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Future USN Aircraft Carrier Analysis of Alternatives

ABSTRACT In March 1996, the Department of Defense established a new program, then known as CVX, to develop a new class of aircraft carrier that would eventually replace the *Nimitz* class. The first step in the concept develop was exploring a wide range of alternative design concepts in a formal study known as an Analysis of Alternatives (AOA), which assessed their cost and operational effectiveness. About 70 total ship studies were developed to explore the range of design features, including airwing size and type, propulsion type, ship mobility performance, and a variety of survivability features. The AOA also assessed the performance of and total ownership cost of a large number of potential subsystem technologies.

This paper summarizes the total ship studies developed for the AOA, describes the ship system performance and total ownership cost of these alternatives, and discusses the rationale for determining some of the primary system requirements. Thus, the paper will provide insight into the Navy's intentions for system requirements and features to be incorporated into the U.S. Navy's future aircraft carriers.

Introduction

In March 1996, the Defense Acquisition Board (DAB) authorized the Navy to establish a program for a new class of aircraft carrier, then known as CVX, that could ultimately replace the existing *Nimitz*-class carriers. As is the case with all major new programs, the Secretary of Defense's staff (OSD) directed the Navy to conduct a formal Analysis of Alternatives (AOA) to re-examine basic assumptions about aircraft carrier design—including aircraft types, ship sizes, and propulsion concepts—and to explore other key system design parameters.

The AOA was conducted in three parts. Part 1, completed in October 1997, focused on small vs. large carriers and conventional take-off and landing (CTOL) vs. short take-off and vertical landing (STOVL) aircraft. Part 2, completed in September 1998, focused on large vs. mid-size carriers and nuclear vs. fossil-fuel propulsion concepts. Part 3, the final part, focused on the cost implications of various configuration and technology issues and was completed in October 1999. This paper summarizes the overall effort.

AOA General Approach

The AOA involved two types of activities. One was the design work and associated cost estimates, carried out by the NAVSEA design team and cost estimating office. The other part was the analysis of operational effectiveness, which involved a variety of people and was led by the Center for Naval Analyses. This paper describes both aspects, with emphasis on the design work.

The starting point for the AOA is a broad statement, known as the Mission Need Statement (MNS), of the functional requirements for a new carrier. The CVX MNS calls for improvements in core capabilities of aircraft carriers: combat capability, survivability, adaptability, and growth potential plus improved affordability through reduced life-cycle cost. According to the MNS, to provide acceptable combat capability, CVX "must be able to operate sufficient numbers of tactical aircraft and carry sufficient ordnance and fuel to conduct simultaneous power projection, battle-space dominance, and surveillance for extended periods . . . independent of land bases." The MNS does not, however, specify that this requirement must be met by a single ship; combinations of smaller ships were viewed as possible candidates and thus were examined in the AOA.

The approach in each part of the AOA was to develop a range of design alternatives that illustrated possible approaches to satisfying the mission needs examined in that portion of the AOA. The designs served as the basis for estimating the life-cycle cost of each approach and for assessing the operational effectiveness of various combinations.

- The design baseline for the CVX AOA was the latest ship of the *Nimitz* class, the USS *Ronald Reagan* (CVN 76), which is currently under construction. While a modified version of this ship was acknowledged as a candidate for CVX from the outset, the broad scope of the AOA study requirements mandated that most of the AOA ship studies be based upon totally new ship configurations. A computer-based design synthesis model, the Monohull Aircraft Carrier Version of the USN's Advanced Surface Ship Evaluation Tool (ASSET/MONOCV), was used for all CVX AOA new configuration ship studies. The use of the ASSET/MONOCV design model had the following significant advantages.

- The design model accomplished all routine design calculations in a credible, reproducible, and consistent way. Thus, the naval architects and system designers could focus their attention on the more unique and challenging technical aspects of these studies.
- The use of a design model enabled many design alternatives to be investigated by a relatively small design team. This saved required resources and, by keeping the design team small, facilitated the exchange of useful technical information.
- A degree of design documentation was achieved automatically and design data could be quickly digitally passed to the CVX Cost Team.

Major Design Practices and Assumptions

A set of major design practices and assumptions was established for the purpose of accomplishing the desired feasibility studies. Such a set is necessary to maintain consistency among the studies so as to illuminate the major issues of interest without distorting the results due to application of different or inconsistent design practices. The set of design practices and assumptions discussed below apply to "new configuration" or "clean sheet" studies rather than "modified repeat" studies based upon retention of major configuration features of existing carriers.

NOTIONAL AIRWINGS

Through the first two parts of the AOA, airwing capacity was a major parameter of interest. In AOA Part 1, notional airwings of 40, 60 and 80 aircraft were developed for both CTOL and STOVL aircraft cases. For AOA Part 2, the airwings evolved to 55, 65 and 75 CTOL aircraft. Helicopters were included in all airwings as exceptions to the general CTOL and STOVL designations. These airwings shared the following assumed characteristics:

- Fighter/attack aircraft made up about 70% of the aircraft in all airwings. In the case of the CTOL air wings, about half of the fighter/attack aircraft were F/A-18E/F and about half were the CTOL version of a notional Joint Strike Fighter (JSF). For STOVL airwings, all fighter/attack aircraft were the STOVL version of a notional JSF.
- For the CTOL airwings, a notional electronic warfare aircraft (about 5% of the aircraft in the airwings) was assumed which was similar in dimensions and weight to the F/A-18E/F. For the STOVL airwings, this mission area was assumed to be covered by a version of a notional STOVL support aircraft, which was similar in dimensions and weight to the V-22 Osprey.
- For the CTOL airwings, the airborne early warning (AEW) and anti-submarine warfare (ASW) missions were assumed to be accomplished by a notional support aircraft (about 17.5% of the airwing's aircraft) which was similar in dimensions and weight to the current S-3B. For the STOVL airwings, these mission areas were assumed to be covered by a version of a notional STOVL support aircraft, which was similar in dimensions and weight to the V-22 Osprey.
- All airwings used the SH/HH-60 helicopter. In the case of the CTOL airwings, these aircraft made up about 7.5% of the aircraft in the airwings. The STOVL airwings contained a smaller number of helicopters (about 5% of the aircraft in the airwings) since it was assumed that the notional STOVL support aircraft could pick up some portion of the usual helicopter missions.

