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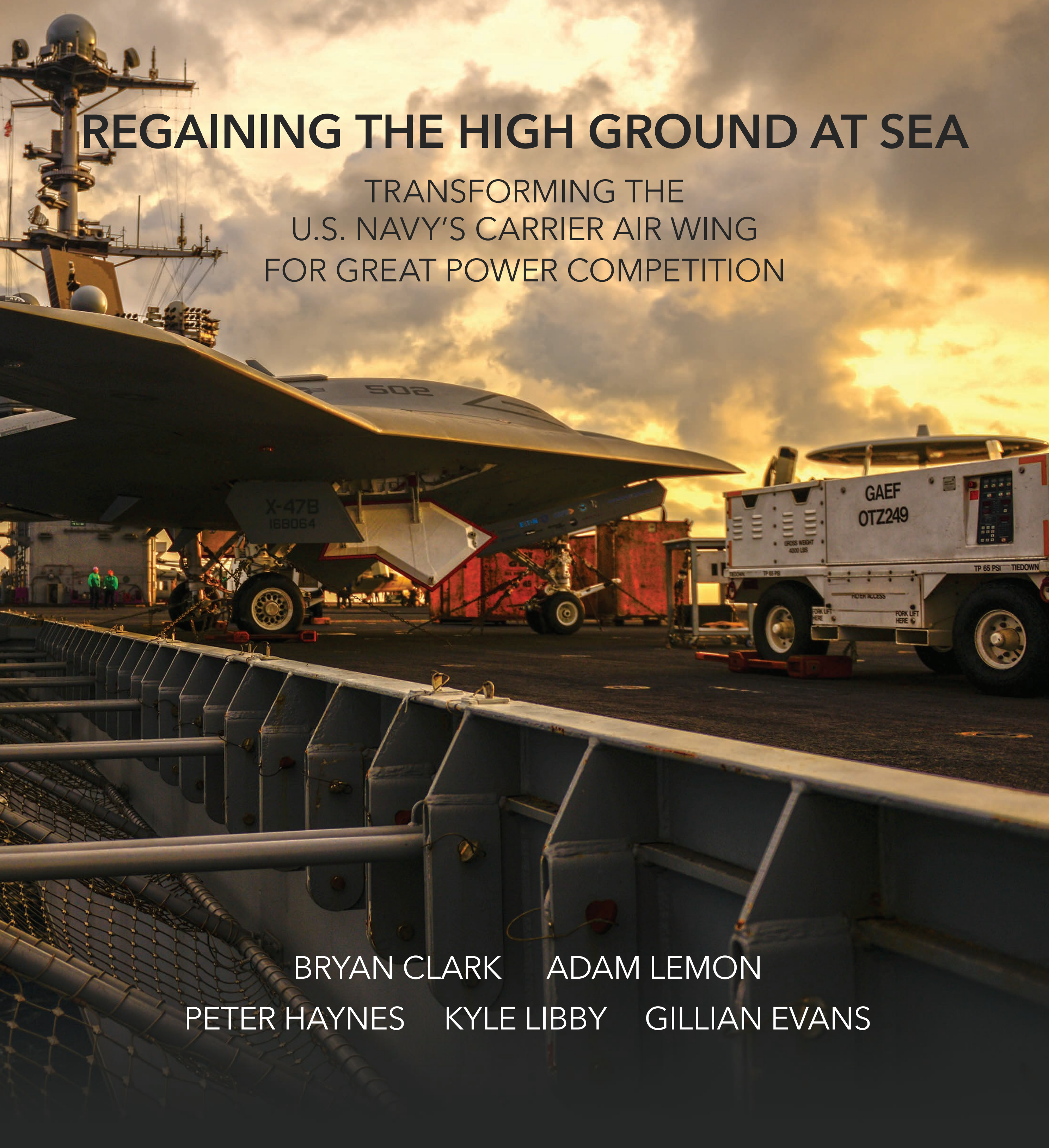
REGAINING THE HIGH GROUND AT SEA

TRANSFORMING THE U.S. NAVY'S CARRIER AIR WING FOR GREAT POWER COMPETITION



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ABOUT THE CENTER FOR STRATEGIC AND BUDGETARY ASSESSMENTS (CSBA)

The Center for Strategic and Budgetary Assessments is an independent, nonpartisan policy research institute established to promote innovative thinking and debate about national security strategy and investment options. CSBA's analysis focuses on key questions related to existing and emerging threats to U.S. national security, and its goal is to enable policymakers to make informed decisions on matters of strategy, security policy, and resource allocation.

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Cover: An X-47B Unmanned Combat Air System (UCAS) demonstrator aircraft is secured aboard the aircraft carrier Harry S. Truman (CVN 75), December 2012. U.S. Navy photo courtesy of Northrop Grumman by Alan Radecki.

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Executive Summary

Starting as an experiment in scouting for battleships and cruisers, naval aviation has grown during the last century into the primary offensive arm of the U.S. Navy and the centerpiece of the American fleet. In that time, shipboard aircraft evolved from small detachments of piston engine float planes that could only land on the water to carrier air wings (CVW) of several dozen jet aircraft able to launch from and recover on 100,000-ton nuclear-powered aircraft carriers (CVN). Improvements in performance also enabled naval aircraft to diversify and take on a wider variety of missions previously performed only by ships or land-based aircraft.

Aircraft carriers (CV) are arguably the ultimate modular military platform, as they can exploit the diversity of naval aircraft to address emerging threats and opportunities by changing the size and mix of aircraft in their CVWs. The Navy's CVWs evolved to address new missions such as strike against targets ashore, close air support (CAS) of ground troops, air defense against enemy CVWs or land-based aircraft, and anti-submarine warfare (ASW). Some new missions, like strike and CAS, implemented new strategies for using carrier-based aircraft; others, such as air defense or ASW, were created to protect the carrier and forces ashore from a growing variety of threats. Without the ability to evolve and support new missions, carriers and their CVWs would likely have gone the way of the battleship and left the fleet decades ago.

Today the Navy needs to transform its CVWs to counter the emerging challenges posed by great powers like China and Russia and implement new defense and military strategies. During the quarter century since the end of the Cold War, CVWs emphasized cost effectiveness and versatility because the United States did not face a peer adversary. Today's CVWs, however, now lack the range, endurance, survivability, and specialization to carry out the operational concepts needed to defeat great power militaries. If the Navy is unable to transform its CVWs, Navy leaders should reconsider whether to continue investing in carrier aviation or shift the fleet's resources to more relevant capabilities.

This report examines trends in U.S. strategy, capabilities, and threats between now and 2040 to describe the operational concepts CVWs will likely need to use in the future, as well as the implications for how CVWs should evolve over the next 20 years. The 2040 timeframe was chosen because new capabilities being developed now could be fielded in operationally

relevant numbers by that year. 2040 is also approximately when the F/A-18 variants that comprise all the tactical aircraft in current CVWs will have retired, requiring the Navy to consider today what will replace them.

