CVN 79 is under construction, and CVN 80 is starting advance procurement of long-lead material. Figure 1.1 also summarizes, along the bottom of the chart, the possible snapshot of platforms in the fleet as of 2015 and in 2030, 2040, and 2050.

There is congressional concern that the acquisition costs of the *Ford*-class carrier might be higher than needed to effectively support warfighting capabilities and might affect the entire shipbuilding budget—particularly during the period in which recapitalization of the strategic deterrent submarine program moves through production— and might thus impose significant trade-offs with other portions of the Navy budget.³ The procurement cost for the lead ship of the *Ford*-class carriers was \$12.9 billion in then-year dollars in the Navy's fiscal year (FY) 2017 budget estimate.⁴

The Senate Armed Services Committee, among others, noted that alternatives could be developed that maintain sufficient capability

 $^{^2~}$ Title 10 of the U.S. Code § 5062(b) requires the Navy to maintain a force of not fewer than 11 operational aircraft carriers.

³ Office of Senator John McCain, "Statement by SASC Chairman John McCain on U.S. Navy Fleet Architecture Series," press release, Washington, D.C., February 10, 2017.

⁴ Ronald O'Rourke, *Navy Ford (CVN-78) Class Aircraft Carrier Program: Background and Issues for Congress*, Washington, D.C.: Congressional Research Service, RS20643, March 16, 2017.

with a lower procurement cost.⁵ Given these concerns, the committee asked the Navy to examine lower-cost alternatives. More specifically, the National Defense Authorization Act for FY 2016 directed the Navy to do the following:

- Assess fleet sea-based tactical aviation capability requirements in probable scenarios.
- Establish alternative platforms that provide supported capabilities across a minimum of three platforms, whether nuclear or nonnuclear, whether a new or existing design, considering incorporation of unmanned aircraft into the future air wing.
- Perform an acquisition cost assessment of various alternatives.⁶
- Develop a notional acquisition strategy for development and construction of the ships and expected Navy shipbuilding demands.⁷

The Navy asked the RAND Corporation to perform a study that could then inform the Navy's response to these tasks. This report is a shorter version of a classified, restricted-distribution report provided to the Navy in July 2016. Neither study is a formal analysis of alternatives and presents only acquisition costs and not life-cycle costs. It is a description of conceptual variants that might be alternatives to the *Ford*-class carrier, an assessment of the operational impact of adopting

⁵ Office of Senator John McCain, "Opening Statement by SASC Chairman John McCain at Hearing on *Ford*-Class Carrier Program," floor statement, Washington, D.C., October 1, 2015.

⁶ The study cost analysis focuses on acquisition cost by direction. In this study, we did not examine ownership or operating costs. *Ford*-class carriers are planned to have a \$4 billion lower total ownership cost across the 50-year service life than the predecessor *Nimitz* class.

⁷ Public Law 114-92, National Defense Authorization Act for Fiscal Year 2016, November 25, 2015, § 128.

these variants, and a description of acquisition costs. It considers but is not bound by previous work done, including the following:

- a Center for Naval Analyses, CVX Analysis of Alternatives (AoA), 1997–1999.⁸ This effort examined a wide range of platform solutions and hosted CVWs. CVN 78 class was the eventual choice among several, but the acquisition strategy evolved, and the later CVN 68–class hull form was retained. The AoA focused on air wing size, ship size, and propulsion type and reflected a focus on total ownership cost.
- a Defense Science Board 2001 study, Future of the Aircraft Carrier.⁹ The resulting report stated that the Navy had little choice but to proceed with the CVN 78 class carrier and revalidated both the carrier mission and capacity requirements.
- a 2011 RAND study, Trading Capability for Cost.¹⁰ That study, performed for the Office of the Secretary of Defense Cost Assessment and Program Evaluation directorate, examined changes within the current carrier program to reduce cost.
- a 2015 RAND study, Options for a Common Mobile Platform, which considered options for aviation support platforms capable of supporting both integrated CVWs and the operations of the Marine Air–Ground Task Force under differing scenarios.

Key Tasks and Assumptions

To emphasize the earlier discussion, we note that this report is not of a formal analysis of alternatives (AoA) or detailed engineering study

⁸ Center for Naval Analyses, CVX Analysis of Alternatives (AoA), 1997–1999, Arlington, Va., 1997.

⁹ Defense Science Board Task Force on Future of the Aircraft Carrier, *Future of the Aircraft Carrier*, Washington, D.C.: U.S. Department of Defense, October 2002.

¹⁰ John F. Schank, Mark V. Arena, Ken Munson, Kathryn Connor, Kay Sullivan Faith, and Clifford A. Grammich, *Trading Capability for Cost: An Examination of Future Aviation Platform Options*, Santa Monica, Calif.: RAND Corporation, June 2011, not available to the general public.

and is not a requirement document. It is an exploration of possible alternatives that the Navy can begin considering to replace the legacy force as it begins reaching expected service life in decades to come. Some things might be—or appear to be—infeasible at the moment but do not represent major engineering leaps forward. These recommendations are intended to fulfill the desire to consider alternatives, not as recommendations about a future course of action.

Several related but separated tasks were associated with this study. These include the following:

- 1. Informed by the threat, describe likely air wing requirements.
- 2. Develop potential alternative platforms with lower acquisition costs that could replace existing platforms as they reach expected service life.
- 3. Use existing defense planning scenarios (DPSs) projected forward into the period in which carrier recapitalization occurs to assess operational feasibility.¹¹
- 4. Compare costs between alternative platforms and the program of record, and describe potential acquisition strategies.

The study began with the following assumptions:

- Existing platforms will be retained until they reach the end of service life, and replacement will not take place before then.
- Although peacetime presence is critical for deterrence, the major driver for capability and capacity will be the ability to perform prescribed wartime missions. As we evaluate potential alternatives, we are not questioning the overall number of aircraft; the portion of targets allocated to tactical aircraft (TACAIR); or the need for tanking, airborne early warning (AEW), electronic attack (EA), or aviation sustainment.
- Existing DPSs can be projected until the time frame (2045) when the existing force structure begins to reach expected service life.

¹¹ Actual DPSs are treated in more detail in a restricted-distribution companion report. This report uses generalized scenarios that require comparable operational capability.

- We did not assess the impact that a changed threat environment might have on other joint forces, including land-based TACAIR. We assume that they are based in the same places in the same numbers as in the guiding DPS.
- Although nonstate actors and asymmetric challenges might limit CSG effectiveness, the principal threat will remain an organized state military force.
- There will be no major shifts in relative national power or in expected national strategies.

Approach and Methodology

The study required an assessment of operational impact of alternative carrier variants within an expected fleet architecture and in reference to scenarios occurring far beyond the time horizons of existing DPSs. In this report, we use generalized threat scenarios resembling those that fleet commanders use in Joint Task Force Exercise (JTFEX) certifications to assess CSG readiness for deployment. These scenarios specify a mission-essential task list (METL) required for operation in existing theaters and provide an opposing force against which the tasks are applied. If the tasks are insufficient or inadequately executed, the CSG must continue training until the tasks are satisfied. The METL is a specific expression of what a CSG is currently expected to do in a range of scenarios.

METLs and JTFEX certifications reflect current force capability requirements, and these will no doubt evolve as threats and capabilities evolve. We identify cases in which missions are likely to change in some way that might affect capability requirements or assessment. However, the missions associated with CSGs do not seem likely to change and, indeed, do not change significantly when we consider the relationship between existing operations plans—on which certifications are based—and future-oriented DPSs.

One major operational key performance parameter (KPP) for the *Ford*-class carrier is sortie generation rate (SGR). According to the CVN 21 operational requirements document, as quoted by the Director of Operational Test and Evaluation:¹²

Sortie generation is the defining measure of the supported combat power of an aircraft carrier. It is the measure that includes the ability to launch, recover, service, load and prepare the aircraft in all ways for the succeeding mission. This includes requirements for both the flight deck systems attendant in aircraft operations and the sustainability requirements for magazine and fuel stowage.

Accordingly, initial assessment of operational impact (task 3) was oriented toward impact on force sortie generation in varying scenarios with varying force flows. However, we also considered other relevant factors and assessed the continuing validity of SGR as a measure of combat power.

The cost assessment (task 4) involved a straight comparison between the alternative concept platforms and the current *Ford*-class program-of-record (POR) budget data based on weight changes but also included the nonrecurring engineering (NRE) expense incurred for new design; the cost associated with different equipment; the potential loss of learning resulting from new designs for a new lead ship; and, to the extent possible, any force structure changes needed to support new platforms (such as the need for more carriers or replenishment ships). The Navy study sponsor established an executive steering committee for the study to provide recommendations, receive periodic progress briefings, and clarify matters concerning requirements and operations.

Organization of This Report

The remainder of the report presents the results of our analysis. Chapter Two discusses operational requirements for the CSG, the CVW, and the aircraft carrier itself and how these requirements might evolve in light of the anticipated future threat. It also details the capabilities a

¹² U.S. Navy, *Future Aircraft Carrier (CVN-21) Operational Requirements Document*, Washington, D.C., 2004.

carrier must possess to meet these requirements. In Chapter Three, we describe and compare the four aircraft variants considered in our analysis. Chapter Four contains our assessment of the operational impact of the carrier concept variants, and Chapter Five compares their costs. In the final chapter, we present our conclusions and identify options that might warrant further investigation. Appendix A reproduces the forwarding letters that the Navy provided to Congress for this report. We also provide appendixes with some details of the CVN METL and deployment preparation (Appendix B) and the aircraft and seacraft mentioned in the report (Appendix C).

Introduction and Background

The U.S. Navy performs a variety of functions, but among its most important is maintaining the ability to operate as part of a joint force and win a major conventional war against a capable opponent or opponents. Although it remains largely unchallenged in the maritime realm since the collapse of the Soviet Union, the Navy now faces increasing challenges from China, Russia, Iran, North Korea, and nonstate actors in contesting its ability to project power.

The U.S. Navy deploys in a variety of configurations, but its major power-projection capability resides currently in the ten CSGs. Within the CSG, an integrated air wing provides capability for defensive counterair (DCA); strike; anti–surface ship warfare; AEW; airborne command and control (C2); EA; and, through helicopters, anti-submarine warfare (ASW). When considering what aircraft carriers need to do, people writing requirements must ensure that those requirements are related to the needs of the CVW they support.

As historical background, the original requirements for the *Ford*class aircraft carrier were developed with the air campaigns for Operation Desert Storm as a baseline for capability requirements. The general campaign outline was that suppression of enemy air defense, targeting of C2 nodes, and early attrition of the enemy air force would then result in a situation in which the ability to rapidly generate sorties would be key.¹ If a campaign were expected to transition from securing air and

¹ U.S. Navy, 2004.

maritime dominance to sustained strike, sortie generation would be a dominant capability requirement.

However, the world and the threat environment have evolved, and the threats are beginning to demand longer standoff ranges and potentially a longer period in which to establish air and sea dominance. Integrated air wings remain capable of operating in this environment, but the evolving threat will likely require a change in concepts of operation and might also affect the required capability for the supporting aircraft carrier.

Unique Features of Sea-Based Tactical Aviation

Aircraft carriers are platforms intended to support and deliver TACAIR that can flexibly react to threats and targeting. In most important ways, sea-based and land-based tactical aviation carry out similar missions and fulfill similar roles. Both can perform DCA; both can attack a variety of targets in different environments. Both require support and sustainment from bases or platforms and are unusable if those bases or platforms are unavailable or significantly degraded. In the last war that focused primarily on heavy use of tactical aviation for sustained combat—Operation Desert Storm—both land-based and seabased tactical aviation could operate from land bases or aircraft carriers effectively without interference. That advantage has degraded over time, and the trend toward increasing vulnerability of TACAIR support capabilities is likely to accelerate.

Sea-based tactical aviation does have the advantage of having a mobile support platform: an aircraft carrier. Although there are numerous and growing threats to ships operating on the surface, ships can vary position, complicating targeting and remaining out of harm's way until ready to launch attacks, to a greater degree than land-based tactical aviation. Although operational capabilities of the conventional takeoff and landing Lightning II (F-35A) and Lightning II carrier variant (F-35C) are almost identical, the sea-based aircraft can be moved into range by a platform that can then move out and remain operational. A land base cannot be moved and therefore has to adopt other
defensive measures, which themselves are likely to become increasingly ineffective.

Beside mobility, the CSG needs other capabilities to defend itself against a spectrum of attacks. Potential enemies have ships and submarines that carry antiship cruise missiles. Although surface-ship escorts do possess area air defense capabilities, these are limited by magazine capacity, and it would be possible to exhaust entire magazines defending against a series of large raids. The theme of magazine limitations will recur as we consider CSG capabilities, with the ability to replenish ordnance being a particular strength of the CVN and CVW capability. The CVW needs to be able to attack and sink enemy surface combatants before these combatants close to within weapon range. The CVW should also be able to detect and engage cruise missiles.