Further details concerning the aviation efforts accomplished in support of the AOA are contained in Baker (2000).

FLIGHT DECK REQUIREMENTS

For CTOL flight decks, the total length of the landing area is 778 ft. (182 ft. from ramp to 1st arresting wire, 87 feet for a 3-wire arresting system, 400 ft. for wire run-out, and 109 ft. for aircraft turn-out after it stops).

Catapults, whether steam or the developmental electromagnetic aircraft launch system (EMALS), have a 302 ft. power stroke. Large airwings (75-80 aircraft) are provided four catapults, medium airwings (55-65 aircraft) are provided three catapults, and small airwings (40 aircraft) are provided two catapults.

If aircraft elevators are outboard, there must be at least one on each side; this is to provide the flexibility for heavy weather aircraft elevator operation on the lee side without the necessity for a major ship course change.

For STOVL flight decks, there must always be one landing spot available at the beginning of a launch cycle. Large airwings require at least four landing spots on the side of the ship away from the island during recovery of a major launch group. Small airwings require at least three landing spots on the side of the ship away from the island during recovery of a major launch group. Landing spots are 80 ft. athwartship by 115 ft. longitudinally; spots of this size can be immediately adjacent to one another. Multiple take-off runs are provided to accommodate various aircraft and scenarios: (1) 750 ft. with or without ski jump for JSF, (2) 400 ft. with ski jump for JSF, and (3) 300 feet without ski jump for notional STOVL support aircraft. Jet blast deflectors are needed for any takeoff runs that do not initially exhaust directly over the edge of the flight deck. STOVL flight decks for medium airwings were not addressed in the CVNX AOA.

AVIATION SUPPORT

Space is provided in the hangar for a minimum of 30% of the aircraft in the airwing. The minimum clear hangar height is 19.7 ft. For studies with a clear hangar height less than 25.6 ft., "high hat" areas are provided in each hangar bay to allow shipboard maintenance evolutions to be accomplished. The deck area under each "high hat" is of sufficient size to accommodate at least one V-22 aircraft.

Large airwing studies provide aviation fuel tankage and magazine space equal to or greater than that on the Nimitz class. Requirements in these areas on studies with smaller airwings are ratioed by number of aircraft in the airwing.

While the V-22 aircraft is not specifically in all nominal airwings investigated, all studies have aviation support features that would allow operation of this aircraft.

PASSIVE SHIP PROTECTION FEATURES

In general, the passive ship protection features of the studies are equal to or greater than the capability of the latest ships in the *Nimitz* class. A few studies addressed the possibility of more austere features in this area to establish the cost versus capability impacts.

SHIP MOBILITY/MACHINERY SYSTEMS

The baseline speed capability for machinery system trade-offs was similar to that of the current *Nimitz* class ships, but machinery plants providing both higher and lower speed capabilities were investigated. In the case of fossil-fueled machinery plants, the baseline ship endurance was equal to USS *John F. Kennedy* (CV 67). All ship auxiliary systems are electrically driven. The type of distilling plant is reverse osmosis.

WARFARE SYSTEM

The warfare system is assumed to be that currently under development for the CVN 77. Most major warfare system equipment will be changed from CVN 76. The centerpiece of this change will be replacing the multiple radars on the CVN 76 with two phased array radars, the Multi-Function Radar (MFR) and the Volume Surveillance Radar (VSR). Communications and command and control systems will also be updated and the integration of ship electronic systems will be improved to achieve better performance and reduce workload and manning requirements. Further information concerning warfare systems for future USN carriers is available in Canning (2000).

ACQUISITION MARGINS

The following explicit acquisition margins were provided in all new configuration studies to cover the period of design and construction:

- Weight : 7.5% of light ship weight
- Vertical center of gravity (KG): 5.5% of light ship KG
- Space: 5% of internal deck area (not including "large object spaces" and passages)
- Accommodations: none (somewhat covered by space margin)
- Electric power load: 8.3% of maximum electric load condition
- Air conditioning load: none (considered to be covered by conservative load estimating methodology and criteria for selecting air conditioning plant capacity)
- Speed/power: 8% of effective horsepower

SERVICE LIFE ALLOWANCES

The following service life allowances were provided in all new configuration studies to cover the expected CVX 50-year service life:

- Weight: 7.5% of full load displacement
- KG Rise: 0.75m
- Space (not including accommodations): none
- Accommodations: 10% for officers, CPO, and other enlisted men
- Electric power: 20% of maximum electric load condition
- Air conditioning load: 10%
- Speed/power: none

HABITABILITY

All new configuration studies were required to meet a habitability standard significantly more demanding than that in the latest ships of the *Nimitz* class since *Nimitz* class ships fall significantly short of meeting current USN habitability standards. The total "personnel support" space budget was set at a minimum of 56 square feet per man, about 25% above that on the CVN 76. This space budget is adequate to meet the current minimum USN habitability standards. In addition, the weight budget for personnel outfit and furnishings items was increased by 25% per man over that on the CVN 76.

AOA Results

The primary study results on cost and operational effectiveness are summarized in the following sections of the paper; the major areas of interest being related to the aircraft type, airwing size, and propulsion plant.