A Stalled Evolution

During the early years of carrier aviation, CVWs expanded their missions from scouting to surface warfare (SUW) when aircraft achieved the power and capacity to carry larger payloads over longer distances, making them capable of damaging and eventually sinking enemy warships. This also made carriers more lucrative targets for enemies seeking to protect their own fleets. During the Second World War, the threat of air attack compelled the Navy to incorporate growing numbers of air defense fighters into CVWs to protect carriers, even as demands for CAS and strike grew in support of the Allies' "island hopping" campaign against Japanese forces in the Pacific. With more than 100 carriers at the end of the war, however, U.S. naval forces were still able to deploy sufficient aircraft for offensive operations.

The competition between offensive and defensive missions continued to play out during the decades following the Second World War. With the primacy of atomic weapons in U.S. strategy, Navy leaders increased the size and number of CVW strike aircraft and long-range fighters so the fleet could support nuclear missions against the Soviet Union and compete bureaucratically with the new U.S. Air Force. This changed by the 1960s, when nuclear-powered ballistic missile submarines (SSBN) assumed most of the naval nuclear mission and the Navy replaced some carrier-based bombers and fighters in its CVWs with multi-role fighter-attack aircraft to meet the growing need for conventional strikes and CAS that emerged during the conflicts in Korea and Vietnam. As the Cold War wore on, however, Soviet ships, bombers, and submarines improved their anti-air and anti-ship capabilities. This required CVWs to shift again during the 1970s and shed some multi-role aircraft in favor of specialized air defense fighters, ASW hunter-killers, or electronic warfare (EW) aircraft.

Following the Soviet Union's dissolution in 1991, the Navy faced a situation it had not encountered since the birth of naval aviation: the lack of a peer competitor. The more permissive environments and less challenging missions of the post-Cold War period allowed the Navy to eliminate specialized airframes, including the F-14 Tomcat fighter and S-3B Viking ASW aircraft, in favor of multi-role F/A-18 A-D Hornets and F/A-18 E/F Super Hornets. This evolution will reach its apotheosis by the end of this decade with CVWs consisting entirely of F/A-18 E/Fs and similar E/A-18Gs supported by E-2D Hawkeye airborne early warning and control (AEW&C) aircraft and MH-60 ASW and multi-mission helicopters.

The Navy's adoption of a common multi-role airframe for most of its CVW aircraft reduces logistics costs, improves efficiency, and enables carriers to support a wide range of missions. The current CVW configuration, however, is not well suited for the tactics that U.S. naval forces will need to employ against great power competitors, such as China and Russia, and regional powers fielding improved capabilities, like North Korea and Iran. These potential adversaries are deploying anti-ship, anti-air, and undersea threats that will require new operational concepts for U.S. CVWs and a different mix of aircraft to implement them.

New Strategy, Posture, and Operational Concepts

The 2018 U.S. National Defense Strategy (NDS) is focused on the challenges that China and Russia pose to U.S. interests. An important aspect of the NDS is its adoption of a new approach to deterring aggression, which emphasizes delaying, denying, or defeating an adversary's attacks when they occur. This is in contrast to the United States' de facto post-Cold War approach of responding to aggression weeks or months later, as in Operation Desert Storm against Iraq, Operation Allied Force against Serbia, and Operation Enduring Freedom against Afghanistan.

The emphasis of the NDS on stopping or slowing aggression when it occurs is based in large part on the proximity of China and Russia to their likely objectives as well as their growing ability to contest access to their periphery. For example, if China's leaders wanted to take the Senkaku Islands from Japan, People's Liberation Army (PLA) naval and air forces could reach the islands within hours and attempt to gain control of the skies and seas around them. Russian forces could similarly cross from the Western Military District into Latvia and be in the capital, Riga, within hours. In both cases, dislodging adversary forces after the fact would be very difficult in the face of their long-range sensors and anti-air and anti-ship missiles.

As part of this new strategy, the NDS directs a new posture for the U.S. military in which the United States would rely upon forward-deployed naval forces to delay, deny, or defeat aggression in concert with local U.S. and allied ground and air forces, as well as U.S. long-range bombers. This approach will place a premium on survivability in contested environments, where China and Russia can launch large missile salvos, and on long-range strike capabilities, to allow attacks from areas where the missile threat is manageable. A U.S. carrier strike groups (CSG) fighting a capable adversary would be required to operate at a distance of between 800–1,200 nm, depending on the specific threats and geography, to both reduce the threat to manageable levels and maximize the effectiveness of their offensive air operations.

Countering great power competitors' efforts to contest areas around their territory will drive CSG operations into the following three main efforts, which are similar to how carriers were used in previous great power competitions and conflicts:

- Smaller-scale operations at long range against highly defended targets of great power adversaries, such as strike and SUW attacks of 200 weapons or less, electromagnetic warfare (EMW) or escort missions, and ASW;
- Sustained operations at the periphery of great power confrontations, such as in the Philippine or South China Seas against China or in the Norwegian Sea against Russia; and

- The full range of operations against regional powers such as Iran or North Korea that lack integrated, long-range surveillance, anti-air, and anti-ship capabilities.

Within these broad categories, CVWs will need perform the same missions they do today, but using new operational concepts that address ongoing and future enhancements to adversary threats and the geographic advantages enjoyed by great power and some regional competitors. These concepts are described below.

AMD and ISR&T

The number of precision-guided missiles that Chinese or Russian forces could launch against U.S. carriers and shore bases will eventually overwhelm even the high-capacity missile defense systems being pursued by the Department of Defense (DoD), including directed energy weapons and short-range interceptors. To survive in highly contested environments, U.S. forces will need to complement ship- and ground-based air defenses with operations to thin out missile salvos in flight and attack missile-launching "archers" before they can launch their "arrows." For this reason, U.S. CVWs implemented the Outer Air Battle operational concept during the Cold War to engage Soviet bombers before the bombers could launch their anti-ship cruise missiles (ASCM) against U.S. carriers. Outer Air Battle required long-range fighters to patrol more than 200 nm from the carrier on the most likely threat axes, supported by E-2C AEW&C aircraft and S-3B refueling tankers.

ASCMs now reach almost 500 nm and will likely approach the 1,000-nm ranges of land-attack cruise missiles (LACM) by 2040. Although Chinese or Russian bombers will not be able to detect U.S. and allied ships or ground forces at these ranges, both adversaries have extensive air, space, and third-party surveillance and targeting capabilities. To address enhanced missile threats, the Navy will need to implement a distributed approach to air defense in a 21st Century version of Outer Air Battle.

In this new air defense concept, CVW defensive counterair (DCA) combat air patrols (CAP) would operate 800–1,000 nm from carriers or threatened bases ashore along the most likely threat axis. DCA CAPs that engage enemy aircraft would be combined with shorter-range CAPs that thin out ASCM salvos, effectively adding capacity to ship and shore-based air defenses. To engage enemy aircraft in sectors outside the most likely threat axes, DCA CAPs would be complemented by Intelligence, Surveillance, Reconnaissance, and Targeting (ISR&T) CAPs that would detect and target enemy aircraft to be engaged by CSG surface combatants, ground-based air defenses, and DCA aircraft.

Executing future concepts for Air and Missile Defense (AMD) will require long-range, long-endurance aircraft that are survivable in a contested air environment. These aircraft could exploit advancements in passive ISR&T, long-range air-to-air missiles (AAM), and directed energy technology to attack enemy bombers without themselves being detected, which could reduce requirements for DCA aircraft speed and maneuverability.