Historically, the CSG has possessed organic ASW capabilities, including both helicopter and fixed-wing ASW aircraft. The Navy no longer has fixed-wing capability but relies on land-based aircraft for detecting and attacking submarines, and it has no plans to develop a dedicated, fixed-wing carrier-based ASW aircraft. Of the aircraft carrier options we are considering, none is expected to support a fixed-wing ASW-capable aircraft in the future. Although the *Ford*-class carrier is built with passive and active ASW defense, the CVW is not being designed to have ASW capability beyond what escorts and helicopters provide.

Defending the CSG against maritime threats is necessary, but the ultimate goal of the CSG is to influence events ashore. The majority of the powers the U.S. Navy is likely to face might not pursue conventional maritime power and might rely on capable and numerous landbased systems. The CSG has to defend against attacks from land-based assets—which are likely to come in waves and rapidly stress the magazines of escorts—and then be able to generate strike sorties to penetrate enemy air defenses and deliver ordnance against targets of interest. The Navy does have other strike assets, including attack submarines with varying missile load-outs and surface ships. But these assets also have magazine and replenishment limitations. The sophisticated air defenses that some potential adversaries possess will only get more advanced, and it is likely that penetration will require a large number of weapons to be used nearly simultaneously. That means that one weapon does not equate to one target. The available force of missile-firing ships might rapidly expend its missiles, and, again, there is no current means to replenish them other than by the vessels returning to port.

TACAIR are vulnerable flying into integrated air defense, even if we assume a degree of stealth, and a concept of operations that relies on manned aircraft penetrating air defenses to deliver bombs directly might not be tenable. However, TACAIR possess multiple weapon loading points and can approach targets from multiple directions, even if the weapons need to be released at a range outside the enemy air defense envelope. The aircraft carrier also has near-limitless ability to replenish and begins with a large magazine (depending on variant). The CSG can be nearer the contested area than U.S.-based bombers and might thus be better able to respond to short-notice cuing. The CSG—and, in particular, the CVW, if equipped with sufficient standoff weapons and aircraft capable of carrying these weapons—would remain useful elements of the joint campaign. In evaluating our carrier options, we assume that sea-based tactical aviation will remain a key capability.

Carrier Strike Group and Carrier Air Wing Requirements

CSGs operate forward in areas of strategic interest and carry out combat operations for ten to 15 days, depending on the intensity of operations, the number of sorties generated, and the amount of ordnance expended, until the arrival of other joint forces. Besides the aircraft of the CVW, the CSG includes surface escorts carrying both defensive and strike weapons, adding to the overall force capability and capacity. CVWs deliver a wide variety of weapons—weapons that must be stored on and loaded on and off the aircraft by the crew of the CVN. The aircraft of the CVN require maintenance, refueling, parts support, and general sustainment, which the CVN organically must provide. A CSG and CVW typically are composed of the following:

- one Nimitz- or Ford-class CVN
- four or five guided-missile destroyers (DDGs) or guided-missile cruisers
- one 60-aircraft CVW, with integrated capabilities, including strike fighters, EA, AEW, logistics support, and rotary-wing support.

Although CSGs generally operate in joint environments, CVWs are designed to provide the majority of their own warfighting requirements, from organic tanking from air wing aircraft to AEW and EA. Table 2.1 shows the POR and projected future integrated air wings. Future programs for aircraft that might populate carrier flight decks until 2060 are being examined now. An AoA for the F/A-XX, or next-generation sea-based strike fighter after the F-35C, will commence in the near future. The F/A-XX replaces the Navy Super Hornet F/A-18 E/F aircraft and will drive future-carrier requirements to some extent for decades to come. The research, development, test, and engineering and procurement funding for the aircraft programs have much larger NRE platform costs than ship programs do. In fact, the aircraft programs for replacement aircraft might be well established by the time a first alternative aircraft carrier could be delivered in 2042. A move to change air wing composition might be considerably more difficult than trying to change the support platform. The platform-supported requirements these aircraft are expected to have will likely not change significantly, and, if the aviation platform does not support all these aircraft in a range of embarked numbers, the gaps, alternatives, and mitigations must be identified when known.

In considering the CSG, and, in particular, the air wing, it is important to understand the attributes most important to making the CSG into an effective warfighting instrument. Narrow concentration on any one scenario, mission, or metric can prove misleading. Broadly speaking, a CSG provides the ability to establish and maintain battlespace dominance across multiple domains, provide a highly mobile and partially self-sufficient force, and generate strikes and other compo-

Туре	2017	2020	2025	2030 and Beyond
Strike fighter (F/A-XX, F/A-18, F-35)	44	44	40-44	36–44
Airborne EA (EA- 18G)	- 5	5–8	8	8
AEW (E-2C, E-2D)	4 or 5	5	5	5
Multimission naval helicopter (MH-60S)	6 (8 total across the CSG)	6 (8 total across the CSG)	6 (8 total across the CSG)	6 (8 total across the CSG)
Multimission naval helicopter (MH-60R)	5 (11 total across the CSG)	5 (11 total across the CSG)	5 (11 total across the CSG)	5 (11 total across the CSG)
Carrier onboard delivery (C-2, CMV-22)	2 C-2s	2 C-2s	3 CMV-22s	3 CMV-22s
Unmanned air system (MQ-25)	Not applicable	Not applicable	To be determined	To be determined

Table 2.1 Projected Carrier Air Wing Force Structure (Number of Aircraft)

SOURCE: Office of the Chief of Naval Operations, 2016.

NOTE: F/A-18 = Hornet. F-35 = Lightning II. EA-18G = Growler. E-2C = Hawkeye. E-2D = Advanced Hawkeye. MH-60S = Seahawk. MH-60R = Seahawk. C-2 = Greyhound. CMV-22 = Osprey. MQ-25 = Stingray.

nents of ashore power projection. Surface ships and submarines are important parts of the overall battle force. However, their ability to generate high-volume strike is limited by relatively small magazines and inability to replenish these. The same CVW can generate many times the number of strikes that the complete force of submarines and ships can.

What the Aircraft Carrier Force Must Be Able to Do

As we consider what an aircraft carrier must do, we orient this toward what the CVW and CSG must do. The evolving threat and operational environment will affect what characteristics must be inherent in platforms. DPSs are not an inclusive guide to everything a unit might be expected to do, but they allow a structured look at a likely operations setting and allow development of an architectural approach. The analysis described in this report similarly places requirements for carrier capability in the context of both potential threat and projected capability.

The best characterization of the current CSG force is that it offers overmatch in some scenarios but will be challenged in others. As discussed earlier, in the environment that the Navy and, indeed, the joint force face, there were few challenges to the CSG's ability to operate with nearly complete freedom of action in the period following Operation Desert Storm and continuing through Operations Iraqi Freedom and Enduring Freedom. Although some competitors were developing anti-access capabilities, there generally were few significant impediments to operation of an integrated air wing flying from a large-deck aircraft carrier.

Of particular note is the fact that a major impetus for development of a carrier capable of supporting a high SGR was the Navy's experience in Desert Storm, in which distances were short and the target environment rich. In such a context, high SGR would enable the faster delivery of ordnance and possibly a shortening of the campaign. Even in the current environment, there are operational scenarios in which high SGR would be highly desirable, with defense against a swarm of small boats being one notable example. There is a large number of targets; the major detection sensor is radar and visual; the ability to use standoff munitions is limited. DCA in an environment in which rapid expenditure of air-air munitions is expected might be another.

In recent experience, however, there has been little need for large numbers of short sorties and a larger emphasis on longer-range sorties in which such features as ability to tank, ability to provide organic EA, and ability to provide long-range battle-space awareness are particularly important. Having the ability to rapidly generate sorties is not a detractor, but it has been less important than other features, and, in either case, the ability of current platforms to provide this support has been more than sufficient.

The ability to operate unchallenged has diminished over time. Against a near-peer with extensive capability to contest battle space with a large air force and capable integrated air defense system, the CSG's capabilities are likely to be stressed. This stress is not likely to diminish with time. Indeed, given an enemy with these capabilities, TACAIR, sea-based or otherwise, might not be able to operate except in a standoff role during early phases of a campaign.

As defense threats are neutralized and recede, the CSG might be capable of moving in closer to potential strike targets. Note that possible excess in sortie generation capability does not mean that numbers of aircraft or ordnance delivery requirements will be diminished in stressing scenarios. The best interpretation is that, because aircraft are flying longer missions, they do not need to be launched and recovered as often. This should not be interpreted to mean that fewer aircraft are required or fewer targets required to be serviced. Large numbers of weapons are likely to be necessary to penetrate integrated air defense systems and hit dispersed targets, which implies an ability to launch large-scale standoff attacks on a reactive basis—in other words, it will be beneficial for the aircraft to be in the air and awaiting attack orders. CVWs operating just beyond standoff would be able to offer large, persistent, and well-coordinated attacks. This, in the longer term, might imply larger aircraft with larger weapon load-outs and support platforms with the ability to handle large airplanes, large magazines, and the continued ability to replenish.

Derived Requirements for a Nuclear-Powered Aircraft Carrier

We have specified what an aircraft carrier must be able to do: In the most stressing scenario, generate sufficient TACAIR capability and capacity to support the joint campaign (which includes mission capabilities, a specific number of aircraft, and an ability to rearm and sustain these aircraft); support an integrated air wing, including AEW and EA; and be able to operate at ranges at which tactical air can carry out its missions. These requirements imply specific capabilities a carrier must possess, which will, in turn, drive equipment and design:

- For the foreseeable future, the only organic aircraft capable of providing AEW and EA are the E-2D and the EA-18G. Both are fixed-wing aircraft requiring catapult-assisted takeoff and arresting gear recovery. We consider aircraft carrier variants without this capability and note potential mitigations, all of which rely on other platforms or land bases. It is also possible that AEW and EA systems not hosted on these aircraft will become available in the future. But an inability to organically provide these capabilities would be a significant limitation.
- The provision of organic AEW and EA constrains some capability choices. Specifically, although some strike fighter aircraft variants are capable of short takeoff and vertical landing (STOVL), there are currently no AEW or EA platforms existing or planned that can launch and recover from an aviation support platform without catapults and arresting gear.
- In addition, assuming that the platform would be equipped with strike fighters using arresting gear, the ship will have deck-length and wind-over-deck requirements affecting speed and overall size requirements. Note that unmanned aircraft contemplated for inclusion in the CVW are fixed wing and intended to carry fuel and payload comparable to other CVW aircraft. Requirements for catapult-assisted launch and arresting gear recovery, along with the size and speed requirements for the aircraft, would remain.
- In the aviation POR, the principal tactical air strike aircraft will be the F-35C, which requires catapult launch and arresting gear recovery. Fully loaded, this is a heavy aircraft that will impose size and speed requirements on the host platform. Launch and recovery operations require a flight deck that is approximately 1,000 ft. long and includes an angle-deck design. The carrier would need

to operate with speeds sufficient to generate winds necessary for takeoff and landing in various conditions.

- We examine smaller aircraft carrier concept variants that can currently support only the STOVL-capable Lightning II (F-35B) and rotary-wing aircraft. These carriers can be smaller because they would not require catapults and arresting gear. However, this option would require a departure from the Navy's current aviation program plans. Moreover, as previously described, the numbers of TACAIR required to support future operational scenarios is not expected to diminish. To support planned requirements for TACAIR, the aircraft could be distributed across several smaller platforms rather than centered on a few larger ones, but the force structure would be larger and possibly more costly.
- The propulsion systems must be able to support speed requirements, provide redundant propulsion capability, and meet electrical power generation requirements. Several power generation systems could meet these requirements, but they differ in terms of cost, fuel consumption, reliability, and impacts on endurance. Specific designs of alternative propulsion plans would require further Navy study, but we did construct concept variant propulsion plant schemes and notional components to support cost-comparison analysis.
- Magazine size must be adequate to support sustained operations, with replenishment occurring not more frequently than every seven to ten days during combat operations.

There is a variety of ways in which platforms could meet some of these requirements, and we show how well each variant analyzed in this study meets all or part of the requirement. Where the platform cannot inherently meet a requirement, we describe potential options that mitigate the shortfalls—options that have to be considered when calculating the overall cost of an alternative platform. Table 2.2 summarizes the relevant platform requirements.