AIRCRAFT TYPE (CTOL VS STOVL)

The current way of doing business on aircraft carriers is with conventional takeoff and landing (CTOL) aircraft that launch with an assist from high-powered catapults. Upon landing, the aircraft's tailhook catches an arresting wire, which stops the aircraft within about 300 feet. Another option is a short takeoff and vertical landing (STOVL) aircraft that could take off in short distances without a catapult assist and land vertically. This requires powerful aircraft engines plus devices to vector thrust in a downward direction for takeoff and landing.

STOVL aircraft were seriously considered for carrier operations in the late 1970s, but were ultimately rejected because, with 1970s technology, a carrier-suitable STOVL aircraft was significantly larger and more expensive than a comparable CTOL aircraft. But technology has advanced since the 1970s. In fact, the Joint Strike Fighter (JSF) program is developing a new, more capable STOVL strike fighter for the Marines. Perhaps now is the time to reconsider STOVL aircraft for carriers.

STOVL aircraft have long been associated with small carriers. Indeed, for carriers of less than 30,000 tons or so, STOVL aircraft are required because a ship of that size cannot accommodate the launch and recovery areas needed for modern CTOL combat aircraft. That's why the Royal Navy developed STOVL aircraft for their current small carriers, which are about 25,000 tons and carry about 20 aircraft. For the range of 40 to 80 aircraft, however, the AOA design work showed that STOVL aircraft and carrier size are separable issues. STOVL aircraft are not required for a 40-plane carrier design of modest size, as shown by *Charles DeGaulle*, the new nuclear-powered French carrier of about 40,000 tons, which is designed to accommodate 30 to 40 aircraft.

Moreover, STOVL aircraft do not require STOVL-only carriers. STOVL aircraft can operate effectively from CTOL-capable carriers. The reason for considering a STOVL-only design is the potential cost savings. The issue is whether these potential savings would justify the limitations of a STOVL-only carrier. Design and cost data in the CVX AOA say that the answer is "no". Here are the main reasons:

The cost savings due to STOVL are relatively modest. Sacrificing some operational capability might be justified if the result is large cost savings. However, the AOA design and cost work showed that the savings due specifically to a STOVL-only design (no catapults or arresting gear and a smaller flight deck) are relatively modest in percentage terms. The saving is about six percent in full load displacement and also about six percent in both initial construction and life-cycle costs. This perhaps surprising result is heavily influenced in the case of CVX by the design standards and assumptions discussed earlier. The CVX mobility, aviation support, and survivability requirements lead to ship configurations for both CTOL and STOVL aircraft cases that are "volume limited"; that is, the dimensions and total internal volumes of these studies are driven by the cumulative space requirements of the functions that must be contained within their hulls. As an example, Figure 1 shows comparative flight decks for large CTOL and STOVL airwings.

The STOVL flight deck area in this case is about 7% smaller than the CTOL flight deck area and the STOVL "safe parking area" (area available for parking aircraft during recovery) is about 35% more than the CTOL case. The

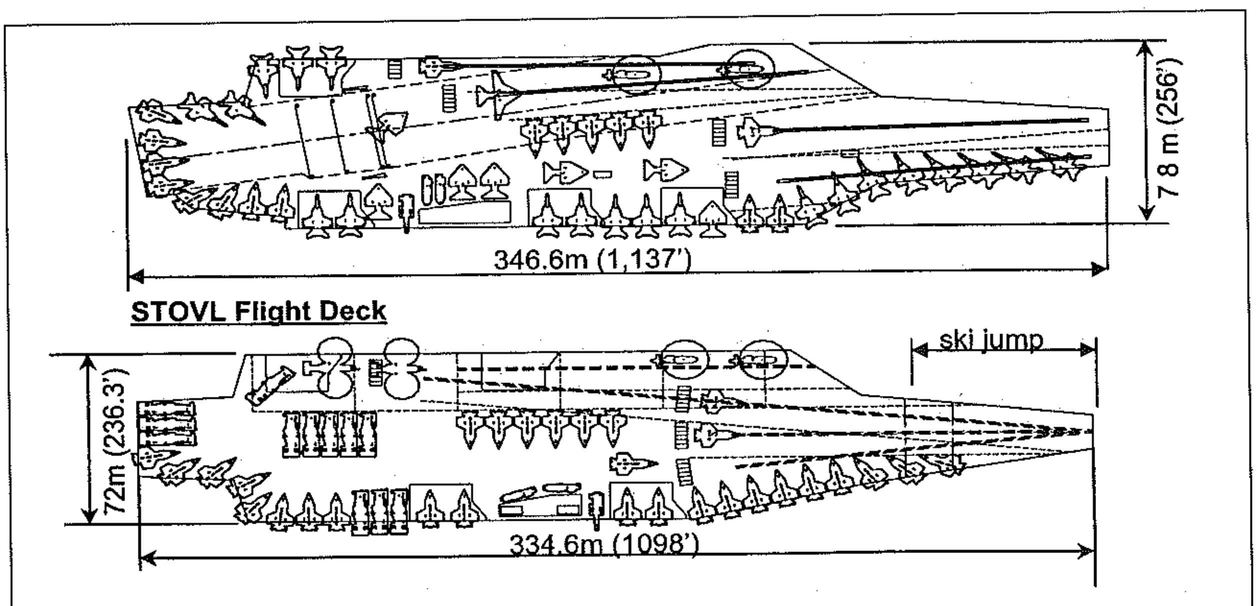

FIGURE 1. CTOL vs. STOVL Flight Decks (80 Aircraft Airwings)

STOVL flight deck seems less congested and more flexible than the CTOL flight deck. In fact, it could be argued that from an aviation perspective that the STOVL flight deck could be further reduced in size. However, the volume limited nature of the STOVL ship, driven by other requirements, precludes reductions in basic hull dimensions and makes impractical any significant reduction in size of the large airwing STOVL flight deck.