Strike and SUW

Future strike and SUW operations will need to occur 500–1,000 nm away from the CSG, depending on the adversary, to reduce air and missile threats to a level manageable by CSG air defenses without reducing the CVW's offensive capacity. CVW strike and SUW operations will deliver fewer weapons than those possible with land-based bombers, but could be sufficient for small or less hardened targets such as surface combatants, installations on islands in the South China Sea, or isolated coastal command and control (C2) or sensor facilities.

Similarly, CVWs will need to be able to conduct SUW at ranges of 500–1,000 nm or more to engage enemy surface combatants before they can launch attacks against either the carrier or the targets ashore that the carrier is defending. Using standoff weapons such as the Joint Air-to-Surface Standoff Missile (JASSM) would allow carrier aircraft to launch strike and SUW attacks from closer to the carrier, but these weapons are more expensive than shorter-range weapons such Small Diameter Bombs (SDB) and may not be available in sufficient numbers to be used for each SUW attack. As a result, strike and SUW operations may require a combination of highly survivable aircraft, offensive counterair (OCA) and EMW operations, and penetrating weapons.

ASW

The proliferation and improvement of submarine-launched land attack and anti-ship cruise missiles increases the importance of ASW to defeat enemy naval forces and protect surface forces or bases and facilities ashore. Today's ASW platforms such as the P-8A Poseidon are potentially too vulnerable to conduct ASW operations near a great power adversary's territory. Others, like the MH-60R Seahawk helicopter, lack the range or endurance to conduct ASW operations beyond the reach of enemy submarine-launched cruise missiles. To conduct ASW in contested areas, U.S. naval forces will need to rely increasingly on unmanned sensors to find and target submarines. CVW aircraft operating in ASW CAPs would then promptly engage submarines detected by unmanned sensors at ranges of up to 1,000 nm from the carrier or defended areas ashore. This may place them near adversary territory and would require aircraft with greater survivability than today's patrol aircraft or strike fighters.

OCA and EMW

U.S. adversaries are likely to protect valuable ports, airfields, and sensor and C2 facilities with their own DCA CAPs and integrated air defense systems (IADS). To enable CVW and land-based attack aircraft to closely approach targets and use smaller short-range weapons, escort aircraft could attack IADS, help protect strike aircraft from CAPs, and launch expendable jammers and decoys to confuse aircraft and air defense radars and weapons. CVW OCA fighters and airborne electronic attack (AEA) aircraft could also exploit the greater mobility and protection of the carrier (compared to land bases) to engage enemy fighters and bombers as part of denying, degrading, or delaying aggression across maritime areas such as the South and East China Seas.

Escort missions will require a combination of long-range fighters able to engage enemy DCA CAPs and attack aircraft with the payload capacity to carry missile- or unmanned aerial vehicle (UAV)-borne jammers, sensors, or decoys. An attack aircraft could also carry high-power standoff jammers such as the Next Generation Jammer (NGJ) that will be carried by the E/A-18G Growler until it retires in the 2030s.

Aircraft and Composition of the Future CVW

The operational concepts needed to implement current and likely future defense strategies will require new aircraft and a different CVW configuration than that of today's fleet. Most importantly, future CVWs will need greater range and survivability, while sustaining the same approximate payload as today's combat aircraft. This report proposes the following new aircraft be added to U.S. carrier air wings between now and 2040.

Long-range Multi-mission Survivable Unmanned Combat Air Vehicle (UCAV)

As described above, Integrated Air and Missile Defense (IAMD), ISR&T, strike, SUW, ASW, and EMW missions are all evolving in a way that makes them best conducted by aircraft with longer range or endurance, higher survivability, and a payload on par with today's CVW strike fighters. An attack aircraft such as an unmanned combat air vehicle (UCAV) could have an unrefueled range of up to 3,000 nm through a fuel-efficient airframe, which could achieve high levels of survivability through a radar-scattering shape, electronic warfare systems, and self-defense weapons. A large flying wing, a blended wing-body, or a traditional tube-and-wing UCAV could carry similar internal and external payloads as today's strike fighters. And, by being unmanned, the UCAV would be capable of longer endurance than manned strike fighters when refueling is available. A larger aircraft would also be better able to carry accurate, long-range passive and low probability of intercept/low probability of detection sensors and, potentially, the electrical generators needed for directed energy weapons and high-power EW systems.

UCAV-based AEA Aircraft

The Navy plans to continue using the E/A-18G as its AEA platform into the 2030s and beyond, but its reliance on standoff effects from outside the range of enemy air defenses is likely unsustainable in the face of improving passive sensors and the increasing range of surface-to-air missiles (SAM) and AAMs. A low-observable platform such as the proposed UCAV could be made into an AEA platform by incorporating subsystems of the E/A-18G into its mission bay and installing multiple active electronically scanned arrays (AESA) along its wings and fuselage.

Compared to the E/A-18G and its pod-based AEA systems, incorporating EW systems into the body of an aircraft could enable more antenna apertures that provide greater sensitivity in passively monitoring threats, dispersion of EW effects in more directions, and the use of narrower jamming beams. As a result, the new AEA aircraft would be able to enter contested airspace and conduct jamming and deception operations with precise beam shapes and power levels that can affect the target sensor without significantly increasing the risk of counter-detection to the AEA aircraft. The AEA aircraft could also carry and deploy expendable EMW UAVs and missiles that would conduct ISR&T, jamming, decoy, and deception operations over target areas.

Unmanned Aerial Refueling Aircraft (MQ-25)

A dedicated carrier-based aerial refueling tanker could enable CVW aircraft to reach CAP stations 1,000 nm from the carrier and conduct long-range attacks to respond promptly to aggression while keeping the carrier far enough away from threat areas to reduce the density of air and missile threats to within the capacity of the CSG's defenses. The U.S. Navy is already pursuing the MQ-25 carrier-based tanker UAV for this reason and recently awarded design and construction contracts to the Boeing Company for the first MQ-25 demonstrators. The full MQ-25 specifications are classified, but the unclassified official Request for Proposals (RFP) requires that the MQ-25 be able to supply at least 15,000 lb of fuel to F-35C or F/A-18 aircraft 500 nm from their carrier.

To exploit the potential of the MQ-25, the Navy should re-designate it as a multi-mission UAV. The initial version of the MQ-25 would remain focused on the aerial refueling mission to avoid delays in program development. While fielding and testing MQ-25 Engineering Demonstration Models (EDM), however, the Navy could develop modifications that would enable it also to conduct intelligence, surveillance, and reconnaissance (ISR), attack, and EW missions in appropriate operational environments. These modifications could be incorporated into production MQ-25s starting in 2025. Operationally, MQ-25s would be able to complement UCAVs when the risk is acceptable, providing the future CVW a potentially less expensive option for surveillance, EW, or attack missions in less stressing environments.

Long-range Fighter (FA-XX)

Future CVW DCA, counter-ASCM, and escort operations will require carrier-based aircraft with the ability to intercept enemy aircraft or cruise missiles and engage them with either AAMs or directed energy weapons. The long-endurance, survivable UCAV described above could conduct these missions, particularly in areas closer to adversary sensors and air defenses. Survivability is a lesser concern for aircraft flying ASCM CAPs located only 100–200 nm from their carrier, placing them inside the sensor and air defense envelopes of CSG ships and aircraft. Strike fighters like the Block III F/A-18 E/F or a variant of the MQ-25 would be well suited for this mission, particularly if they were upgraded with a high-energy laser or high-powered microwave (HPM) weapon pod.