Some of these characteristics can be manipulated within existing concepts of operation and employment and simply involve the imposition of trade-offs. For example, aircraft carriers currently operate in

Mission Requirement	Required Platform Characteristic	Indicator
Host an integrated air wing.	Launch or recover AEW or EA	Catapults or arresting gear
Host an air wing with sufficient TACAIR capacity for specified campaigns.	Flight-deck and hangar- bay size and general arrangements	Vessel size relative to air wing requirement
Generate sufficient speed for aircraft launch and recovery.	At least 26 knots for F-35C recovery	Vessel maximum speed (including reliability)
Generate tactical speeds.	Relative to scenario or threat	Vessel maximum speed
Be capable of sortie generation consistent with the mission.	Flight-deck and hangar- bay size and arrangements	Flight-deck cycle time and aircraft capacity
Be able to replenish aviation fuel and ordnance at sea.	UNREP stations	Generally present on all carriers
Store ordnance.	Magazines and ordnance- handling equipment and capacity	Magazine size relative to ship and air wing size
Have passive survivability.	Armoring, compartmentation, arrangements, and redundancy	Tonnage and specific design choices and systems
Have active survivability.	Self-defense systems	Installed systems
Store aviation fuel.	JP-5 capacity	Fuel tankage capacity
Be sustainable.	Propulsion energy	Time on station
Provide seakeeping.	Stability in sea states to launch and recover aircraft	Deck movement in differing sea states

Table 2.2Summary Mission Requirements for Aviation Platform Support

NOTE: JP-5 = a kerosene-based aviation fuel. UNREP = underway replenishment.

strike groups and have escorts for active defense. Decisions to forgo additional active defense on high-value units can be made without changing the fundamental nature of CSG operations. Similarly, speed for tactical maneuver might be desirable, particularly in an ASW environment, but a decision to forgo this might not change the fundamental way in which CSGs carry out local sea-control operations. Other choices, however, impose fundamental changes. Forgoing organic AEW and EA are two major examples. Such a change would shift the air wing from being an integrated unit capable of performing fullspectrum operations with minimum support to a unit dependent on land-based support for critical portions of a warfighting mission. This fact might not in itself be a reason to refrain from a development path; the impact would, nevertheless, need to be understood, along with the cost and required mitigations. Our assessment of carrier alternatives and their operational effectiveness considered four ship concept variants:

- a follow-on variant continuing the current 100,000-ton *Ford*-class carrier but with two life-of-the-ship reactors and other equipment and system changes to reduce cost (CVN 8X)
- a 70,000-ton USS *Forrestal*—size carrier with an updated flight deck and hybrid nuclear-powered integrated propulsion plant with capability to embark the current large integrated air wing but with reduced sortie generation capability, survivability, ship speed, and endurance compared with the *Ford* class (CVN LX)
- a 43,000-ton variant of the USS *America*-class, fossil fuelpowered and arranged to support only STOVL operations but at a higher tempo than the current LHA 6 (USS *America*) (CV LX).¹ This variant would incorporate the larger ship's beam excursion that the Navy examined in the USS *Bougainville*-class flight 1 studies.²
- a 20,000-ton variant that will resemble escort carriers that some allied navies currently operate (CV EX). Similar to the 43,000-

¹ We depart from the Navy's convention of using the *LH* designation for STOVL support platforms. We use CV to ensure that it is clear that these proposed variants are replacements for the current CVN force.

² Naval Sea Systems Command (NAVSEA) general-purpose amphibious assault ship (LHA) flight 1 studies examined alternatives of the LHA design for the USS *Bougainville* (LHA 8) AoA. NAVSEA, Surface Ship Design and Systems Engineering, provided the data.

ton variant, it will be conventionally powered and will operate STOVL aircraft.

These choices were consistent with congressional language in the FY 2016 National Defense Authorization Act.³ However, they also represent a range of characteristics that could reasonably be traded to arrive at some of the requirements discussed in Chapter Two. The first concept variant largely maintains capabilities of the Ford-class program and supported CVW with some variations that would lower Navy shipbuilding costs, commencing with CVN 81. The second concept variant is a new, large carrier design of 70,000 tons (approximately 30,000 tons less than a Ford-class carrier) or roughly the size of a Forrestal-class carrier, which would also support a large multimission CVW. The two smaller variants would require major changes in Navy concepts of operations for CSGs and changes to the Navy's procurement plans for sea-based aircraft; in addition, they would not be one-to-one replacements for the current force. In the remainder of this chapter, we describe each variant in more detail. In subsequent chapters, we evaluate both the operational impacts and costs of these alternatives.

CVN 8X

The *Ford*-class aircraft carrier has high initial acquisition costs but lower life-cycle costs than the previous *Nimitz* class.⁴ The *Ford*-class mission needs statement that formed the basis of the program focused on lowering total ownership cost, which is much larger across time than initial procurement cost but might not be as obvious initially. Some of the initial procurement costs are, in fact, higher to achieve longer-term savings, and it would likely be shortsighted to trade these off. Beyond investment in life-cycle savings, *Ford*-class procurement

³ Pub. L. 114-92, 2015, § 128.

⁴ The *Ford*-class aircraft carrier program has a KPP for reduced total ownership cost—in particular, reducing the threshold requirement for crew size.

costs are driven by new technologies in catapults, arresting gear, and radars; a new propulsion plant and overall ship design general arrangements; systems for supporting a higher SGR; and improvements in passive survivability features. Although these features were incorporated to provide capabilities to meet projected threats, the Navy could choose to trade off some capability to reduce costs while still potentially pacing the threat.

The Ford-class carrier currently has four catapults of the new Electromagnetic Aircraft Launch System (EMALS) design. This system is new, and, although it is likely to be less maintenance-intensive than the steam catapult that it replaces, its reliability is not yet fully demonstrated. However, if the reliability for these systems is as expected, the four catapult systems might be beyond what is necessary to meet the Ford sortie generation KPP. As reliability of the EMALS improves and is proven to design levels, it might be possible to move to a threecatapult configuration. Although this could result in some possible impact to sortie generation, the impact ranges from the minimal (with all three catapults operating) to major (with only two). Indeed, the major reason for seeking four catapults appears to center on whether the system will be reliable enough to regularly make four available. This is a matter of empirical operation and testing, but there is little reason to assume that operational availability will improve to the point that three will not be generally available. Moving to three systems would save procurement costs for one EMALS catapult with minimal NRE cost. The CVN 8X concept variant would have one catapult removed, and, therefore, a decrement in the capacity to generate the current Ford-class SGR would likely result. Nevertheless, the resulting SGR would not result in proportional decrements to other factors, such as flight-deck size, arrangements, or reliability in the EMALS catapults.

The passive survivability features of the *Ford* class were enhanced significantly from the later *Nimitz*-class carriers, with associated increases in weight and construction cost. Given Navy changes in carrier operational concepts in future threat scenarios, it might be possible to forgo some of these enhancements and thus reduce cost with acceptable risk, given expected future-carrier concepts of operation. Some of these changes are to ship structure and might therefore result in

additional production efficiency during ship construction. The Navy has already removed some combat system capability from the followon *Ford*-class carriers—specifically, volume search and air and missile defense radars—with the rationale that these are cost-reduction choices with acceptable risk. A similar calculation for passive self-defense capabilities might be made based on an evolving carrier concept of operations. Preventing attacks or modifying CSG operations, as opposed to providing terminal defense, might be operationally effective and less costly in the future.

In the CVN 8X concept variant, some cost savings might come from modifying the current Ford-class A1B reactor engineering plant. Current plans for the *Ford*-class carrier are based on two approximately 25-year reactor cores with a total 50-year ship service life per pair.5 Replacing the cores with a single pair of 40-year (or longer) life-of-theship reactor cores that would not require the refueling portion of the RCOH at mid-life might be one approach to realize life-cycle savings while retaining the Ford-class program and capabilities. Although the current refueling work scope is not the dominant factor in the RCOH cost and not a critical path in the RCOH schedule, eliminating the RCOH will increase its operational flexibility across its service life. A 40-year reactor for aircraft carriers has not been developed, so additional research and development will be required to develop this life expectancy for a core reactor, but we explored this concept variant to examine whether such an approach might be a pathway to explore toward a lower-cost Ford-class variant.

Because the CVN 8X *Ford*-class excursion concept is essentially identical to the *Ford* class in many capability aspects, we do not separately compare its capability with the POR or the other variants. Even with this variant three–EMALS catapult configuration, it will have greater capacity for aircraft sortie generation than the *Nimitz* class but less than the *Ford* class. It would have the same increased *Nimitz*-class magazine as the initial *Ford*-class ships and could operate independently in scenarios in all the places a *Ford* class can.

 $^{^5~}$ A 25-year reactor is a reactor (or, more accurately, core) designed to last 25 years.

CVN LX

Although it is significantly smaller in tonnage than a Ford-class carrier, this concept variant is still a large-deck aircraft carrier designenvisioned at 70,000 tons and roughly the size and standard displacement of the Forrestal-class carriers. The place this concept variant serves in the study is to examine one possible concept that would house the modern air wing and provide a warfighting capability that had been demonstrated previously. The Forrestal-class carriers were the first "super carriers" and ushered in the ultralarge-carrier design to the Navy. The hull form was approximately 50 ft. shorter at the waterline than the Ford class, and the beam at the waterline was modestly shorter, approximately 5 ft., but the Forrestal-class carriers were capable and proven in service of supporting a large, integrated air wing and capable of providing sufficient aircraft and ordnance to service targets in warfighting scenarios. However, for a variety of reasons, the CVN LX, which would have an improved flight-deck layout, would not have the same sortie generation capability of either the Nimitz or the Ford class. For purposes of operational impact comparison, we conservatively assume a sustained sortie generation capability of 80 per day, half of a Ford-class carrier and consistent with observed sortie generation seen on similar-sized ships in actual high-tempo combat operations.⁶ The CVN LX design might have weapon magazine and passive survivability capabilities near equivalent to the Nimitz-class carriers, but these requirements can present trade-offs for cost reduction.

The CVN LX concept ship, and any new carrier concept pursued, would possess an improved flight-deck design, leveraging, to some extent, analysis done for *Ford*-class development on aircraft elevators, aircraft spots, refueling, and rearming concepts. The flight deck would have improved weapon-elevator arrangements from the *Forrestal* class and likely three deck-edge elevators, arrangements, shape, and design also leveraged from the *Ford* class. Analysis for such a concept ship

⁶ GAO, Navy Aircraft Carriers: Cost-Effectiveness of Conventionally and Nuclear-Powered Carriers—Report to Congressional Requesters, Washington, D.C., GAO/NSIAD-98-1, August 27, 1998.

might include a smaller island in a new deck arrangement, such as that adapted for *Ford*, to increase flight-deck aircraft spots.

Most of the cost savings for this alternative are derived from the aforementioned reduction in overall displacement and in eliminating one of the *Ford*'s two nuclear reactor power plants. For power generation, this concept variant, as envisioned, possesses a single, current A1B reactor plant, along with an arrangement of six *Ford*-class main turbine generators (MTGs). In a hybrid configuration, the concept variant was modeled to also include, notionally, four USS *Zumwalt* (DDG 1000) 35-megawatt gas turbine generator (GTG) sets that would be positioned above the ship's hangar-deck level, similarly to the GTG sets arranged on the United Kingdom's HMS *Queen Elizabeth*–class carrier (as an example), an approximately 70,000-ton carrier to be delivered in 2017. Note that the *Queen Elizabeth* class is a hybrid diesel and gas turbine plant, which presents different challenges from those presented by a hybrid nuclear–diesel engine variant.

The CVN LX concept variant examined in this study would be an integrated propulsion system (IPS) design whereby high-voltage electrical power is generated and provided to large motors driving the ship propellers and all other systems, such as in the DDG 1000-class ships. Such IPS shipboard design schemes have been used increasingly with examples from the U.S. Navy and other naval forces worldwide. For the concept variant CVN LX, we assumed four DDG 1000-class main propulsion motors7 for commonality with the IPS plant already in use on the Navy DDG 1000, generating approximately 200,000shaft horsepower. These specific plant characteristics are notional, and specific design characteristics would require the Navy to conduct a full engineering Navy concept design study in conjunction with the shipbuilder. However, such an IPS, single-reactor hybrid configuration could reduce weight, increase design arrangement flexibility, provide a less complex and maintenance-intensive engineering plant, and reduce construction cost. There would be substantial NRE costs associated with updating the whole-ship arrangements for the legacy hull form.

⁷ And associated IPS electrical equipment (e.g., motor drives).

This proposed power generation concept could result in design challenges and trade-offs driven by ship arrangements and would require formal engineering study by the Navy. There are a variety of ways a new carrier concept variant of this size could be powered, and the ultimate decision would require detailed engineering study beyond the conceptual description presented here. Working in conjunction with the Navy, and for a variety of reasons, we reviewed and examined a concept variant with nuclear propulsion. First, to retain the current or near-current power levels generated by large U.S. carriers, including the power levels in this concept variant CVN LX, a non-nuclear design was deemed unlikely to be successful. To replace the entire power generation level considered for CVN LX with an all-gas turbine plant, for example, would likely present an unachievable and unsuccessful design and arrangement pathway and was not considered feasible. The retention of the single-A1B reactor plant and up to six Ford-class MTGs provides a substantial baseline of power, with necessary weight low in the ship with the inherent endurance benefits of the legacy A1B reactor plant and nuclear power. Availability of the Ford-class A1B reactor plant and main turbine generators, as well as the inherent advantages of nuclear power, are key enablers of this concept variant. It is important to bear in mind the developmental timelines of any change to a new large carrier design. In the case of a transition to a concept variant, such as CVN LX, there would be significant NRE and an expansive acquisition timeline. Figure 3.1 shows a likely minimum, required timeline and NRE scope in man-hours for transitioning to a CVN LX concept variant ship with a large three-phase design effort of concept design, arrangements and detailed design overlaid on the current CVN 81 funding profile. In this illustration, a CVN LX or similar-scope redesigned carrier replacement for the CVN 81 would be impractical, and any transition point, if determined to be feasible and acceptable, would be in the CVN 82 POR time frame.