A STOVL-only ship could not operate legacy CTOL aircraft. The Navy has a large investment in CTOL aircraft that will be in the Fleet for a long time to come. For example, F/A-18 strike fighters and E-2C surveillance and support aircraft will be around for decades.

There is not a good STOVL airframe for surveillance and other support missions. The performance penalties for STOVL aircraft design are smallest in high-performance fighter-attack aircraft; the high thrust-to-weight engines for combat performance are also helpful for STOVL operations. But for support aircraft—such as the E-2 and S-3 surveillance aircraft—the requirements for high payload weight and long endurance result in much different designs, with much less thrust to weight, which are not efficient for STOVL operations. STOVL designs that meet current Fleet requirements for range, payload, altitude, and endurance would be nearly half-again as large and heavy as a CTOL design, which is not practical for carrier operations. Because of these considerations, there was a consensus that CVX should be designed with catapults and arresting gear to operate CTOL aircraft —but also include features that would facilitate operation of STOVL strike fighters from these ships in the future.

AIRWING CAPACITY: LARGE VS. SMALL CARRIERS

What kind of carrier makes sense for the 21st century? In light of military-technical trends and the uncertain future of international affairs, are big carriers still the right answer? The historical debates about large-deck carriers versus small and mid-size carriers were re-examined in detail in the CVX AOA. Here are the main findings:

A single small carrier does not carry enough aircraft. A 40-plane carrier would accommodate about 25 aircraft on the flight deck for operations. This is simply not enough to maintain even a modest posture to counter air and surface threats (what the Navy calls battlespace dominance), conduct meaningful strike operations, and conduct surveillance operations, ECM support, and tanking. Two 40-plane carriers could do the job, but would cost half again more than a comparable large-deck CVX that could carry 75 to 80 aircraft. There are options to supplement a small carrier, but none work in all important cases, as discussed below.

Land-based aircraft: very capable, but not always available. History demonstrates that bases are not always available when and where needed. A mobile offshore base (MOB)—a mile-long semi-submersible structure—is one idea to overcome the base-access problem. DOD was considering this concept for logistics applications, but the idea is less well suited to tactical combat applications that would expose a MOB to potential threats. In addition, the cost and technical performance of a MOB are speculative at this time.

Missiles: an important role, but too expensive to replace aircraft for sustained strike. Using missiles to supplement the strike role of a small carrier is more credible. Tomahawk and CALCM land-attack missiles have demonstrated their value in contingency strikes. But million-dollar missiles are less well suited for the "heavy lifting" of a sustained strike campaign. For example, with the precision-guided weapons now entering the inventory, a single carrier air wing can deliver the strike potential of roughly 5,000 Tomahawks over a 30-day strike campaign. Replacing a significant portion of sea-based (or land-based) aviation strike potential would require expansion of the missile force from a few thousand to tens of thousands plus extensive (and expensive) new basing schemes for the additional missiles.

Mid-size carriers: a little cheaper; a lot less combat power. If small carriers don't have enough combat power, what about a mid-size carrier that could accommodate 55-60 CTOL aircraft? The capabilities would be greater than a small carrier, but so would the costs. Figure 2 summarizes the results of studies done to identify the sensitivity of ship size and cost to CTOL airwing capacity.

Figure 2 is based upon data from ship studies with nuclear propulsion, but similar results were obtained with fossil-fuel propulsion systems. The modest nonlinearity in Figure 2 is mainly attributable to the fact that the number of catapults and aircraft elevators did not vary linearly for the 55, 65 and 75 airwing capacity studies; three of each were assumed for the 55 and 65 airwing capacity studies, whereas four of each were assumed for the 75 airwing capacity study. Figure 2 demonstrates several fundamental truths regarding the relationship between aircraft carrier size and cost and the capacity of the airwing.

- The marginal impact, in terms of both displacement and ship cost, of adding airwing capacity to a mid-size carrier is modest. This follows from the fundamental truth that there is inherent efficiency (when measured by tons of displacement or dollars per aircraft) in carriers designed for larger airwings.
- The ship cost savings achieved though reducing airwing capacity is, on a percentage basis, significantly less than the reduction in displacement. A primary reason for this truth is that a large percentage of the displacement increase due to increasing airwing capacity is in ship structure and load items that have modest ship cost impacts.