Escort and OCA operations, however, will require a long-range fighter to counter enemy DCA CAPs and enable U.S. land-based strike aircraft to closely approach targets and use smaller short-range strike weapons. The range, sensor capability, and weapons capacity needed in a future long-range fighter could be provided by a modified version of an existing fighter or strike fighter by shifting weapons payload to fuel capacity and incorporating additional fuel efficiency measures. This modification could also avoid the potentially unsustainable cost of developing a new fighter development program.

Current Aircraft Retained in Proposed 2040 CVW

Between FY 2017 and FY 2023, the Navy plans to complete the procurement of MH-60R ASW and MH-60S logistics helicopters, E-2D AEW&C aircraft, and E/A-18G EW strike fighters. The proposed 2040 CVW includes MH-60s and E-2Ds, which may require some life extension; both aircraft will, however, have reduced roles in 2040 compared to today due to their constrained range and survivability.

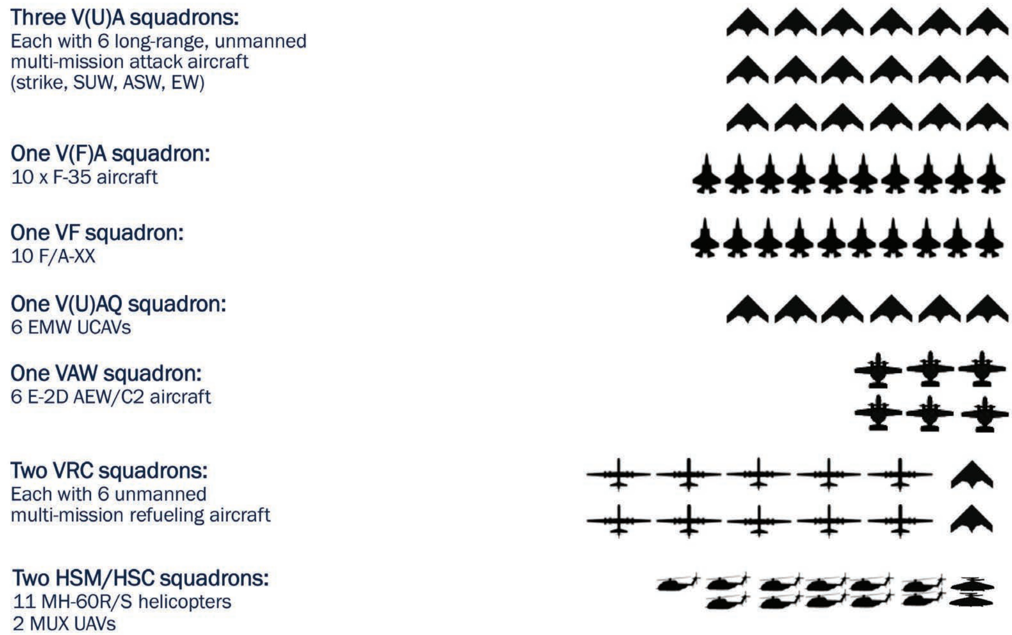
In terms of aircraft currently in development, the Navy is procuring F-35C strike fighters, which are now incorporating the Block 3F software needed for naval missions, and plans to buy enough to fill two squadrons of ten aircraft in each of its nine CVWs. The proposed 2040 CVW would buy the first half of the F-35C program to supply one squadron per CVW, but the second squadron would be replaced with the FA-XX. Although not formally part of the CVW, the proposed 2040 CVW assumes the Navy's ongoing plan to replace the C-2A logistics aircraft with the CMV-22 Osprey. The 2040 CVW also includes in its helicopter squadrons a medium-altitude, long-endurance (MALE) Vertical Take-Off and Landing Tactical Unmanned Aerial Vehicle (VTUAV) based on ongoing development efforts in the Navy and Marine Corps for an unmanned multi-mission aircraft, known as the Marine Air-Ground Task Force (MAGTF) Unmanned Aerial System (UAS) Expeditionary (or MUX).

Future CVW Composition

The proposed 2040 CVW, shown in Figure ES-1, includes the new and existing aircraft described above in a mix that improves range, endurance, survivability, and payload capacity compared to today's CVWs. Whereas the Navy's planned CVW would center around 20 F-35C and 24 F-18 E/F or FA-XX strike fighters, the proposed CVW is built around 18 UCAVs, ten FA-XX fighters, ten F-35C strike fighters, and six UCAV-based AEA aircraft. Although the aggregate payload capacity of the proposed CVW is about the same as the Navy's plan, the 2040 CVW could deliver its payload twice as far or remain on station much longer.

The proposed CVW also incorporates more specialized aircraft to address the growing capability of great power competitors. The long-range FA-XX fighter will be better able to counter enemy DCA aircraft, and the UCAV will be a more effective platform to support long-endurance CAP missions for air defense, ASW, SUW, and ISR&T than the Navy's planned CVW of short-range strike fighters. The CVW also includes more MQ-25 tankers to maximize the CVW's reach and endurance.

FIGURE ES-1: PROPOSED 2040 CVW



Comparison of Alternatives

The proposed 2040 CVW provides a significant improvement in range and survivability compared to the Navy's current and planned CVWs. Although a large number of alternatives is possible, there are two main categories of alternatives. In one, the Navy continues to sustain a strike fighter-focused CVW consisting of F-35Cs and new or life-extended F/A-18 E/Fs. In the other, the Navy incorporates some unmanned combat aircraft to replace retiring F/A-18 E/Fs, achieving a balanced fleet of manned and unmanned aircraft. These are shown in Figures ES-2 and ES-3 below.