RAND RR2006-3.1

CV LX

This 40,000-ton ship is a STOVL variant based on the LHA 6 class but modified for a larger flight deck and increased fuel and aviation ordnance. In its 2012 LHA flight study, NAVSEA examined the concept in some detail.⁸ The concept variant "full" included an 8-ft. increase in the beam at the waterline of the hull form to enable increased fuel and ordnance design accommodations. Such an increase would add hangar-bay and flight-deck size also permitting either additional aircraft spots or other capability that would require Navy analysis. The CV LX concept variant would notionally carry 25 F-35Bs and was assumed to generate 50 to 55 strike aircraft sorties per day, but this variant would not be able to support the Navy's AEW or EA aircraft currently in the POR. Consequently, it could not carry an integrated

⁸ NAVSEA, *LHA Flight 1 Study Report*, U.S. Department of the Navy, May 2012.

air wing and would thus require support from either a legacy carrier or land-based joint assets. It can operate in areas where air defense threats are not significant or in company with a battle force. The CV LX is not the capability of choice as a first on-scene responder because it lacks an integrated air wing and, in particular, lacks AEW and EA.

The ship would have fossil fuel propulsion and be capable of speeds up to 22 knots. There would be some development cost associated with modifying the ship design, and, because this would multiply the number of conventionally powered ships, there would be impact on the combat logistics force. If we assume that the total amount of TACAIR required for the most-stressing operational campaigns will not diminish, more of these platforms would need to be built to provide the same capability as ships in the current POR. It would not replace the legacy force on a one-to-one basis.

Even with drawbacks, this platform would nevertheless be capable of responding to many day-to-day contingencies that do not require all the capabilities inherent in a larger aircraft carrier with an integrated air wing. If these contingencies are considered to be the most-likely requirements for CSGs, CV LX can be purchased at lower cost and, as a result, in greater quantity than its larger counterparts. However, although this variant could be used in major contingencies with external support, this would require a considerable change in the Navy's warfighting concept of operations.

CV EX

The CV EX variant would be a 20,000-ton (or more) STOVL carrier with six to ten STOVL aircraft generating 15 to 20 daily sorties. An example of a representative platform could be the Italian aircraft carrier, *Cavour*, although a U.S. Navy–developed ship would almost certainly be of greater displacement because of Navy shock requirements and other design and survivability features. The CV EX has all the limitations of the CV LX with a much smaller flight deck, fuel, and magazine capacity and would therefore have to be used either as a responder to low-level contingencies or in conjunction with a legacy CVN. It could contribute to fleet dispersion schemes, and we discuss some potential mitigation options. However, there is little value in comparing it directly with legacy forces for performance in approved scenarios, and it would likely not be a direct substitute for aircraft carrier acquisition because of these significant limitations.

Comparisons

The relevant points of comparison between these variants are how the different characteristics and capabilities affect operational impact and cost. However, it is important to understand that head-to-head comparisons between ships are often not meaningful for a variety of reasons. First, legacy and new ships will operate in the fleet together, and their combined operational effectiveness will vary as the number of new ships increases over time. Second, some of the alternatives would require significant changes in the way the Navy would fight wars. So, although we provide some direct comparison, we emphasize that proposed capability needs to be considered in the context of overall fleet architecture, not for individual ships in isolation.

Table 3.1 depicts the degree to which each of the variants discussed in this chapter meets the basic requirements.

This table summarizes the major characteristics and differences between the variants, which we have discussed as we considered the variants. None of these can be considered independently of the overall concept of operations for CSGs or overall fleet architecture. However, within these constraints, each of these brings different levels of capability. The *Ford* class brings a formidable level of high-end capability. A descoped *Ford* would have similar levels of capability but would not be in the fleet as long. CVN LX is a large and capable aircraft carrier, but there are capability trades that would impose risk on operations. The other variants would require major changes in fleet concepts of operations.

This report does not make recommendations on the selection of alternatives, the validity of particular requirements, or the viability of alternative concepts. Instead, our analysis focuses on the operational effects and the costs associated with each variant, as we discuss in Chapters Four and Five.

		Concept Variant				
Characteristic	CVN 80 Actual	CVN 8X	CVN LX	CV LX	CV EX	
Length, in feet	1,090	1,090	1,040	850	800	
Standard displacement, in long tons	100,000	100,000	70,000	40,000	20,000+	
Flight-deck maximum size, in feet	1,100 × 250	1,100 × 250	1,070 × 250	820 × 120	720 × 110	
Maximum speed, in knots	30+	30+	28	22	28	
Embarked aircraft	80	80	70–80	25–35	10	
SGR sustained per day	160	140–160	80	50-55	15–20	
Ship service life, in years	50 with RCOH	40 with EOH	50 with RCOH	35–40	30–35	

Table 3.1 Requirements and Variant Capabilities

SOURCES: For CVN 80, Jane's *Fighting Ships*; for the rest, authors' analysis. NOTE: EOH = engineered overhaul.

Assessing Operational Impact of Carrier Concept Variants

To assess the operational impact of the four carrier concept variants, we begin with a description of the attributes important to warfighting and then describe the capabilities and limitations of each variant. We show differences that could be expected in notional campaigns, although these are not tied directly to classified operational scenarios. The classified version of this report does describe impact on DPS campaigns in some detail.

Assessing Operational Impact

CSGs must be capable of supporting a joint campaign, and generally the preparation is for the most stressing campaign. Although this might not be the most likely, CSGs are unique in being mobile and deployed forces that might already be in the area of conflict. The CSG needs to arrive ready, even in what are expected to be normal peacetime circumstances, to face a more significant contingency. Indeed, CSGs have been among the first battle-ready units for contingencies ranging from Desert Storm to western Pacific shows of force to tsunami relief.¹

Guidance for what CSGs must perform comes from a METL, against which a CSG is assessed, trained, and equipped. The CSG METL is a compilation of the individual METLs of the units, although the command elements themselves also have METLs, primarily related

¹ This is not to imply that CSGs were the optimum force or the only force, just that, by design, they are intended to be ready to operate on short notice while deployed.

to ability to control and direct events. Because we are considering the carrier and alternatives, we concentrate on the CVN METL. This list contains both very broad and very specific guidance. Any of the proposed alternatives can carry out all these requirements to some degree. The differences are not in *whether* the requirements can be carried out, but *to what degree* and *in what manner*. To arrive at this, we have to look at more details concerning what CSGs—and their CVN elements—are expected to do. Appendix B contains the specifications of the CVN METL.

For the command elements, ships, and CVW to be considered ready to deploy, they undergo several weeks of advanced training intended first to train the units to operate together and then to face the challenge of operations in simulated combat environments, with actual units simulating an opposing force. This follows several weeks of integrated training, with exercises gaining in complexity and sophistication and degree of free versus scripted play.

By any account, these exercises are challenging and reflect the Navy's best assessment of both the specific tasks combatant commanders can expect and core functions that the Navy as a service feels important to enduring missions. These exercises can also function as tests for Navy capabilities. For example, a 1997 JTFEX included a fleet experiment intended to demonstrate the number of TACAIR sorties a CSG might be able to generate. This was of interest to both the Navy and combatant commanders.

Demonstrating Proficiency in Mission Before Deploying

Individual ships and the CVW must fulfill and maintain basic proficiency, material, and sustainment levels that are specific to the unit types. For the air wing, to a greater extent than for the ships, a portion of this relies on continued individual proficiency of personnel. The requirements for so many hours and so many kinds of landings and demonstrations of airmanship remain as long as the CVW is operating. Shipboard personnel do have individual training requirements, but basic readiness is measured mostly by what the ship does as a unit.

The Navy has used a variety of different schedule constructs to ensure that CSGs are ready to deploy—most recently, the optimized

fleet response plan (OFRP), begun in 2015. OFRP is a 36-month cycle intended to keep elements of the CSG together even through maintenance, basic phase training, and advanced training. Appendix B depicts the OFRP and shows the lines of effort and the expected time within each phase of the plan.

We consider these events because they represent currently what the Navy expects that CSGs must be capable of doing and can use them as a measure of whether the carrier variants analyzed can meet these requirements. CSGs are expected to arrive in theater with particular capabilities. The Navy devotes many months and millions of dollars to ensure that the force is capable of carrying out a set of tasks that will be assessed before the CSG is allowed to deploy. Although this assessment reflects more than just the physical capabilities of the ships and aircraft, the ships—including the carrier—and aircraft must be capable of performing in the scenarios these deployment preparation events specify.

Comparing the Variants

As we compare these variants, it is important to remember the long expected service life of the existing force. We posit that the POR force will be operated until reaching expected service life and that CVN 79 and CVN 80 will be constructed and delivered on schedule. The replacements we are considering will not begin reaching the fleet until the early 2040s, and the force will retain legacy capabilities past midcentury. However, there are capability consequences in selecting different variants, and these require examination. Regardless of overall battle force composition, individual CSGs will be on station as in-theater forces that might not have immediate access to other joint capabilities.

Sortie Generation Rate

We earlier discussed the various characteristics a carrier requires to support air wing and other CSG operations. All of these could be measured and compared separately. However, for a variety of reasons, the Navy elected to use SGR as a KPP for the *Ford*-class carrier, which,

in the operational requirements document for this class, is specified as the ability to generate 160 aircraft sorties per day on a sustained basis, with *sortie* defined as the launch and recovery of an aircraft flying in a 75-minute (1 + 15) operational cycle. The *Ford*-class operational requirements document makes the following statement concerning SGR as a KPP:

CVN 78 key performance parameter—sortie generation rate: Sustained sortie rate of 160/220 operational combat aircraft sorties/12 hours of launching sustained over 30 days – total cycle of 4200/5600. Surge sortie rate of 270/310 operational combat sorties generated during each successive 24-hour period of 4/6 consecutive days with designated 75 aircraft airwing.

Rationale for selection: Sortie generation is the defining measure of the supported combat power of an aircraft carrier. It is the measure that includes the ability to launch, recover, service, load, and prepare the aircraft in all ways for its succeeding mission. This includes requirements for both the flight deck systems attendant in aircraft operations and the sustainability requirements for magazine and fuel storage.²

The *Ford*-class carrier is thus very specifically designed to carry out high-tempo operations, with an assumption that missions will be relatively short (75 minutes). For the CVW to be using the sortie generation capability that CVN 78 provides, it would have to be flying short distances, staying on station for a limited time, then returning as more aircraft are launched to continue the mission. In some scenarios, this might be tactically valuable. For example, if the threat is a large formation of small boats that are closing on the CSG to attack, the ability to launch large numbers of aircraft quickly and maintain a steady operational tempo would be valuable, more valuable than the ability to put up a few aircraft with a large weapon load-out. High SGR is similarly valuable in cases that require attacking a large formation of

 $^{^2}$ U.S. Navy, 2004. *160/220* indicates 160 sustained daily SGR and 220 surge daily SGR. The 30-day reference is how long the pace has to be maintained. *4200/5600* indicates the total numbers of sorties under the sustained and surge conditions, respectively.

moving targets where the ability of manned aircraft to track, identify, and deliver precision weapons is particularly important.

Nimitz-class carriers were not designed with a specific sortie generation KPP. In fleet experiments in which sorties were intentionally kept short and conditions were optimized, a *Nimitz*-class carrier was capable of generating 197 sorties per day in a four-day period and could surge to levels much beyond that.³ This demonstrated that the ship could support this amount of movement on its decks and that a heavily augmented air wing could fly this number of missions. Since this experiment, which the Navy acknowledges is an experiment under ideal conditions, a 120-per-day sustained SGR has been the posited capability for the *Nimitz* class. This has not been codified as a requirement and is not directly related to observed operational performance but is instead an observation of what the *Nimitz* class and an air wing ought to be able to do based on the results of a Fleet Battle Experiment.

However, this SGR level has never been attempted in real-world operations, nor has it been required. In a conflict that involved a sustained air campaign over a period of several weeks in an at least partially contested air environment, Operation Desert Storm, SGRs for U.S. carriers—including the *Nimitz*-class CVN 71—were higher than in Operation Iraqi Freedom. Table 4.1, from a 1998 U.S. General Accounting Office (GAO) report, shows the comparison of SGRs.

Some of the differences among the carrier SGRs can be attributed to stationing: *Saratoga* and *Kennedy* were stationed in the Red Sea, while *Midway*, *Ranger*, *America*, and *Theodore Roosevelt* were in the Arabian Gulf with shorter flight times and resulting shorter cycles. But, a more fundamental point is that no carrier was required to generate 120 sorties each day, and those that came closest were those whose CVWs had the least distance to fly.

The total number of U.S. Navy sorties in the invasion phase of Operation Iraqi Freedom was 8,945 across a 30-day period from five

³ Angelyn Jewell, Maureen A. Wigge, Colleen M. Gagnon, Lawrence A. Lynn, and Kevin M. Kirk, USS Nimitz and Carrier Airwing Nine Surge Demonstration, Alexandria, Va.: Center for Naval Analyses, April 1998.