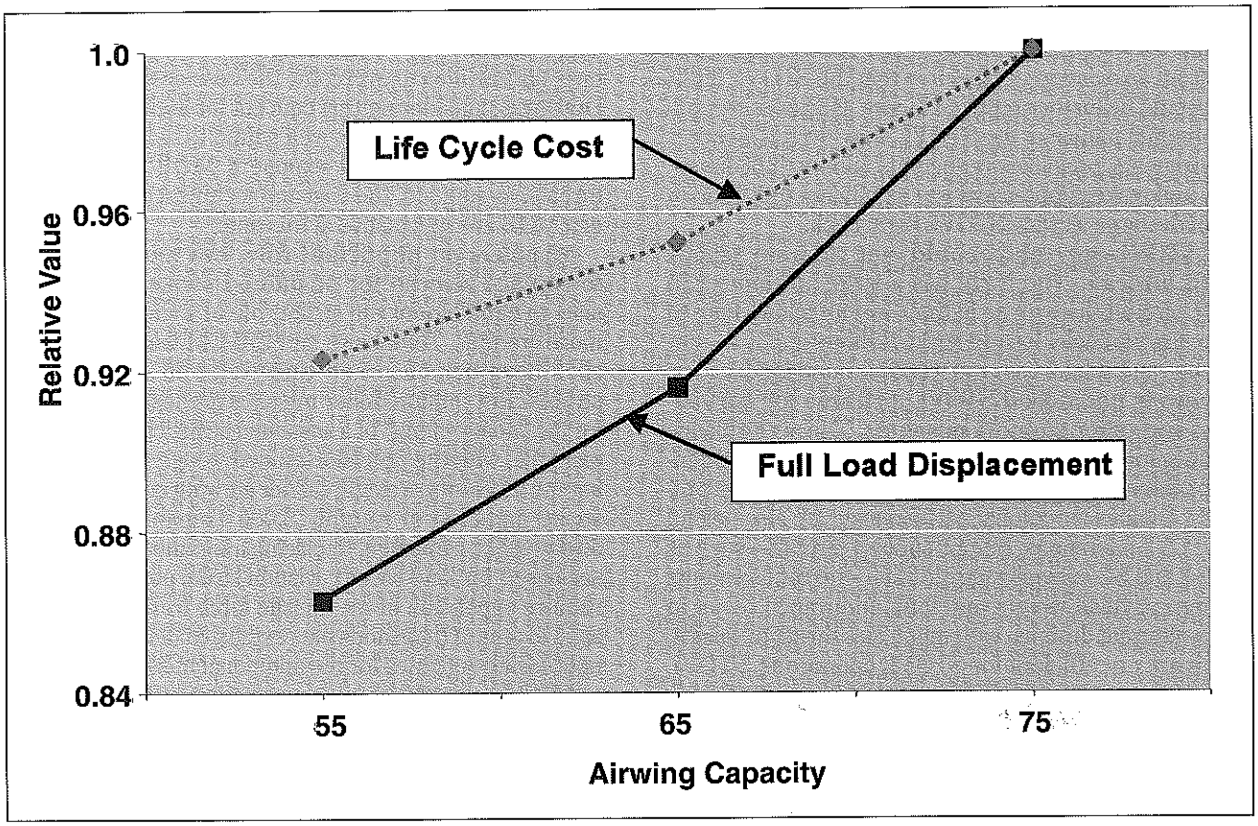

FIGURE 2. Impact of Airwing Capacity

Specifically, the savings for a 55 airwing capacity carrier, compared to the cost of a comparable 75 airwing capacity carrier, would be only about 8 percent for both initial construction and ship life-cycle cost. On the other hand, over the course of a campaign, a 55-plane CVX force generates roughly half the number of strike sorties as the same number of 75-plane carriers.

Because of these considerations, there was a consensus that a large airwing capacity is the right way to go for CVX.

PROPULSION PLANT TYPE AND SPEED

The CVX AOA did a comprehensive investigation of the advantages and disadvantages of alternative propulsion plant types and on the influence that required ship speed has on ship cost and operational capability. Nuclear, conventional steam, gas turbine and diesel propulsion alternatives were studied and both mechanical and electric drive options were looked at as considered appropriate. The range of ship speeds considered ranged from 5 knots slower to 2 knots faster than the current *Nimitz* class.

Figure 3 summarizes the displacement and follow ship life cycle cost impacts of the primary propulsion plant options investigated with 65 CTOL aircraft airwings and ship mobility and passive survivability features similar to CVN 76. The data is presented on a relative basis with the nuclear option taken as the baseline.

The nuclear plant is a new development, incorporating many of the lessons learned and technologies from several generations of submarine nuclear propulsion plant development since the design of the original *Nimitz* class nuclear plant. The conventional steam plant is a "modern" 900 psi steam plant based on current steam plant technology. The gas turbine plant is based on six General Electric LM 6000 "Sprint I" engines in an integrated electric drive configuration. The diesel plant was based on use of eight medium speed engines in an integrated electric drive configuration. However, because of the high space and weight required when providing the large total power requirements with diesel engines that are typical of a carrier, the diesel plant option selected was of lower power (about 75% of the *Nimitz* class) in a three shaft arrangement. In this case, the resulting reduction in maximum ship speed of 2-3 knots relative to the other primary plants was accepted.

Compared with existing carriers, the new nuclear concept will incorporate significantly greater electrical