FIGURE ES-2: STRIKE FIGHTER-FOCUSED ALTERNATIVE CVW

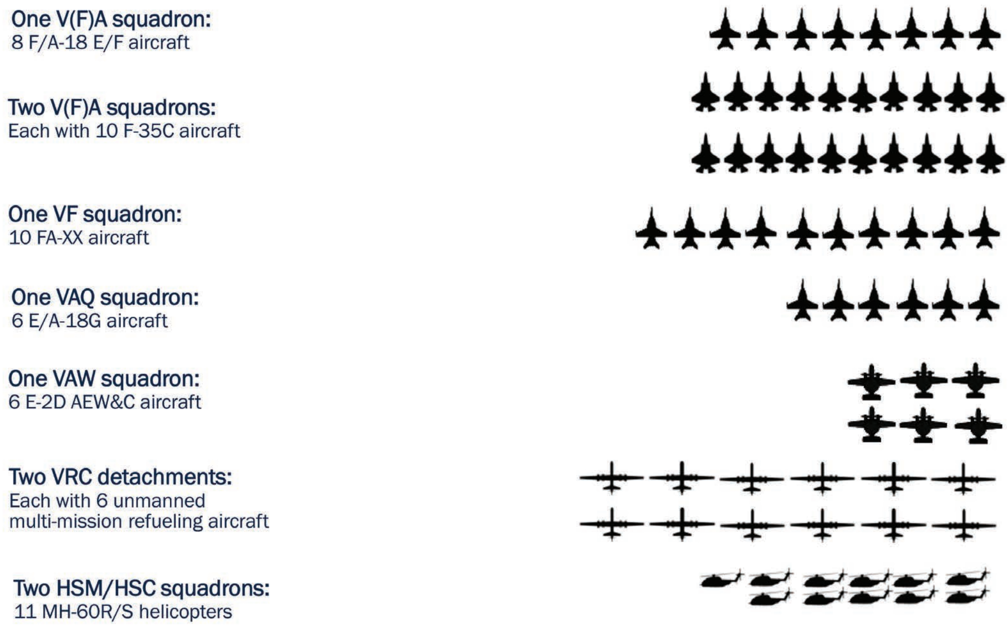
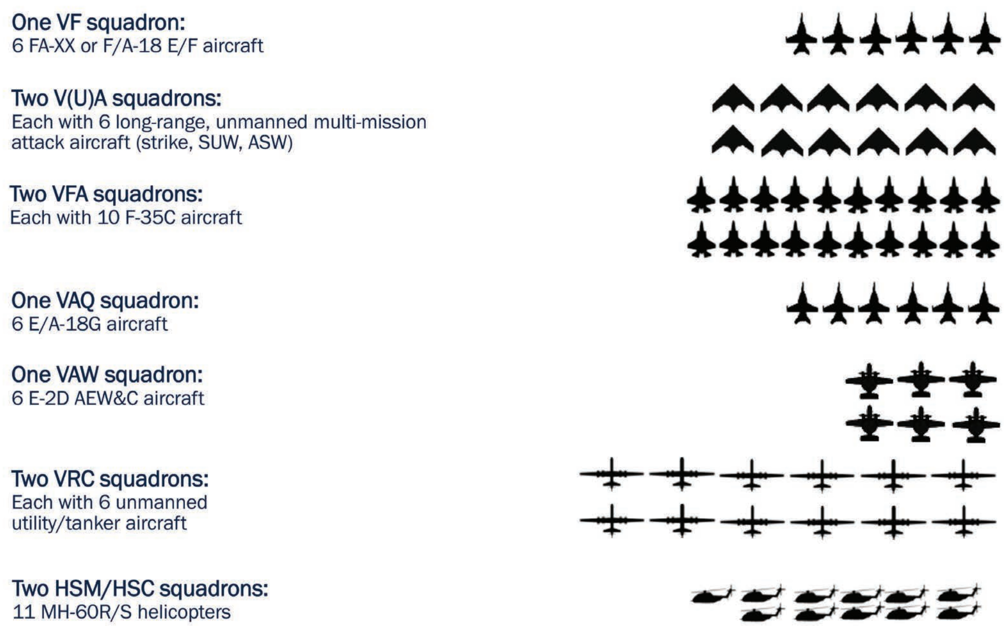
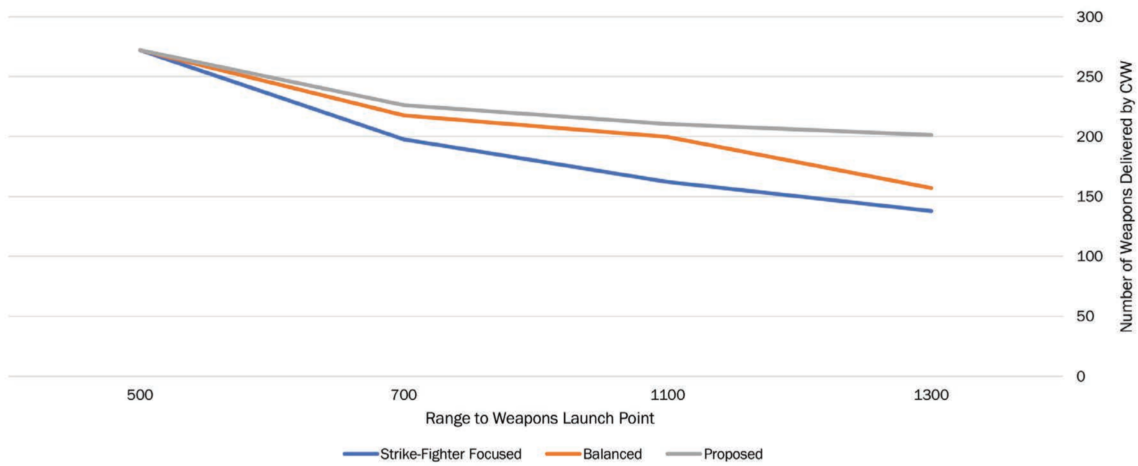


FIGURE ES-3: BALANCED ALTERNATIVE CVW



The proposed 2040 CVW provides more offensive capacity at range than either category of alternatives. For example, as shown in Figure ES-4, strike capacity for the three alternatives diverges significantly as range to the target increases for a large strike mission consisting of all CVW strike-capable aircraft except for four air defense fighters.

FIGURE ES-4: STRIKE CAPACITY OF CVW CONFIGURATIONS CONSIDERED IN STUDY



Recommendations

There are several different combinations of programmatic changes that could be used to reach the proposed CVW by 2040. This study recommends the following actions, starting with the President's Budget (PB) for FY 2020. Notably, the new procurement proposed by this study would not begin until after the FY 2020–2024 Future Year's Defense Plan (FYDP), although some research and development funding would be repurposed within the FYDP.

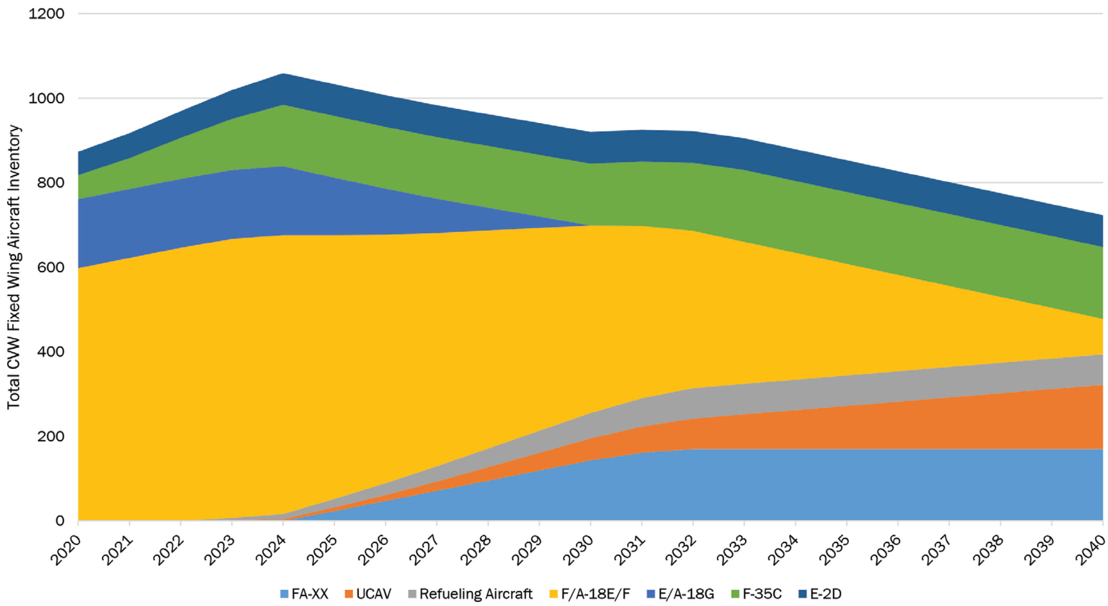
- Sustain procurement of F/A-18 E/Fs as planned through 2023. Although the future CVW requires half the strike fighters of the Navy's planned CVW, these aircraft will fill near- to mid-term capacity gaps. F/A-18 E/Fs still in service by 2040 can be used in place of UCAVs or F-35Cs if those aircraft are not yet fully fielded. Another reason to sustain procurement of F/A-18 E/Fs is to address the increasing cost of maintaining older aircraft. The planned service life of a new or modernized Block III F/A-18 E/F is 9,000 flight hours, and CVW strike fighters fly an average of 400 hours a year, resulting in a 20-year replacement cycle. Beyond 20 years, the cost to maintain older aircraft for another 5–10 years may exceed the cost of replacing them with new aircraft that have 20 years of more reliable service life.[1]