Measure	CV 41	CV 60	CV 61	CV 66	CV 67	CVN 71
Total sorties	3,019	2,374	3,329	2,672	2,574	4,149
Aircraft assigned	56	72	62	73	78	78
Operating days	34	33	38	31	31	39
Average sorties per operating day	88.8	71.9	87.6	86.2	83.0	106.4

Table 4.1Operation Desert Storm Carrier Sortie Generation Rates

SOURCE: GAO, 1998.

NOTE: CV 41 = USS *Midway*. CV 60 = USS *Saratoga*. CV 61 = USS *Ranger*. CV 66 = USS *America*. CV 67 = USS *John F. Kennedy*.

aircraft carriers.⁴ Just using an average sortie count for the whole force (60 per day per carrier) could be misleading. All five CVWs were not flying the same number of sorties every day, with staggered flying days, and consequently allowing periods during which CVWs might be flying large numbers of sorties while other CVWs were off-line. However, in any interpretation, this is a low SGR for the capabilities present. Part of this is likely due to the overall intensity of the campaign, the ready availability of land-based aircraft, and the rapidly moving characteristics of the overall campaign. U.S. ground maneuver units were relying on rapid movement and might have benefited more from aircraft loitering for immediate response than from aircraft rapidly ferrying ordnance from a ship or base to the battlefield. Location of supported units, precision in weapon delivery, and exploitation of air superiority were more-important values than rapid ability to deliver a high volume of ordnance. The low SGR relative to capability emphatically does not mean that sea-based TACAIR did not play a valuable role. It does suggest, however, that whatever capabilities these assets brought, high SGR was not one of the more important.

⁴ U.S. Air Forces Central Command, Analysis and Assessment Division, *Operation IRAQI FREEDOM: By the Numbers*, April 30, 2003.

If we look to the even more-recent training and operational record, deploying carriers are not expected to generate more than 110 sorties a day, even in JTFEXs emphasizing high-end combat. Following is an example of a typical scenario from the *Enterprise* CSG's last deployment:

USS ENTERPRISE, At Sea (NNS [Newport News Shipbuilding])—The Enterprise Carrier Strike Group (CSG) completed its Joint Task Force Exercise (JTFEX) Dec. 12, marking the final step in the carrier's preparation for its upcoming 21st deployment.

The culmination of months of training, the exercise presented scenarios and situations the strike group crew may face while deployed.

On this last day of the scenario, Carrier Air Wing (CVW) 1 and USS Enterprise (CVN 65) launched 31 aircraft in 36 minutes and, within one hour, had 41 of the air wing's 54 aircraft airborne in support of two massive air strikes for a total of 106 sorties in one day.

"This was the biggest strike, under the worst conditions, against the most simultaneous targets that this air wing has ever accomplished, and it was all organic to Big 'E' (Enterprise) with no outside force support," said Capt. Kenneth Whitesell, commander of CVW $1.^5$

In an even more recent example from the *Harry S. Truman* CSG deployment in 2015–2016, the primary combatant command requirement was presence, with U.S. Central Command requesting continuous presence, resulting in extension of the *Eisenhower* CSG pending the *Truman*'s completion of work-ups. When on station, the *Truman*'s deployment went on for nine months, one month past the original schedule. But this deployment, although eventful in terms of opera-

⁵ Alex R. Forster, "Enterprise Carrier Strike Group Completes JTFEX," U.S. Navy, December 13, 2010.

tions, did not involve the CSG full METL. Operations included disaggregated operations, strikes against the Islamic State of Iraq and Syria from both the 5th and 6th Fleet areas of responsibility. These involved 1,407 combat sorties across the entire nine-month deployment, involving delivery of 1,118 precision-guided munitions. These were longrange sorties flown from the Mediterranean or Arabian Gulf and did not greatly tax sortie generation capabilities. In addition, the CSG conducted individual rescue operations and normal periodic training events.⁶

Although there are operational circumstances in which the ability to generate large numbers of sorties rapidly would be important, for the most-stressing scenarios, this will likely not be the case. The most-stressing scenarios-those involving a near peer with significant defensive capabilities—will likely not allow the CSG to close the target area until after significant suppression of the enemy's air defense and countermaritime capabilities have been diminished. Even if we could assume that the stealth characteristics of fifth-generation aircraft are such that they could penetrate defended airspace, they would not be launched close enough to allow a 1 + 15 cycle. As distances increase, the significance of high SGR diminishes. Moreover, it is not the case that SGR diminishes proportionately between ships that have greater and lower SGRs. A ship that can launch 160 sorties with 1 + 15 cycle times will launch only half that amount if the cycle time is doubled; the constraints are in the number of aircraft and the distance they have to travel, not in the rate at which the aircraft are launched and recovered. There is no operational advantage in this particular circumstance over the carrier whose maximum SGR is 80.

At this point, it is not the ship's characteristics that limit SGR but the distance and time the aircraft are required to fly to complete a cycle. If every mission required a longer cycle time to complete, there would never be an advantage to faster sortie generation. As we have noted, there are likely to remain missions flown at short distances for which higher-volume sortie generation will be desirable. But these do

⁶ Anthony Flynn, "Setting the Bar: Truman Drops Record Number [sic] of Ordnance," America's Navy, Story NNS160418-13, April 18, 2016.

not seem prevalent enough to warrant making SGR the sole operational performance KPP. Although there is no penalty for being capable of a high SGR when it is not needed and it might be of considerable value in certain operational environments, designing a carrier with this as a principal and overarching characteristic is seeking a capability that is highly relevant in only a very narrow set of circumstances.

SGR would be one of the capabilities diminished under all the variants being considered. CVN LX has a smaller flight deck, fewer catapults, and less flexibility in handling arrangements than CVN 78. It is comparable, however, to older conventional carriers in size and, conservatively, would have an SGR comparable to that of the *Midway* class. The CVN LX variant would still have access to CVN 78's capability enhancements. Part of what enhances CVN 78's SGR capability could be incorporated into any large aircraft carrier—elevators and magazine arrangements, electromagnetic-assisted launch systems, and advanced arresting gear. These systems have been developed, and there would be, at best, limited savings in returning to legacy systems, and possibly even additional cost to regenerate systems that are already out of production.

SGRs of CV LX and CV EX are significantly lower because of the size of the platform, the number of strike aircraft, and the inherent delays of STOVL launch and recovery. Because these vessels would be smaller and less expensive per ship than CVN 78, we could plausibly purchase more of these to host an equivalent number of TACAIR, albeit with a diminished SGR because of flight-deck size and the inefficiencies of STOVL compared with fixed-wing operations.

Ability to Support an Integrated Air Wing

Historically, the U.S. Navy has operated different classes of aircraft carrier with different characteristics. Escort carriers, "jeep" carriers, and attack carriers all had contributing roles but were understood to be different, primarily in the number and types of aircraft that could be supported. However, since the 1970s, the Navy has exclusively designed and procured carriers that support the operations of an air wing that can operate in the full spectrum of conflict with a high degree of autonomy. When a CSG arrives on scene, it has the capability

not only to fly strike sorties but also to provide integrated air defense, EA, joint C2, and battle-space dominance. Amphibious assault ships with embarked Marine Corps air combat elements do not provide, and are not intended to provide, this kind of capability.

Considering the concept variants, CVN LX would not relinquish this type of capability. The ship is large enough to host a squadron of E-2 aircraft to provide AEW and airborne C2. It has catapults and arresting gear to support both the E-2 and the EA-18G that is currently the only aircraft in the entire joint force capable of performing EA. These missions are long duration and not affected by limited SGR. Limited SGR could affect DCA missions in particularly intense air defense environments in which defensive aircraft rapidly expend air munitions and then need recovery to rearm. In such a case, air defense aircraft would need to continuously fill stations and would thus be launched and recovered at a rapid rate. The number of available and armed strike aircraft ready to launch should be sufficient to preclude empty DCA stations. However, the ability to flexibly arm and repurpose aircraft would be diminished by the need to keep most fighters armed for DCA and ready to launch. One important point concerning CVN LX is that it lacks the propulsion redundancy of the Ford class and has an estimated maximum speed of 28 knots, which might not be sufficient for aircraft recovery if the ship experiences a propulsionlimiting casualty in low-natural wind conditions.

Neither CV LX nor CV EX could support an integrated air wing. Both would be constrained to STOVL and rotary-wing aircraft, none of which can currently perform AEW or EA missions. DCA would be restricted to stations monitored by surface ships using air search radars, and the overall limited numbers of aircraft would make operations in an intense air defense environment untenable. These vessels would have to operate in company with a legacy CVN and air wing or depend on land-based forces to operate in anything but a low-threat environment.

Although no recent events have stressed the sortie generation capability of CVNs and CVWs, there have been operations in which lack of organic AEW would have been an issue. There are more areas of potential conflict lacking nearby facilities for secure basing of AEW assets than areas that possess them, particularly when such issues as basing rights are considered. Even if smaller carriers might be capable of meeting the sortie generation demands in some theaters, the inability to deliver an integrated air wing would continue to be a major limitation.

There might be value in combining CV LX or CV EX with legacy forces to improve dispersion and allow multi-axis approaches to targets or areas of interest. Networking could give these ships required cuing and situational awareness and allow positioning that gives a tactical advantage even in the absence of organic AEW. EA, moreover, is a capability that could be developed for other aircraft besides the EA-18G. However, these possibilities involve concepts of operation and capability development changes that the Navy has not yet been adopted. In the absence of such changes, CV LX and CV EX would have limited value in the most-stressing scenarios.

Logistics Supportability

For all these concept variants, aircraft operations impose logistics requirements, apart from those the ships themselves generate for fuel and stores. All of these would be capable of UNREP, and thus all would support a major advantage of sea-based TACAIR—the ability to be rearmed frequently and without a requirement to leave station.

However, there are significant advantages inherent to large, nuclear-powered vessels. The most obvious is that the ship itself does not require refueling. Although the air wing does, if the air wing is not flying, there is no continuing demand for an oiler to refuel the ship. CV LX and CV EX would require refueling regardless of how much or how little the embarked aircraft might be operating. A second is that CVN 78 has large magazines, fuel storage tanks, and general stores that allow it to operate for many days before it requires replenishment. If the CSG is on scene when a conflict breaks out, it will not be immediately hampered by lack of logistics support. The ship also benefits from economy of scale. Generally, it will be less expensive and more efficient to construct a single large magazine than multiple small ones on multiple ships.

However, economy and efficiency do need to be weighed against the advantages of dispersion. Having to find multiple smaller targets rather than a single large one complicates enemy targeting, imposing expense and risk. Conventionally powered ships can be designed with large fuel reserve capabilities for both ship and aircraft fuel to allow longer required periods between refueling. In addition, required replenishments would generally be shorter for smaller units, requiring less time alongside, a time when ships are particularly vulnerable.

Another aspect of logistics supportability is aircraft maintenance. Larger ships with larger repair shops and aviation stores capability will generally have an easier time maintaining an air wing with a large number of similar aircraft. Smaller ships will face issues ranging from space (which could be designed into the vessel) to sea state. The Navy would likely need to purchase more spare parts to support dispersed operations rather than depend on economy of scale and a reliable supply chain.

These factors are important to consider, but they do not appear definitive. The U.S. Navy routinely deploys ships to areas where logistics support is a challenge and has supported them with appropriate adjustment to concepts of operations and without major additions to force structure. All these vessels are conceptual, and, if the Navy chose to examine these concepts in detail, the formal concept engineering analysis could incorporate the larger tanks, shops, storerooms, and magazines.

Survivability

The *Ford* class (and CVN 8X concept variant) is designed with significant passive protection that enables operation in some contested environments. CVN LX is envisioned with less of such protection, and this would be considered an operational trade-off. The classified version of this report considers some of these possibilities. There are also differences in speed and redundancy that would need consideration as the Navy considers alternatives. Of note is the fact that no aircraft carrier could be expected to operate unescorted in the most-stressing scenarios, and the capabilities of the CVW and escorts might be more important than the specific features of the aircraft carrier itself. The ability to support a full-capability, integrated air wing, in fact, becomes a major component of survivability. Part of the concept for survivability for any smaller aircraft carriers requires reliance on alternative models for ship positioning during combat operations, apportionment of the overall sea-based aviation capability, and a larger and more dispersed fleet. However, such ships will be smaller, less able to absorb damage, and unable to support the type of aircraft that can assist with CSG defense.

Variant Operational Impact Comparison

Table 4.2 summarizes operational impacts. This is meant as a broad comparison. Specific capability differences would require detailed engineering and threat assessment. The broad outlines suggest that CVN 8X could be introduced with minimal operational impact. CVN LX would impose trade-offs that appear consistent with current warfighting concepts of operation but would require a thorough consideration of risks and impacts. CV LX—and CV EX, to an even greater degree—would require major changes in fleet operations.