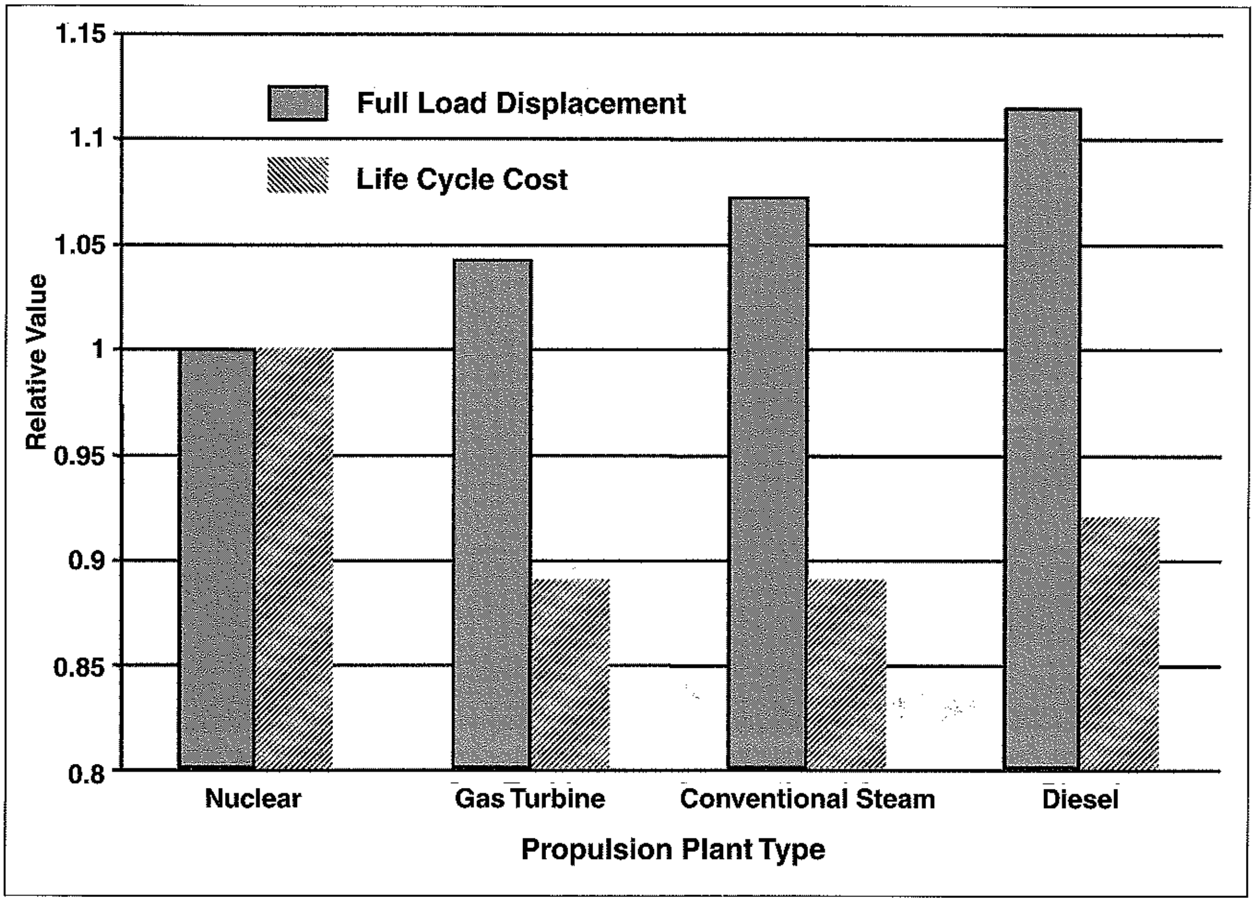

FIGURE 3. Relative Full Load Displacement and Life Cycle Cost of Propulsion Plant Type

generation capacity to: (1) enable replacement of steam auxiliaries with electrical systems, including an electromagnetic aircraft launch system (EMALS) in place of steam catapults, and (2) provide the capacity needed for future electrical systems, electric drive, and, in the more distant future, perhaps electromagnetic weapons. A new reactor provides the greater energy needed to generate the electricity plus a simplified design that reduces personnel and improves maintainability.

The non-nuclear designs in the AOA were also more capable than existing USN non-nuclear carriers. Among the non-nuclear options, gas turbines have slightly lower life cycle cost than diesel or oil-fired steam. Gas turbines also provide greater power than diesels and significant maintenance advantages over steam. Thus, the propulsion discussion focused on gas turbine and nuclear designs. Given the excellent track record and proven advantages of nuclear power, the only reason to consider gas turbines would be a potential for significant savings.

Figure 3 shows that, for the propulsion plants investigated, the nuclear plant results in the ship with the lowest full load displacement, but the highest life cycle cost. Nuclear power provides important advantages for aircraft carriers at a life cycle cost that is only about 11 percent more than the most attractive conventional propulsion plants. The life cycle cost of a new nuclear carrier would still be 15 to 20 percent less than existing USN CVNs.

Figure 4 summarizes the displacement and follow ship life cycle cost impacts of varying propulsion plant power and ship speed. The data is presented on a relative basis for the nuclear propulsion case, but similar results were obtained with other propulsion plant types. This information indicates that changing the CVX trial speed requirement by 5% from a CVN 76-like baseline causes a life cycle cost impact of less than 3%.

The overall assessment of the nuclear and gas turbine propulsion plant options focused on the following major points.

- **Life cycle cost (LCC):** the new nuclear power plant reduces costs; gas turbines save a little more. The AOA estimates indicate that operating and support costs account for three fourths of the 50-year LCC of today's nuclear carriers. The AOA designs show that major reductions in personnel and maintenance can