1 Sam LaGrone, "First Super Hornet Inducted Into Service Life Extension Program," *USNI News,* April 6, 2018, available at https://news.usni.org/2018/04/06/first-super-hornet-inducted-service-life-extension-program; and Federal Aviation Administration (FAA), *Aircraft Capacity and Utilization Factors* (Washington, DC: FAA, 2016), p. 3-21, available at https://www.faa.gov/regulations_policies/policy_guidance/benefit_cost/media/econ-value-section-3-capacity.pdf.

- Sustain F-35C procurement as planned through the first half of production, ending in 2024, to support the proposed 2040 CVW's squadron of ten F-35Cs.
- Develop the FA-XX fighter during the 2020–2024 timeframe as a derivative of an existing aircraft, with production starting in 2025. Block III F/A-18 E/Fs and F-35Cs will be in production during the FY 2020–2024 FYDP, and either they or another in-production fighter or strike fighter could be modified into an FA-XX. Although this approach will require some additional funding for non-recurring engineering between about 2020 and 2024, it will save billions of dollars in the Navy's planned funding to develop a new fighter aircraft from scratch.
- Develop a low-observable UCAV attack aircraft (as described in Chapter 5) during the 2020–2024 timeframe, with production starting in 2025. Although the UCAV could be based on an existing design such as the X-47B, 1–2 years of development may be needed to create a missionized version. If this development effort starts in 2020, low-rate production should be able to start by 2025. Although fiscal and industrial base constraints may prevent reaching 200 UCAVs by 2040, the CVW of the mid-2030s will still have a significant number of UCAVs. The rest of the attack aircraft can consist of F/A-18 E/F strike fighters still in service. The Navy should also develop a refueling variant of the UCAV for production once sufficient attack UCAVs are fielded.
- Continue development of the MQ-25, transitioning the program to the UCAV-based refueling aircraft when sufficient attack UCAVs are fielded. Increase the overall procurement of MQ-25 and UCAV-based refueling aircraft to support twelve per CVW.
- Retire E/A-18Gs as they reach their end of service life starting in the late 2020s, replacing their capability with NGJ-equipped UCAVs and UAV- and missile-expendable EMW payloads.
- In concert with the U.S. Marine Corps, field a MALE rotary-wing UAV such as the Tactically Exploitable Reconnaissance Node (TERN), which can augment CVW helicopter squadrons and could take over some of their ASW operations by the mid-2030s. Because the MALE UAV would be an augmentation to existing Amphibious Ready Group (ARG) and CSG capabilities, the number of aircraft procured would be flexible, although two to three per operational CVW (or 12–18 total) may be sufficient initially.

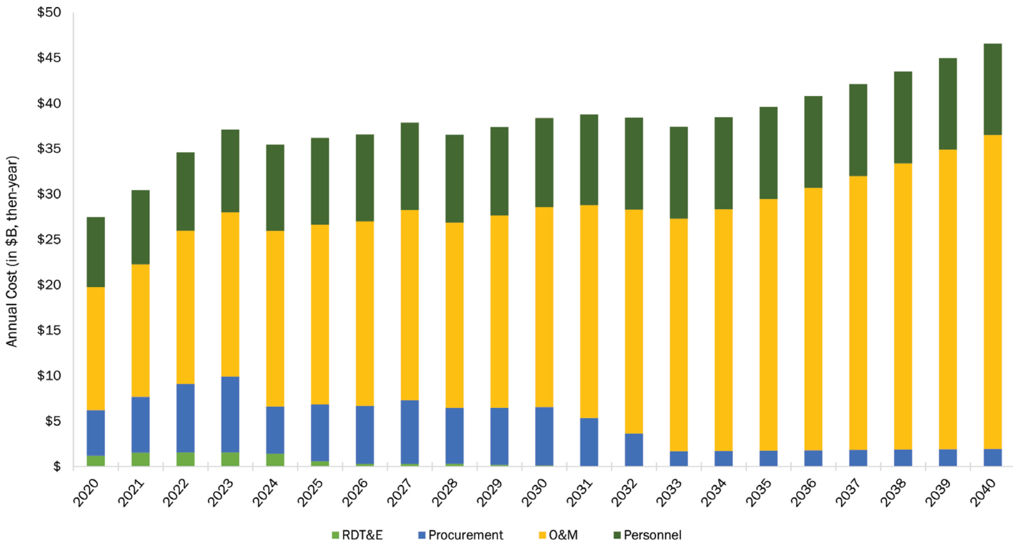
The CVW fixed-wing aircraft inventory associated with these recommendations is shown in Figure ES-5. Under this plan, research and development of the planned MQ-25, modified FA-XX, and new UCAV would occur during the 2020–2024 timeframe, with production of new aircraft starting in 2025. Today's F/A-18 E/Fs and E/A-18Gs would begin retiring in the late 2020s, to be replaced by UCAVs. The overall inventory of CVW aircraft will decrease as unmanned aircraft replace manned platforms, because operators and maintainers of unmanned aircraft can practice using simulators that will be as realistic as actual UAVs, eliminating the need for unmanned aircraft in training squadrons or in fleet squadrons that are not deployed or preparing to deploy. The smaller number of aircraft and squadrons results in a cost savings for unmanned aircraft compared to manned aircraft.