Measure	CVN 8X	CVN LX	CV LX
SGR	Comparable to <i>Ford</i> ; greater than <i>Nimitz</i>	Comparable to <i>Midway</i> class; sufficient for longer sorties	Vertical or short takeoff and landing strike and DCA only; sufficient only in combination with other platforms
Integrated wing	Fully supports all elements of the joint campaign	Supports AEW and EA	Relies on external support for key missions
Logistics support	At-sea refueling and rearming for CVW	Smaller magazines; might require more- frequent refueling	Will require refueling and rearming in dispersed locations
Survivability	Enhanced passive survivability	Relies on CVW and escorts	Relies on dispersion and numbers

Table 4.2 Comparison of Variant Operational Impacts

SOURCE: Authors' analysis.

Operational Impact Conclusions

Ford is an extremely capable platform, bringing unmatched warfighting capability in a variety of scenarios. It has more SGR capability than what is required for the long-distance sorties likely in the moststressing, enduring future scenarios for the prescribed Navy missions in these scenarios, and it certainly brings more than what has recently been imposed by real-world events. But its size, sustainability, and flexibility are important warfighting features and are not to be discounted in the unknown range of scenarios and future threat–driven changes.

A modestly smaller platform, such as CVN LX, can provide an integrated air wing and generate numbers of sorties consistent with real-world environments and operate inside the envelope of a CSG. However, there are risks and trade-offs that Navy would have to evaluate in the drive to reduce procurement cost.

The smaller variants can generate strikes and operate in low-threat environments. These platforms provide important sea-based aviation capability to augment the current force, but the degree to which this would replace current carrier capability is not clear. For example, increased platforms in a CV LX–type concept variant examined might be desirable and valuable across a range of missions, but reduction in current carrier plans do not necessarily result. In higher threats, they would have to rely on dispersion and the protective umbrella of morecapable units. It is worth noting that the timeline for these arriving in service is still decades away, and it is very likely that threats and capabilities will evolve during that time. Any of these paths could be feasible assuming changes in air wing or escort mix.
Chapters Three and Four illustrated the changes in overall capability that result from introducing new carrier variants into the force—both in the near and medium terms, when legacy systems and new carrier variants would coexist in a hybrid force, and in the longer term, when only new variants would be operational. These findings then set up two questions: What would be a feasible ship procurement cost reduction—shipbuilding and conversion, Navy (SCN) cost inclusive of required NRE—for the variants, and how much could the Navy save by replacing legacy ships with one of the four new variants? Are these savings worth the risk in terms of capability degradation? In this chapter, we consider the cost comparisons between the legacy force and possible alternatives. We emphasize that these costs are presented as broad assessments to allow consideration of acquisition options. These should not be considered budget-level cost estimation.

CVN 8X

We examine first, in Table 5.1, CVN 80 base costs for the *Ford*class POR and rough comparative costs of the first concept variant, CVN 8X. The variant is derived from the *Ford*-class carrier, would use the same hull form, and would have essentially the same capability as existing carriers. Program savings would result from removing one catapult and eliminating mid-life refueling costs by using two life-ofthe-ship reactors with an assumed 40-year service life. This approach has the advantage of commonality with an already-programmed force;

Cost Type	CVN 80	CVN 8X
Procurement		
Procurement SCN base (CVN 80 PB 2017)	12,900	12,900
Fourth-ship construction learning ^a	n/a	-160
Reduction to three EMALS catapults	n/a	-160
Subtotal	12,900	12,580
NRE		
Reduction to three EMALS catapults (applies to the lead ship)	n/a	12
Life-of-the-ship core design effort (applies to the lead ship)	n/a	500
Total cost for the lead ship	n/a	18,052
Total recurring ship cost (total cost for the lead ship minus NRE)	18,460	17,540
Other—RCOH or descoping to EOH (per ship)	5,560	4,960
Comparative platform cost per ship (difference between total recurring ship costs)		-920

Table 5.1 CVN 8X Shipbuilding and Conversion Costs, in Millions of Fiscal Year 2018 Dollars

SOURCES: Component cost, learning EMALS NRE, and platform costs are from NAVSEA, data provided to the authors, 2016, not available to the general public, and PMS 379 CVN 79/80 Program Manager, Program Executive Office, Aircraft Carriers, data provided to the authors, 2016, not available to the general public. RCOH reduction estimates are from Navy Program Office data showing that 10.8 percent (\$600 million) of RCOH costs are related to refueling.

NOTES: PB = president's budget. n/a = not applicable. The analysis apportions all NRE costs on the lead ship. NRE costs for the life-of-the-ship core assume learning from *Ohio* replacement program research, development, test, and engineering and a notional overall \$500 million remaining requirement.

^a The fourth-ship construction learning also reduces man-hours by 1.6 million. Although CVN 8X is not identical to the baseline CVN 78–class design, the design similarities make some amount of construction learning likely. the ability to retain learning; and the possible avoidance of large, nearterm NRE costs that would be associated with a new design.

However, over time, the direct savings might be modest. Nuclear refueling costs in the current *Nimitz* RCOH amounts to only 11 percent of total RCOH availability cost. This reduction of the nuclear RCOH costs for the life-of-the-ship core in the CVN 8X concept variant and the removal of the fourth EMALS catapult for the three-catapult design might result in a total per-ship cost savings of \$920 million in FY 2018 dollars. However, the shorter service of this variant life pulls mid-life overhaul earlier and reduces the number of years over which the cost would be amortized. Thus, the 40-year, life-of-the-core reactor does not appear to offer significant long-term cost benefit when these factors and the NRE investment are considered.

From the perspective of operational availability, removing refueling might somewhat reduce the time required in complex overhaul (currently 44 months for an RCOH) and provide some operational flexibility on scheduling of the complex overhaul. It will also provide more flexibility for start date because there will not be a point during the ship's service life at which it will run out of fuel. However, the additional operational flexibility these factors might offer would have to be weighed against budgetary and industrial base constraints of moving the schedule. Hence, the overall degree of flexibility actually offered might be somewhat limited.

CVN LX

As described earlier in the report, the CVN LX concept variant is a design for a 70,000-ton ship, with 26- to 28-knot maximum ship speed, an updated flight deck, aircraft and weapon elevators, and island arrangements leveraging improvements in the *Ford* class to optimize sortie generation. It has a single *Ford*-class reactor and a hybrid IPS scheme, which could, notionally, be powered by six *Ford*-class main turbine generators and three DDG 1000–class GTGs for all power generation. Such an arrangement with a *Forrestal* hull form and other trade-offs in fuel and survivability from *Ford* levels might allow for a weight reduction of approximately 30,000 tons from the *Ford* class.

Although some elements of the *Ford*-class design product model and design learning might be used in the new CVN LX variant design, an NRE investment for a new carrier design, including a modified *Forrestal* hull form and complete ship arrangement changes, would be required. The Navy collaborated with RAND and provided an estimate that the NRE required would be 25 million man-hours of shipbuilder design effort for hull-form and general arrangements and 20 million hours of propulsion plant design. They estimated \$1 billion for government modeling of general ship, flight-deck, and propulsion characteristics. A reasonable NRE for CVN LX is thus approximately \$4.9 billion (in FY 2018 dollars), resources that would have to be expended in the near term to meet projected delivery dates.

Once the NRE investment is made, however, follow-on shipbuilding costs are significantly lower than for the *Ford* class—a reduction of nearly \$5.0 billion per hull based on a ship with less weight using NAVSEA's weight-based cost estimation relationship¹ and component government-furnished equipment costs, which would yield substantial savings over time. Table 5.2 depicts the long-term savings.

There is risk for cost growth in the lead ship because the platform would be a new design. However, the majority of the systems on this ship are not radically new or expected to carry an excessive level of technical or program risk.

¹ The weight-based cost estimation relationship used here roughly estimates costs per ton using averaged propulsion and nonpropulsion plant component and system weights and costs.

Cost Type	CVN 80	CVN LX						
Procurement								
Procurement SCN base (CVN 80 PB 2017)	12,900	12,900						
Weight-based construction cost estimate for 25,000–long ton reduction	n/a	-2,370						
Propulsion plant component reductions (main reduction gear, main engine)	n/a	-170						
Propulsion plant component additions (+ two MTGs, + three GTGs, + four main propulsion motors)	n/a	235						
Reduction to a single-A1B plant	n/a	-1,040						
Reduction to three EMALS catapults	n/a	-160						
Subtotal	12,900	9,395						
NRE								
Government design effort (applies to the lead ship)	n/a	1,000						
25 million man-hours for ship, hull-form, and general arrangement design and 20 million man-hours propulsion plant design effort (applies to the lead ship)	n/a	3,900						
Other—RCOH	5,560	4,170						
Total cost for the lead ship		18,465						
Total recurring ship cost	18,460	13,565						
Comparative platform cost per ship (difference between total recurring ship costs)		-4,895						

Table 5.2 CVN LX (Shipbuilding and Conversion, Navy) Costs, in Millions of Fiscal Year 2018 Dollars

SOURCES: Component cost, learning EMALS NRE, and platform costs are from NAVSEA, 2016, and PMS 379 CVN 79/80 Program Manager, 2016. Reduction to a single A1B cost estimate is from Navy Program Office data showing one CVN 78 propulsion plant ship-set cost.

NOTE: Life-of-the-ship core is not assumed for the CVN LX variant.

CV LX

Moving on to the first conventionally powered variant, CV LX, the construction and NRE costs are considerably lower than for the *Ford* class, as detailed in Table 5.3. However, the CV LX would not replace the *Ford*-class carriers one for one. Assuming that the sea-based TACAIR

Table 5.3	
Comparison of CV LX Shipbuilding and Conversion Costs, in Millions	of
Fiscal Year 2018 Dollars	

Cost Type	CVN 80	CV LX						
Procurement								
Procurement SCN base (CVN 80 PB 2017)	12,900	n/a						
Concept variant based on LHA flight 1 2012 study "full" with 8-ft. beam increase	n/a	4,200						
Subtotal	12,900	4,200						
NRE								
"Full" hull-form and other general arrangement (applies to the lead ship)	n/a	464						
Other—RCOH or descoping to EOH (per ship)	5,560	n/a						
Total cost for the lead ship (total procurement cost plus NRE plus other costs [RCOH or descoping to EOH, per ship])	n/a	4,664						
Total recurring ship cost	18,460	4,200						
Total recurring platform cost per carrier replacement ^a		8,400						
Comparative platform cost per carrier replacement (total recurring platform cost per carrier replacement minus total recurring ship cost)		-10,060						

SOURCE: NAVSEA, 2016.

NOTE: Total recurring platform cost per carrier replacement assumes a 2.0 replacement factor of CV LX per CVN 78 base design to support total TACAIR aircraft requirements. In the platform cost comparison, we do not account for aircraft or other non-SCN costs associated with displacement of non-STOVL aircraft and missions. The costs also do not include the annual cost of fuel or possibly required additional combat logistics force structure.

^a There is an assumption that two of these variants would need to be built to replace one POR carrier.

requirement for contingencies does not change but is only distributed differently across platforms, the Navy would need to deliver additional support platforms. The cost comparison shows a reduction in per-ship cost of \$10 billion per hull, with minimal NRE expenditure. However, this reflects just single-ship replacement, not the total cost of the required force structure in which two ships will be needed to replace one. The long-range cost summary will show the complete cost when we apply the two-to-one ship replacement requirement.

Adoption of this platform would also affect the Department of the Navy aircraft procurement plan, requiring additional F-35Bs rather than F-35Cs, as well as requiring development of options for AEW and EA. Although it is likely significant, we do not include the impact on aviation procurement in this analysis.

CV EX

Table 5.4 illustrates comparative SCN costs for the CV EX 20,000-ton concept variant. CV EX requires an even greater adjustment to fleet operating concepts than CV LX does, making a direct comparison of cost even more problematic. CV EX would require changes to the aircraft procurement plan and additional replenishment and support capacity, the costs of which are both significant and difficult to calculate without additional detail on how exactly the Navy would use these platforms. The fleet requirements for a force with CV EX in the architecture have not been developed.

Table 5.4					
CV EX Shipbuilding and Conversion	Costs, in	Millions of	of Fiscal	Year 2	2018
Dollars					

Cost Type	CVN 80	CV EX						
Procurement								
Procurement SCN base (CVN 80 PB 2017)	12,900	n/a						
Concept variant based on LHA flight 1 2012 study "full"	n/a	4,200						
Weight-based reduction based on 20,000–long ton reduction from LHA 8	n/a	-1,700						
Subtotal	12,900	2,500						
NRE								
Hull-form and other general arrangement (applies to the lead ship)	n/a	1,500						
Other—RCOH or descoping to EOH (per ship)	5,560	n/a						
Total cost for the lead ship (total procurement cost plus NRE plus other costs [RCOH or descoping to EOH, per ship])	n/a	4,000						
Total recurring ship cost	18,460	2,500						
Comparative platform cost per carrier replacement (total recurring platform cost per carrier replacement minus total recurring ship cost)		n/a						

SOURCE: NAVSEA, 2016.

NOTE: There is no comparative way to assess CVN replacement comparative costs for the CV EX variant; this variant would likely not substitute in any numbers for current CVN POR replacement in the Navy's Long Range Shipbuilding Plan. Warfighting capability costs associated with production and utilization of this concept variant would involve SCN and aircraft procurement cost changes to a new, to-be-developed force structure plan that would likely also retain a continuing carrier and CVW force.