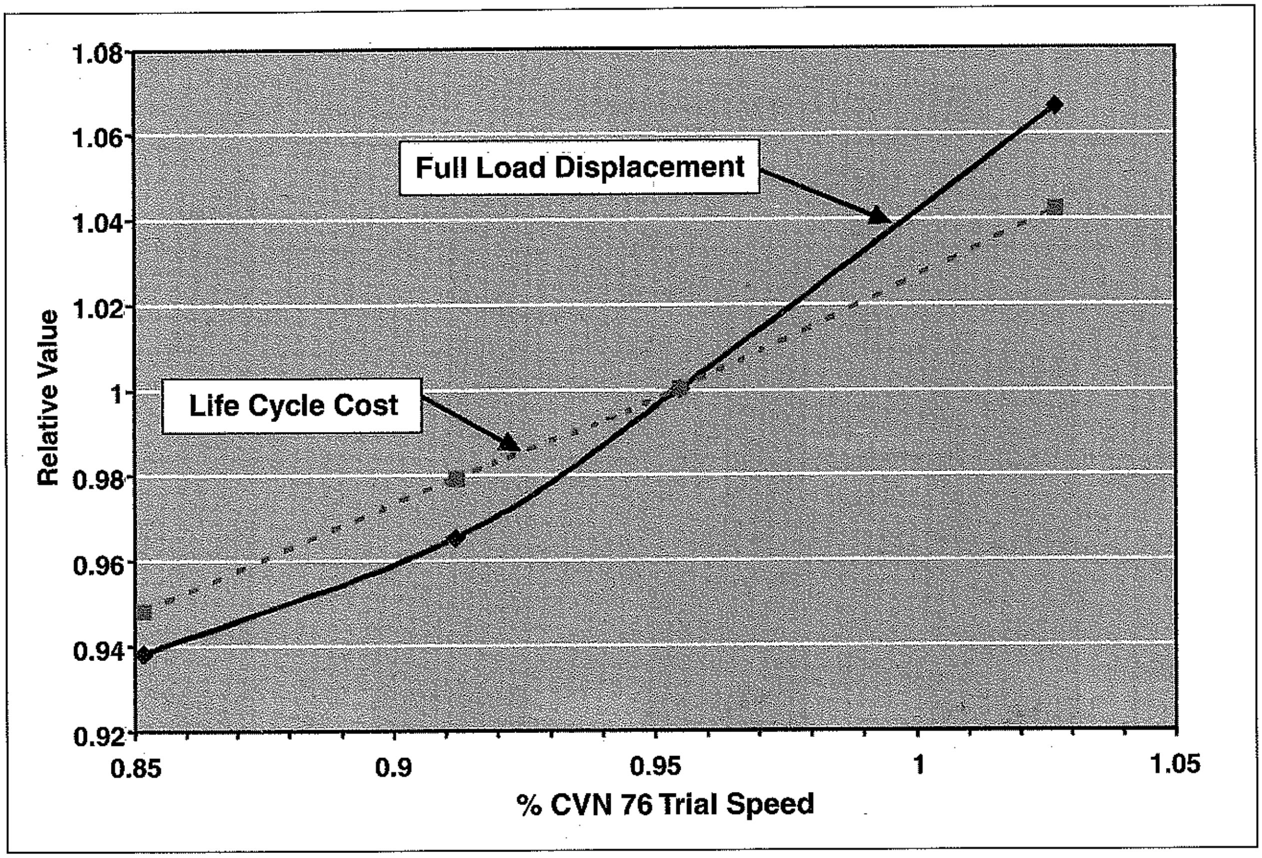

FIGURE 4. Impact of Varying Ship Trial Speed

be achieved in a new nuclear design. For example, the new simplified reactor design will cut reactor department personnel by 50 percent and achieve major reductions in depot maintenance costs. The CVX program office has already identified personnel reductions and applications of current maintainability technologies that will reduce LCC by about 20 percent. Additional savings would be likely with a non-nuclear carrier. For example, the AOA estimates that a gas turbine carrier would cost up to 11% percent less than a comparable nuclear carrier, depending on the future cost of oil and the precise impact on the nuclear industrial base. The most significant difference between nuclear and gas turbine ships is the estimated $1 billion savings in initial construction cost for a gas turbine ship. This would be offset by roughly $300M in projected increases in the cost of nuclear cores and other nuclear components for SSNs, if the USN were to stop procuring nuclear-powered carriers. The net total Navy shipbuilding account cost difference would thus be $700M per ship. The cost premium for nuclear power estimated in the AOA is lower than in some previous studies. That's because the AOA compared comparable carriers that had similar capabilities other than just the propulsion type. In the past, studies have often compared large capable nuclear carriers with smaller less capable non-nuclear carriers. The AOA approach isolates the cost effects of the propulsion choice, which are about $700 million more for construction (~15 percent) and up to 11 percent more over its 50-year service life.

- **Performance:** nuclear power provides warfighting advantages. Existing conventional carriers show that non-nuclear propulsion plants can achieve the substantial shaft horsepower and sustained high speed that are deemed essential for carrier operations. In addition, some of the weaknesses of existing non-nuclear carriers could be addressed in a new design. For example, a new gas turbine carrier can incorporate the magazines of the same size as current nuclear carriers, the same tankage for aviation fuel (JP-5), comparable survivability features, and a rapid acceleration capability not readily achievable with oil-fired steam. But the result is a ship that is 30,000 tons larger in full-load displacement than current USN conventional carriers and about 5,000 tons larger than a comparable new nuclear design. Even with these major improvements, the gas turbine design does not provide the same warfighting capabilities of a nuclear ship, particularly its high-speed endurance and tactical flexibility. The advantages of nuclear power are clearest and easiest to quantify in cases where a deployed carrier responds at high speed to a fast-breaking crisis in an adjacent theater—like the responses of USS *Nimitz* to the Taiwan Straits crisis in 1995 and recent Desert Thunder contingency operation in the Gulf, or the high-speed response of USS *George Washington* to Iraqi troop movements in 1994. In these and other cases, the rapid arrival of carriers was a crucial part of the U.S. response to a potentially serious crisis. The ability of a nuclear carrier to sustain high speeds without the need for oil en route and then fight immediately upon arrival provides significant advantages. The Fleet also sees additional advantages of nuclear power over a wide set of circumstances, which accounts for the strong endorsement of nuclear power by the unified CINCs.

- **Risk:** nuclear propulsion involves lower risk than gas turbines. Given the USN past experience with large nuclear propulsion plants for carriers, a gas turbine plant on a carrier scale is judged to involve greater technical uncertainties and development risks, and so could entail longer development times and higher R&D costs than a nuclear design.

In light of the Fleet's endorsement of nuclear propulsion for carriers, the quantifiable advantages of nuclear power in crisis response, and its proven track record versus risks with gas turbines, the Defense Acquisition Board (DAB) agreed that the warfighting advantages of nuclear power justified the additional cost. In September, 1998, the DAB directed the Navy to proceed with development of a new large nuclear-powered carrier, now known as CVNX.

Evolutionary Approach To Ship Configuration

At the beginning of the CVX program, the Navy intended to develop a wholly new design carrier in one step, the so-called revolutionary approach. But the up front cost for a new design plus developing subsystem technologies—estimated to be about $6 billion—plus another $5 billion for construction was not deemed affordable at the Navy's current budget levels. In response to this near-term affordability problem, the Navy has developed an evolutionary acquisition strategy that would phase in the improvements over several ships—starting with major warfare system improvement on CVN-77. This would be followed by a new nuclear propulsion plant with greatly increased electrical generating capacity in CVNX 1, and then by additional improvements in CVNX 2. The initial design work has started for CVNX 1. For CVNX 2, there is still an issue over whether a totally new design or a modification of the existing Nimitz configuration is the right way to go.