FIGURE ES-5: FIXED-WING CVW AIRCRAFT INVENTORY TO BUILD PROPOSED 2040 CVW



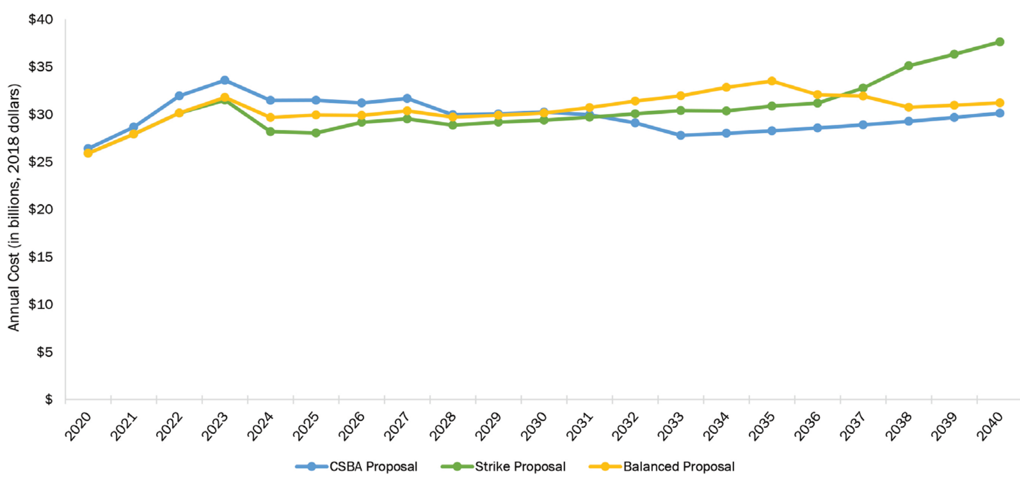
The approximate cost of the proposed 2040 CVW is shown in Figure ES-6. Except for developmental spending associated with the proposed UCAV, the new development, procurement, and operations spending proposed by this study does not begin until FY 2024. The FA-XX's development cost will also be borne during the 2020–2024 period, but because it will be a modified version of an existing aircraft, its development cost will be less than is already planned by the Navy for the program.

FIGURE ES-6: COST OF CVW DEVELOPMENT, PROCUREMENT, AND OPERATION FROM TODAY'S CVW TO PROPOSED 2040 CVW



The cost associated with the proposed 2040 CVW is less than the Navy would likely incur with either of the two categories of alternatives described above, as shown in Figure ES-7. The continued reliance on manned strike fighters in those alternatives results in a larger overall number of aircraft being required compared to the proposed CVW, primarily to train pilots and maintain their proficiency when not deployed. The higher aircraft inventory increases operations and maintenance (O&M) costs during the first decade of the period shown and raises procurement costs during the 2030s when today's F/A-18 E/Fs are replaced with a new manned strike fighter.

FIGURE ES-7: TOTAL COST OF PROPOSED, BALANCED, AND STRIKE FIGHTER-FOCUSED CVWS

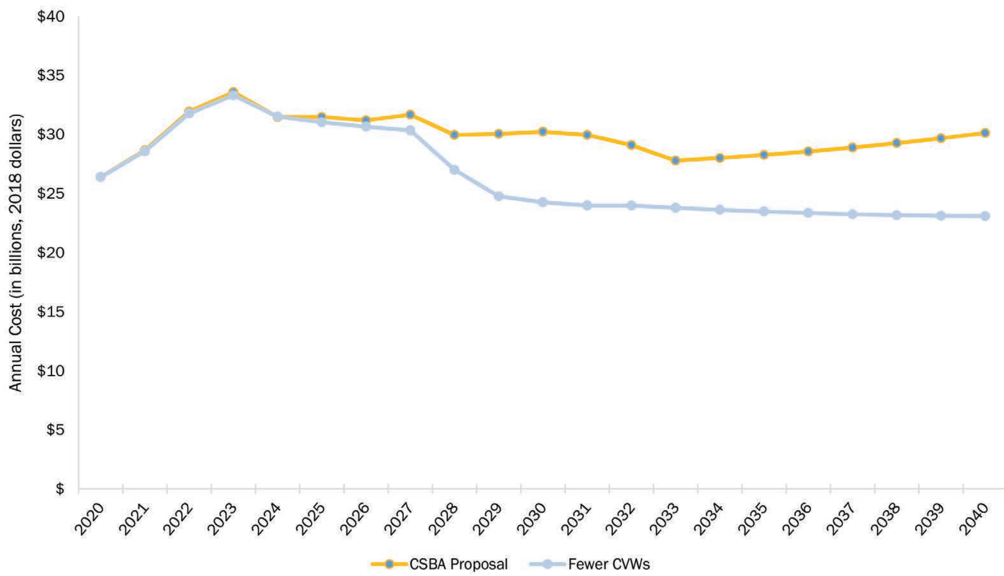


Cost Savings from Reducing the Carrier Fleet

The Navy is facing budget constraints in the near term due to growing budget deficits and spending caps imposed by the Budget Control Act of 2011.[2] These challenges, however, should not prevent Navy leaders from pursuing improvements to CVWs that make them relevant to future warfare. Opting to save money by sustaining today's strike fighter-focused CVWs, rather than developing needed new aircraft, will prevent CVWs from contributing to a growing range of operations during an era of great power competition.

To free up funding to evolve its CVWs, the Navy could reduce the number of carriers and CVWs. Figure ES-8 shows the cost to implement the proposed CVW in ten CVWs for twelve carriers as compared to eight CVWs for ten carriers. It indicates that the cost savings from eliminating two CVWs are almost entirely realized in the second half of the 2020–2040 period because reductions in aircraft procurement are taken from the end of the program. Alternatively, procurement could be slowed to save costs in the near term. The resulting savings, however, would likely be modest. Development costs will be unchanged, and the procurement cost per aircraft will likely rise because manufacturers will gain less proficiency in construction and be less able to buy parts and materials in economic quantities.

FIGURE ES-8: COMPARISON OF COSTS TO IMPLEMENT PROPOSED 2040 CVW IN EIGHT CVWS VS. TEN CVWS



2 Aaron Mehta, "Trump Appears to Call for Defense Spending Cuts," *Defense News,* October 17, 2018, available at https://www.defensenews.com/pentagon/2018/10/17/trump-appears-to-call-for-defense-spending-cuts/.

Reducing the number of carriers and CVWs would generate other savings that could help enable the remaining CVWs to evolve to better address great power competition. Operations, maintenance, and personnel for a *Nimitz*-class carrier cost about $726 million per year.[3] As shown in Figure ES-6, O&M and personnel for each CVW is about $1.8 billion per year. Although not all these costs would be harvested by eliminating two CVWs, enough savings could be realized in the near term to offset the research, development, testing, and evaluation (RDT&E) and procurement associated with new aircraft in the proposed CVW.

Conclusion

The proposed 2040 CVW will be more expensive than the Navy's planned CVW, but the Navy will need to incur these additional costs if it is to prevent carrier aviation from becoming irrelevant to the most pressing defense challenges of the near future. The threats posed by great power competitors, and increasingly by regional powers such as Iran and North Korea, preclude relying on legacy capabilities to protect American allies and interests overseas. Naval forces will be instrumental in deterring and defeating aggression by these adversaries, as described in the NDS. Carrier air wings provide the ability to sustain naval combat operations beyond the first few days, when ship and submarine missile inventories are depleted. Without a clear plan to improve the Navy's CVWs, the United States may not be able to implement its defense strategy, and Navy leaders should decide if they want to continue the Service's investment in carrier aviation or shift resources to more relevant capabilities.

3 Program Executive Office (PEO), Aircraft Carriers, *CVN 78 Gerald R. Ford Class Nuclear Aircraft Carrier (CVN 78)*, Selected Acquisition Report (SAR) (Washington, DC: DoD, 2016), p.73, available at https://fas.org/man/eprint/sar-cvn78.pdf.