Long-Range Cost Summary

For any of these variants, it will be difficult to make a transition to a new carrier before the end of expected service life of CVN 71 in 2034, particularly if it involves the construction for a new platform, such as CVN LX. Given lead-time requirements for design and material procurement, even with an immediate budgetary start, a timeline allow-

ing delivery of a ship in 2034 is unlikely. Although the smaller variants will require less NRE, they would require a change in fleet concepts for operations and sustainment that might also include modification of sea-based aircraft or land-based aircraft concepts. Besides requiring additional aircraft carriers, the Navy would also need to purchase and deploy additional support ships. The speed at which these can be delivered would be limited by industrial capacity. For any variant, it is more realistic to aim for transition at the time of the retirement of CVN 72 in the late 2030s.

Table 5.5 provides one example of a cumulative long-term cost summary for the concept variants that might be constructed. It shows (1) the current *Ford*-class POR, adjusted to meet current law mandating an 11-carrier force structure; (2) CVN LX, also adjusted to an 11-carrier force structure; (3) the CV LX LHA- or multipurpose amphibious assault ship–derived STOVL-only variant adjusted for a 22-ship force structure. We omit CV EX as requiring a force structure so different that it makes comparison difficult, if not meaningless.

Assuming continued production of the *Ford* class, the 11-carrier force program costs approximately \$140 billion over the period depicted. The concept variant CVN 8X with one fewer catapult and 40-year life-of-the-ship reactor does not, in fact, reduce costs over the 40-year life of the ship when compared with the *Ford* and a 50-year service life. The CVN LX concept variant would produce a 23-percent reduction in cost across the life cycle. This is significant savings, which need to be weighed against potential loss of warfighting capability in speed and survivability. CV LX, even with a larger required force structure, does reduce platform cost. This would, however, have to be weighed against the likely costs of different sustainment requirements and changes in the aircraft procurement plan.

Ship	2023 (CVN 81 Procurement)	2027	2032 (CVN 81 Delivery)	2033	2036	2038	2040	2043
CVN 78 ^a	12.74	12.74		12.74		12.74		12.74
POR: 5 yea	r							
RCOH								
NRE								
Cumulative	5							
CVN 8X	12.58	12.58		12.58		12.58		12.58
5-year centers								
EOH								
NRE	0.512							
Cumulative	9							
CVN 78 ^{a, b}	12.74	12.74	12.74		12.74		12.74	
11 CVNs								
RCOH								
NRE								
Cumulative	5							
CVN 8X	12.58	12.58	12.58		12.58		12.58	
11 CVNs								
EOH								
NRE								
Cumulative	9							
CVN LX ^{b, c}	10.36	9.42		9.42		9.42		9.42
5-year centers								
RCOH								

Table 5.5 Long-Range Cost Comparison, in Billions of Dollars

Ship	2044	2048	2052	2053 (EOH)	2056	2058 (RCOH)	2060	2063	2064	Total
CVN 78 ^a		12.74		12.74		12.74		12.74		114.6
POR: 5 year										
RCOH						5.56		5.56		11.12
NRE										
Cumulative										125.7
CVN 8X		12.58		12.58		12.58		12.58		112.5
5-year centers										
EOH				4.96		4.96		4.96		14.88
NRE										0.512
Cumulative										127.9
CVN 78 ^{a, b}	12.74		12.74		12.74	5.56	12.74	5.56	12.74	127.4
11 CVNs										
RCOH										11.12
NRE										
Cumulative										138.52
CVN 8X	12.58		12.58	4.96	12.58	4.96	12.5	4.96	12.58	125.58
11 CVNs										
EOH										14,88
NRE										0.512
Cumulative										140.98
CVN LX ^{b, c}		9.42		9.42		9.42		9.42		85.72
5-year centers						4.17		4.17		
RCOH										8.34

Table 5.5—Continued

Shi	in	2023 (CVN 81 Procurement)	2027	2032 (CVN 81 Delivery)	2033	2036	2038	2040	2043
			2027	Delivery	2055	2050	2050	2040	2045
	NKE	4.9							
	Cumulative								
cv	N LX ^c	10.36	9.42	9.420		9.42		9.42	
	11 CVN LXs	;							
	RCOH								
	NRE	4.9							
	Cumulative	•							
cv	LX ^d	4.68	4.2	8.4	8.4	4.2	8.4	8.4	4.2
	22 CV LXs								
	NRE	0.464							
	Cumulative	2							

Table 5.5—Continued

SOURCES: NAVSEA, 2012; NAVSEA, 2016; PMS 379 CVN 79/80 Program Manager, 2016.

NOTE: Data show problems after CVN 80. POR data are for CVN 80 PB 2017. A 10-percent lead-ship construction cost penalty is applied to the CVN LX lead ship, with recurring costs thereafter.

^a RCOH or EOH starts from the 2032 planned CVN 81 delivery. RCOH occurs at 25 years. EOH occurs for CVN 8X at 20 years.

^b The current Navy shipbuilding report to Congress (Deputy Chief of Naval Operations for Integration of Capabilities and Resources, 2016) does not comply with an 11-carrier force; it drops to ten carriers in 2035 and after. The plans with 11 CVNs and 22 CV LXs illustrate POR costs with changes to ship construction centers to comply with current law.

 $^{\rm c}$ CV LX data reflect platform replacement at a factor of 2.0 times the current CVN inventory.

^d The CV EX concept is excluded.

Sh	ір	2044	2048	2052	2053 (EOH)	2056	2058 (RCOH)	2060	2063	2064	Total
	NRE										4.9
	Cumulative										98.96
C٧	'N LX ^c	9.42		9.42	9.42		4.17	9.42	4.17	9.42	95.14
	11 CVN LXs										
	RCOH										8.34
	NRE										4.9
	Cumulative										107.38
C٧	' LX ^d	8.4	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	92.8
	22 CV LXs										
	NRE										1.5
0	Cumulative										94.3

Table 5.5—Continued

SOURCES: NAVSEA, 2012; NAVSEA, 2016; PMS 379 CVN 79/80 Program Manager, 2016.

NOTE: Data show problems after CVN 80. POR data are for CVN 80 PB 2017. A 10-percent lead-ship construction cost penalty is applied to the CVN LX lead ship, with recurring costs thereafter.

^a RCOH or EOH starts from the 2032 planned CVN 81 delivery. RCOH occurs at 25 years. EOH occurs for CVN 8X at 20 years.

^b The current Navy shipbuilding report to Congress (Deputy Chief of Naval Operations for Integration of Capabilities and Resources, 2016) does not comply with an 11-carrier force; it drops to ten carriers in 2035 and after. The plans with 11 CVNs and 22 CV LXs illustrate POR costs with changes to ship construction centers to comply with current law.

 $^{\rm C}$ CV LX data reflect platform replacement at a factor of 2.0 times the current CVN inventory.

^d The CV EX concept is excluded.

CHAPTER SIX

Sea-based tactical aviation operating from aircraft carriers will contribute significantly, and perhaps increasingly, to the most-stressing warfighting scenarios far into the future. Although our analysis suggests that trade-offs might be possible in the aircraft sortie rate capacity between the Ford-class carrier and a lower-cost platform, neither this study nor the classified study looked at the impact of losing access to regional bases and, in particular, the impact this could have on the overall availability of land-based TACAIR in key conflict scenarios. This potential loss of capacity in the joint force is an important factor for Congress and the Department of Defense to consider before a tradeoff is made to give up the supported air wing sortie capacity in the overall sea-based force. The additional capacity margin of the Ford-class carrier might be used if added requirements or capacity are assigned to the sea base for the joint force in the future. Certainly, other factors and capabilities could be developed for strike capability in the joint force, but such capabilities and new platforms, weapons, or systems also come with a developmental and procurement cost.

However, if the risk in capability trade-offs for lower costs is acceptable to the department and Congress, there might be options for replacing the *Nimitz*-class carriers as these ships reach expected service life, replacements that have lower procurement costs than the *Ford*class carriers that are operationally sufficient in the Navy force structure for scenarios the Navy is likely to face in the next several decades. But these options are accompanied by risk issues in the trade-off for cost that would require additional analysis and, in most cases, detailed design study. Introducing a new, lower-cost, less capable carrier design might also require changes in the concept of operations to deliver the needed sea-based aircraft mission capabilities and volume resident in carriers in the fleet today.

If a new platform is introduced in the mid-2030s, the Navy's force structure would still contain a large legacy force of Nimitz- and Ford-class carriers, at least until the mid-2060 time frame. This enduring legacy force, combined, perhaps, with selected geographic basing of a new, less capable variant focused on preferentially aligning the legacy platforms to the more-stressing regional missions, might lower risk somewhat for a pathway to a less costly aircraft carrier force. The impact of introducing different variants might be manageable for some time if the fleet is operated with such a concept; however, any new variant will, over time, define the carrier force and sea-based aviation capacity and constitute the supported capability available to the Navy. Additional platforms in the force structure could be ordered to deal with projected capacity shortfalls but at additional cost. Last, if the Navy stops procuring large-deck nuclear carriers, the ability to reconstitute that industrial base later, if required, comes with substantial risk.

Going forward, further examination of the long-range fleet architecture for possible integration of the CV LX variant might be warranted. The Navy has conducted substantial work in future fleet architecture, and one challenge is to project such study environments forward into the time frames examined in this study. Such a platform, with the current and near-term additional new aircraft, might have substantial benefit for the Navy's global force management. Department of Defense examination of strike in the joint force projected, again, to the time frames examined in this study might be an important step to understand alternatives or shortfalls in strike driven by threat in the likely enduring scenarios. Such work is essential to understand the risks associated with a departure from the aircraft carrier POR.

Capability Conclusions for Concept Variants Examined

Focusing on warfighting capabilities of the concept variants examined, a lower-cost Ford-class carrier (CVN 8X) might offer an alternative with little diminishment in warfighting capability and retention of the overall POR. However, the study's excursion examining the business case for a life-of-the-ship reactor core, such as that now in the POR for all submarine classes, did not significantly lower cost. The Navy might want to consider Ford-class cost drivers that only marginally improve capability in light of the observation that, in general, the maximum SGR levels and survivability attributes might be more-viable trade-offs with the current concept of operations than that in effect when the initial KPPs were validated. It is likely, in any case, that Ford-class carriers in the POR will continue to evolve to reduce procurement cost to some extent with some risk-based capability trade-offs, and it might be technically feasible, at some point in the future, for a transition to an IPS, for example. The department and Congress might also move to acquire these carriers in increased orders of quantity to yield cost savings. But there is certainly a limit in the cost "floor" for the Ford-class carriers, and their warfighting capacity, as set in the initial requirements, comes with a cost.

One approach, such as the CVN LX concept variant, might offer significant procurement cost savings with an integrated, current air wing with capabilities near current levels but with less organic mission endurance for weapons and aviation fuel. It will not have the same SGR as the *Ford* class, but this might not be a significant limitation for many of the warfighting scenarios. It will be less survivable in some environments than the *Ford* POR ship, will have less redundancy than the *Ford* class, and will degrade in mission execution more rapidly with damage or loss of systems, and these factors might drive different operation concepts. The major means of reducing cost is through loss in engineering redundancy, speed, and air wing fuel capacity, and these trade-offs could affect mobility and theater closure.

The concept variant CV LX, which pursues a larger version of the LHA 6 platforms, might be a low-risk, alternative pathway for the Navy to reduce carrier costs if such a variant were procured in greater numbers, as presented in our analysis. Over the long term, however, as the current carrier force is retired, CV LX would not be a viable option as the eventual carrier force unless displaced capabilities were reassigned to new aircraft or platforms in the joint force, which would be costly. This platform would be feasible for a subset of carrier missions but, even for those missions, could require an increase in the number of platforms. This concept variant might, if procured in sufficient numbers, eventually enable the Navy to reduce the number of *Ford*-class carriers in the overall force structure, but more-extensive analysis of missions, operations, and basing of such a variant and the supported air combat element are required.

The smallest concept variants reviewed, the 20,000-ton sea-based platforms, do not provide either a significant capacity or an integrated air wing and, thus, force reliance on other legacy platforms or landbased assets to provide key elements of capability—in particular, AEW. As such, this concept variant is not really a replacement for current aircraft carrier capability to much degree and would require other platforms, aircraft, weapons, and capabilities in the joint force. These platforms would be a viable pathway only in broad fleet architecture transformation providing a narrow mission set perhaps regionally and would require extensive analysis. Given that such a concept variant is not a viable replacement of an aircraft carrier, such analysis would be required to see whether any adjustment of the current aircraft carrier program would be feasible.

A decision to use either of the smaller concept variants would require a revision of fleet concepts of operations, a refocusing of aircraft procurement to more STOVL strike fighters, and a larger force structure to keep the same number of aircraft in the stressing fights. Neither variant would be effective in warfighting scenarios if it is the first on scene before the arrival of units possessing AEW, airborne C2, and EA.