Implications of a Modified *Nimitz* vs New Ship Configuration for CVNX2

Translating the core capabilities of CVNX into specific technologies and design features involved considerable work by the Navy's technology and requirements communities, including the Fleet. Starting with the CVNX Mission Need Statement, this strategy-to-task-to-technology process identified the most important high-leverage technologies and design features for CVNX—which were then incorporated by the AOA ship design team into a conceptual design with significant improvements over CVN 76 in the following important areas:

- **Aviation.** A larger flight deck with the island moved forward to create more clear area to starboard that enables "pit stop" operations and increased aircraft sortie rate. Improvements in technology and design features to speed fueling and arming while reducing personnel.
- **Survivability.** Improved passive protection against underwater threats, advanced armor protection against air threats and balanced ship signature reduction.
- **Service life allowances.** Restores service life allowances to meet current, more stringent CNO standards. Modular design introduced for electronic spaces to facilitate adapting to future changes in technology.
- **Manpower reductions.** Flight deck redesign and automation plus design features to reduce workload for accomplishing logistics and other ship support functions.

This wholly new design, called the Expanded Capabilities Baseline (ECBL), is focused on meeting the CVNX 2 objectives in the Draft CVNX Operational Requirements Document. Because it would be both more capable than CVNX1 in all core capabilities and less costly over its 50-year service life (a follow ship savings of roughly $1.7 billion per ship in constant FY99 dollars), this new design would be the obvious choice for CVNX 2 were it not for one disadvantage: an up front non-recurring cost of roughly $3 billion (in addition to the cost for CVNX1) for developing subsystem technologies and doing the new design. A further complication is that the dimensions of the ECBL when completed exceed those that can be accommodated at Newport News Shipbuilding and most Naval Shipyards. Thus, there are facility implications to be dealt with, if such a design were to be pursued. Further details on this design are presented by McWhite (2000).

The advantage of a modified *Nimitz* class design is the significantly lower lead ship cost over that of a wholly new design. The drawback is that potential improvements are limited by the modest growth allowances remaining in the current *Nimitz* class hull and the functional constraints and workload implications of having to substantially retain the major dimensions and principal arrangement features of a design accomplished in the 1960s. The AOA's first series of modified *Nimitz* class designs showed that without significant weight reductions, only modest improvements to CVNX 1 would be feasible.

Thus a key question is whether it is possible to reclaim growth margins in the current Nimitz hull without sacrificing essential capabilities. The good news is that, based on estimates by NAVSEA and Newport News Shipbuilding, aggressive weight reduction could reduce CVNX weight by more than 3,000 tons relative to the CVN 76. This would improve service life allowances and open the door to potential additional improvements in ship survivability and aviation capability.

The AOA examined a series of tailored designs that reinvested a portion of the weight reduction to improve survivability or aviation capability. The results indicated that significant improvements would be possible within the current *Nimitz* class hull but not to the same degree as in a new hull and not in all areas. In other words, tradeoffs would be required. Thus the choice between a modified *Nimitz* class hull and a new design for CVNX 2 is a classic cost-versus-capability tradeoff that the Navy faces in every budget cycle.

On one side of the equation is the set of desirable features of a wholly new design plus the assurance that the new ship would have service life allowances and modular design features that would facilitate adapting to future technologies and threats over the 50-year life of CVNX 2 and nearly 100-year life of the CVNX class.

On the other side of the ledger is an extra $2 billion in nonrecurring cost for a wholly new design compared with a modified *Nimitz* class design. This cost would likely have to come at the expense of other Navy programs in one form or another at a time when the Navy is facing the need to replace aging ships and aircraft from the 1970s and 1980s. As a result, the Navy will have difficulty accommodating the added nonrecurring costs for a new design for CVNX 2 unless more funding is added to the Navy budget.

Despite the hard choices concerning CVNX 2 that lie ahead, the carrier program has made great strides. CVN 77 will be authorized in the upcoming budget. The Defense Acquisition Board has ratified the major decisions for CVNX 1, and design work has begun. The AOA has been completed, the draft Operational Requirements Document (ORD) is now in the approval process, and the CVNX Program Office (PMS-378) is well on its way to completing the other documentation needed for the important Milestone 1 review in the Spring of this year.

Conclusion

For over three years, the CVX Analysis of Alternatives investigated major technical, cost, and operational issues relative to future aircraft carriers for the USN. Work accomplished during this effort supports the following major conclusions.

- For the foreseeable future, USN aircraft carriers should be designed to operate conventional takeoff and landing aircraft.
- To accomplish USN aircraft carrier missions, future aircraft carriers should be designed to operate large airwings (about 75 aircraft).
- The operational advantages of nuclear propulsion over fossil-fueled propulsion alternatives justifies the nominal increase in life cycle cost for nuclear propulsion.
- If CVNX is based upon retention of the basic CVN 76 configuration, significant improvements in aviation capability, ship survivability, or ship service life allowances will require an aggressive effort to reduce weight.
- The cumulative effect of achieving large improvements in aviation capability, ship survivability, and ship service life allowances over CVN 76 requires a new ship configuration and introduces an additional significant nonrecurring cost increment over a carrier acquisition based on modifying the CVN 76 configuration.
- A new carrier configuration achieving significant improvements in operational capability and significantly reduced life cycle cost relative to CVN 76 is feasible. However, the relatively near term budget implications of such a ship acquisition make the affordability of this path open to serious question.

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ADVERTISER INDEX