Cost Conclusions for Concept Variants Examined

If CVN 8X results in small impact on capability, it also might have only incremental reduction in overall platform cost. The analysis examining cost reduction with transition to a life-of-the-ship reactor, such as that being done on submarine programs, does not appear to be costeffective. Between the developmental costs and a reduced service life, there is little cost advantage in this variant. Forgoing the requirement for mid-life refueling work scope and some reduction in the mid-life modernization overhaul could add some operational flexibility, but the life-of-the-ship reactor path might not be beneficial from a business case perspective absent technical breakthroughs. We did not examine the technical aspect of such an approach.

The CVN LX concept would allow considerable savings across the ship's service life and appears to be a viable alternative to consider for further concept exploration. Construction costs would be lower; design changes and life-cycle costs would reflect the lessons already applied in the *Ford* class. The reliance on hybrid drive with fewer mechanical parts than legacy platforms is likely to further reduce maintenance costs. However, CVN LX would be a new design that would require a significant investment in NRE in the near term to allow timely delivery in the 2030s. The scope and resultant timeline for this concept variant development, if determined to be feasible and acceptable, would likely move any transition to the mid-2030s, where the USS *Ranger* (CVN 82) of the *Ford* class now resides. That said, over time, the cost savings accumulate, and such a transition might present an alternative pathway to lower procurement costs in the medium term.

CV LX, although it requires a larger force structure, might still reduce overall construction costs if large carrier numbers were reduced. But, as described previously, reducing carrier numbers with the resulting loss of capability should not be pursued without extensive further analysis for all displaced missions in the joint force execution of warfighting scenarios and, potentially, regional basing and narrowly focused missions for these platforms. Any cost savings from reduction in the aircraft carrier POR procurement would likely be offset to an unknown degree by a requirement for additional replenishment capacity; a shift in the procurement plan for strike fighters and other platforms; forward basing for these platforms; or the costs needed to develop or procure joint capability for displaced organic AEW, EA, and airborne C2 capability in the current CVW.

This appendix reproduces the forwarding letters from the U.S. Navy.

Figure A.1 Forwarding Letter to Rodney P. Frelinghuysen, Chair, U.S. House of Representatives Committee on Appropriations



DEPARTMENT OF THE NAVY SECRETARY OF THE NAVY (20350-1000) CHIEF OF NAVAL OPERATIONS (20350-2000) WASHINGTON DC

September 8, 2017

The Honorable Rodney P. Frelinghuysen Chairman, Committee on Appropriations House of Representatives Washington, DC 20515-6035

Dear Mr. Chairman:

As directed by the National Defense Authorization Act for Fiscal Year 2016, in July 2016 Navy submitted a classified report titled "Future Aircraft Carrier Options". The RAND Corporation conducted the study of potential alternatives for the development of future aircraft carriers that could replace or supplement the Ford-class aircraft carrier. This report is the unclassified version of the original report with the changes necessary to support the declassification. It is a high-level exploration of possible alternatives, not a detailed engineering study or requirements document. Similar to the classified report, Navy has identified issues with RAND's methodology and conclusions. Attached is the final unclassified report and NAVSEA 08-authored technical review of the CVN-LX variant.

RAND studied four notional aircraft carrier variants: 20,000, 40,000, 70,000 and 100,000+ tons displacement. In contrast to the classified report, these variants were assessed in the context of Joint Task Force Exercises and unclassified data from previous Carrier Strike Group deployments to evaluate the potential warfighting impacts. RAND also provided platform cost comparisons.

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Regarding the two larger variants (70,000 and 100,000+ tons), RAND focused on potential methods to reduce the cost of these variants through technological

Figure A.1—Continued

advancements and some reduction in capability. These proposed cost reductions, however, impact the capabilities Navy requires in its aircraft carriers for mission success. Navy concludes that 70,000 ton variant has numerous engineering challenges that question its feasibility. While a 70,000 ton variant could be designed, the RAND variant is neither feasible nor cost effective. This conclusion is based on detailed engineering examinations of multiple ship and propulsion configurations Navy has completed in the past, including as part of the CVX Analysis of Alternatives. The Navy can provide a synopsis of these studies if desired.

The Navy remains committed to studying the design of the next generation of nuclear-powered aircraft carrier while continuing to reduce the cost of the Ford-class program at every opportunity. A copy of this report has been sent to Chairmen Thornberry, Cochran, and McCain.

J. M. Richardson

Enclosures: As stated

Copy to: The Honorable Nita M. Lowey Ranking Member Sincerely,

V. Spencer

2

Figure A.2 Forwarding Letter to Thad Cochran, Chair, U.S. Senate Committee on Appropriations



DEPARTMENT OF THE NAVY SECRETARY OF THE NAVY (20360-1000) CHIEF OF NAVAL OPERATIONS (20350-2000) WASHINGTON DC

September 8, 2017

The Honorable Thad Cochran Chairman, Committee on Appropriations United States Senate Washington, DC 20515-6035

Dear Mr. Chairman:

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M. Richardson

Enclosures: As stated

Copy to: The Honorable Patrick J. Leahy Vice Chairman

Sincerely,

Richard V. Spencer

2

Figure A.3 Forwarding Letter to John McCain III, Chair, U.S. Senate Committee on Armed Services



DEPARTMENT OF THE NAVY SECRETARY OF THE NAVY (20350-1000) CHIEF OF NAVAL OPERATIONS (20350-2000) WASHINGTON DC

September, 8, 2017

The Honorable John McCain III Chairman, Committee on Armed Services United States Senate Washington, DC 20510-6035

Dear Mr. Chairman:

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J. M. Richardson

Enclosures: As stated

Copy to: The Honorable Jack F. Reed Ranking Member Sincerely,

Richard V. Spencer

2

Figure A.4 Forwarding Letter to Mac Thornberry, Chair, U.S. House of Representatives Committee on Armed Services



DEPARTMENT OF THE NAVY SECRETARY OF THE NAVY (20350-1000) CHIEF OF NAVAL OPERATIONS (20350-2000) WASHINGTON DC

September 8, 2017

The Honorable Mac Thornberry Chairman, Committee on Armed Services House of Representatives Washington, DC 20515-6035

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The Navy remains committed to studying the design of the next generation of nuclear-powered aircraft carrier while continuing to reduce the cost of the Ford-class program at every opportunity. A copy of this report has been sent to Chairmen McCain, Cochran, and Frelinghuysen.

J. M. Richardson

. M. Kichardsor

Enclosures: As stated

Copy to: The Honorable Adam Smith Ranking Member Sincerely,

Richard V. Spencer

2

APPENDIX B

Details of the Nuclear-Powered Aircraft Carrier Mission-Essential Task List and Deployment Preparation

Table B.1 Mission-Essential Task List for a Nuclear-Powered Aircraft Carrier

Designation	Description						
NTA 1.1	Move tactical forces.						
NTA 1.1.1.7.1	Provide engineering and main propulsion.						
NTA 1.1.1.7.2	Provide combat systems, deck, and communications.						
NTA 1.1.7.3	Provide damage control.						
NTA 1.1.2.3.1	Sail ship from port, anchorage, or moorage.						
NTA 1.1.2.3.3	Conduct flight operations.						
NTA 1.1.2.3.7	Conduct small-boat operations.						
NTA 1.2.1.2	Conduct airspace management and control.						
NTA 1.2.11	Conduct navigation.						
NTA 1.5.9	Conduct information superiority operations.						
NTA 2.2.1	Collect target data.						
NTA 2.2.3	Perform tactical reconnaissance and surveillance.						
NTA 2.4.4.2	Define the battle-space environment.						
NTA 2.4.5.5	Provide intelligence support to targeting.						
NTA 3.1	Process targets.						
NTA 3.2.1.1	Attack surface targets.						

Table	B.1-	-Continu	led
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Designation	Description		
NTA 3.2.5	Conduct EA.		
NTA 3.2.7	Intercept, engage, and neutralize enemy aircraft and missile targets (DCA).		
NTA 3.2.9	Conduct nonlethal engagement.		
NTA 4.1.3	Provide munitions, pyrotechnics, and specialty items.		
NTA 4.1.4	Maintain explosives safety.		
NTA 4.1.5	Onload and off-load ordnance.		
NTA 4.2.4	Provide petroleum, oils, and lubricants.		
NTA 4.3	Repair and maintain equipment.		
NTA 4.4.2.2	Provide food services.		
NTA 4.6.3	Provide UNREP.		
NTA 4.8.5	Maintain cultural awareness.		
NTA 4.12.2	Provide ambulatory health care.		
NTA 4.12.3	Provide surgical care.		
NTA 4.12.4	Provide dental care.		
NTA 5.1.1	Communicate information.		
NTA 5.1.3.1	Maintain and display the tactical picture.		
NTA 5.2.1.3	Review the rules of engagement.		
NTA 5.3.9.3	Plan tactical operations.		
NTA 5.5	Conduct information warfare.		
NTA 5.5.5	Perform information assurance.		
NTA 5.6	Conduct acoustic warfare.		
NTA 6.1.1.1	Protect individuals and systems.		
NTA 6.2	Rescue and recover.		
NTA 6.2.2.1	Perform search and rescue.		
NTA 6.3.1.5	Establish and enforce a protection perimeter.		

Table B.1—Continued

Review and apply use-of-force rules.	
Provide disaster relief.	
i	

NOTE: NTA = Navy tactical task.

Figure B.1 Navy Carrier Strike Group Optimized Fleet Response Plan

ALC: N	3		Optimized Lines of E	d FRP Effort			
		FY14	FY15		FY15	5	
Lines of Effort		Sep Oct Nov Dec Ja	n Feb Mar Apr Ma	ay Jun Jul Aug Sep	Oct Nov Dec Ja	an Feb Mar	
	(USFF / CPF N7)	HST - IOC MAY 14	GHWB	VIN	TR		
	Advanced						
	(USFF / CPF N7)	GHWB – IOC AUG 13			HST		
	Unit Training	TR – IOC SEP 13					
	(TYCOMs)		HST		GHWB	VIN	
	Inspections (USFF/CPF N43)						
			HST	GHW	B VIN		
	Parts (USFF / CPF N41						
	OPNAV N8/N9)						
	Maintenance/ Modernization	нят	GHWB	VIN	TR		
	(USFF / CPF N43/N6	j)					
	Manning/ Individual Training		HST		GHWB	VIN	
	(USFF / OPNAV N1)					
	Alignment	HST / GHWB / TR by M	SG – AUG 13				
	(USFF / CPF N3)						
	FRP Length (USFF/CPF OPNAV N43)	Foundation	to O-FRP	CVN/CVW There Now	SC w/HS1	-	
_	United States Fleet Forces United States Pacific Fleet						

SOURCE: U.S. Fleet Forces Command, 2014.

NOTE: FRP = fleet response plan. OL = operational level. TL = tactical level. HQ = headquarters. USFF = U.S. Fleet Forces Command. CPF = commander, U.S. Pacific Fleet. N7 = fleet training. Aug 13 = August 2013. Sep 13 = September 2013. HST = Harry S. Truman. IOC = initial operational capability. May 14 = May 2014. GHWB = George H. W. Bush. TR = Theodore Roosevelt. TYCOM = type command. VIN = Carl Vinson. N43 = fleet maintenance. N41 = fleet supply. OPNAV = Office of the Chief of Naval Operations. N8 = warfare requirements, resources, and force structure. N9 = warfighting assessments and readiness. N6 = communications and information systems. N1 = total fleet force manpower and personnel. N3 = operations. MSG = maritime surface group. SC = surface combatants. RAND RR2006-B.1

Table C.1 Aircraft Mentioned

Designation	Name
C-2	Greyhound
CMV-22	Osprey
E-2C	Hawkeye
E-2D	Advanced Hawkeye
EA-18G	Growler
F-35	Lightning II
F-35A	conventional takeoff and landing Lightning II
F-35B	short takeoff and vertical landing Lightning II
F-35C	Lightning II carrier variant
F/A-18	Hornet
MH-60R	Seahawk
MH-60S	Seahawk
MQ-25	Stingray

Designation	Lead Ship
 CV 41	USS Midway
CV 60	USS Saratoga
CV 61	USS Ranger
CV 66	USS America
CVN 65	USS Enterprise
CVN 68	USS Nimitz
CVN 69	USS Dwight D. Eisenhower
CVN 70	USS Carl Vinson
CVN 71	USS Theodore Roosevelt
CVN 72	USS Abraham Lincoln
CVN 73	USS George Washington
CVN 74	USS John C. Stennis
CVN 75	USS Harry S. Truman
CVN 76	USS Ronald Reagan
CVN 77	USS George H. W. Bush
CVN 78	USS Gerald R. Ford
CVN 79	USS John F. Kennedy
CVN 80	USS Enterprise
CVN 82	USS Ranger
DDG 1000	USS Zumwalt
LHA 6	USS America
LHA 8	USS Bougainville

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his report is an exploration of possible alternatives for further consideration to potentially replace the U.S. Navy's legacy aircraft carrier force as it begins reaching expected service life in decades to come. The variants are possible alternatives that could be developed for less cost than the current program and potentially with sufficient capability. This is neither a formal analysis of alternatives nor a detailed engineering study.



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