Introduction

Naval aviation began more than a century ago as an experiment to provide scouting for battleships and other surface combatants. In the years since, U.S. Navy aircraft carriers arguably became the most prominent symbols of American military power and are used for a range of missions from striking terrorists in the Middle East and hunting submarines in the Atlantic to reassuring allies and protecting freedom of navigation in the Pacific.[4] Aircraft carriers also became America's most expensive weapon system; they are the single most costly item in the U.S. military arsenal at about $12 billion each, and the aircraft on each carrier cost another $3 to $5 billion.[5]

The visibility, effectiveness, and cost of aircraft carriers has incentivized adversaries to develop tactics and capabilities that undermine their utility as an instrument of deterrence and reassurance in peacetime and destroy or marginalize them in wartime. Today these challenges threaten to make the carrier irrelevant to the most pressing U.S. security concerns. The Navy will need to decide whether to change what its carriers deploy and how they operate or begin divesting itself of carrier aviation in favor of other capabilities that are better able to address the future operational environment.

The need to change with the times is not new to naval aviation. When introduced between the First and Second World Wars, critics questioned the cost of an untested platform and a new warfare community at a time when carrier aircraft were incapable of performing anything more than short-range scouting missions. Although carriers with improved aircraft proved useful and effective during the Pacific Campaign of the Second World War, debates about the carrier's relevance reemerged soon after. Most significantly, leaders of the newly established U.S. Air Force argued its B-36 intercontinental bombers could strike targets in the Soviet Union far more effectively and at a lower cost than the Navy's new long-range strike aircraft

4 Sam LaGrone, "Carrier USS Harry S. Truman Operating in the Atlantic as Russian Submarine Activity is on the Rise," *USNI News*, June 29, 2018, available at https://news.usni.org/2018/06/29/carrier-uss-harry-s-truman-operating-in-the-atlantic-as-russian-submarine-activity-is-on-the-rise.

5 Ronald O'Rourke, *Navy Ford (CVN-78) Class Aircraft Carrier Program: Background and Issues for Congress* (Washington, DC: Congressional Research Service, 2018), p. 4.

and its planned class of supercarriers, which were subsequently cancelled as a cost-saving measure.

During the 1960s and 1970s, critics questioned the carrier's effectiveness in high-end warfare in light of threats posed by the Soviet Union's new nuclear attack submarines (SSN) and long-range bombers that could launch nuclear or conventional ASCMs. Some considered carriers too vulnerable in a conflict between superpowers and advocated that they be restricted to deterrence missions, crisis management, and regional conflicts such as those in Korea and Vietnam. By the 1980s, the Navy restored the carrier's relevance to high-end warfare by introducing new defenses, including the Aegis Weapons System. These improvements and new operational concepts made carriers the centerpiece of U.S. maritime strategy. After the Cold War, with the disappearance of a serious seapower rival, the debate over the need for carriers reemerged.[6] Nevertheless, the Navy continued to build aircraft carriers, even while it substantially reduced the construction of surface combatants, amphibious ships, and submarines.

Changes in U.S. defense policy are again raising questions regarding the carrier's utility in high-end warfare. The 2017 National Security Strategy (NSS) and 2018 NDS argue that America is now in a long-term competition with China and Russia.[7] These states, the strategies argue, seek to revise the U.S.-led international order in their favor through the integrated use of political, economic, military, information, and paramilitary operations.[8]

To address these challenges, the NSS and NDS direct the U.S. military to shift the number, type, and location of U.S. forces based or operating around the world to become more dynamic and robust. This, the strategies argue, would improve the ability of U.S. forces to respond promptly to aggression, reassure allies, and increase uncertainty for great power competitors regarding the success of their aggression. Carriers today are an important element of U.S. military posture and essential to supporting prompt responses to aggression against U.S. allies.

To undermine the contribution of U.S. carriers to deterrence, reassurance, and combat operations, both Russia and China are fielding long-range sensors, an array of advanced ASCMs and anti-ship ballistic missiles (ASBMs), and dense air defense systems. These capabilities will continue to improve between now and 2040, posing a serious threat to the U.S. ability to project power and maintain forward presence in key regions. This has, in turn, led to renewed

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6 Robert Farley, "The Reason Why America's Aircraft Carriers Could Be Obsolete (Thanks to Russia and China)," *The National Interest,* April 12, 2018, available at https://nationalinterest.org/blog/the-buzz/the-reason-why-americas-aircraft-carriers-could-be-obsolete-25334.

7 Donald J. Trump, *National Security Strategy of the United States* (Washington, DC: U.S. Government Printing Office, 2017), available at https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf; and James Mattis, *National Defense Strategy of the United States* (Washington, DC: DoD, 2017), available at https://www.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf.

8 Hal Brands and Eric Edelman, *Why is the World So Unsettled? The End of the Post-Cold War Era and the Crisis of Global Order* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017), pp. 11–15.

debate regarding the carrier's increasing costs and whether its vulnerabilities outweigh its benefits.[9]

Aircraft carriers have endured as an important element of U.S. military posture and power projection because their CVWs have been able to adapt to new strategic and operational environments.[10] As a "truck" without significant organic weapons, a carrier's capability resides almost entirely in its aircraft, and CVWs have evolved dramatically to adapt to new situations, threats, and opportunities during the last century. They will need to transform again by adopting new operational concepts and capabilities if the U.S. military is to continue to exploit the carrier's mobility and flexibility as an element of a dynamic new force posture. If the Navy does not make these changes, it may be better served by shifting resources from carrier aviation toward other capabilities more relevant to great power competition.

This study proposes changes to the operational concepts, aircraft, and composition of U.S. Navy CVWs between now and 2040. These changes are intended to allow carriers to contribute to today's defense strategies and address the range of potential confrontations naval forces may face. Chapter 1 evaluates the future operational environment and how it may affect CVW operations and requirements, which informs Chapter 2's proposed roles and posture for future U.S. carrier operations. Chapter 3 assesses how the Navy adapted its CVWs to address historical challenges and strategies, and Chapter 4 describes the transformation needed in carrier operational concepts to address the emerging environment and U.S defense strategy. Chapter 5 translates these proposed new operational concepts into changes needed in the aircraft and composition of U.S. Navy CVWs, and Chapter 6 concludes by describing how the proposed CVW could be implemented by 2040.

9 Scot Paltrow, "Special Report : Aircraft Carriers, Championed by Trump, are Vulnerable to Attack," *Reuters,* March 2, 2017, available at https://www.reuters.com/article/us-usa-trump-carriers-specialreport/special-report-aircraft-carriers-championed-by-trump-are-vulnerable-to-attack-idUSKBN16G1CZ; and John Louth, Trevor Taylor, and Andrew Tyler, *Defence Innovation and the UK: Responding to the Risks Identified by the US Third Offset Strategy* (London: Royal United Studies Institute, 2017), available at https://rusi.org/sites/default/files/20170707_defence_innovation_and_the_uk_louth.taylor.tyler_final.pdf.

10 Jonathan Greenert, "Payloads over Platforms: Charting a New Course," *Proceedings,* July 2012, available at https://www.usni.org/magazines/proceedings/2012-07/payloads-over-platforms-charting-new-course.

CHAPTER 1

Challenges of the Emerging Strategic and Operational Environment

America has enjoyed geopolitical primacy and largely unchallenged military superiority since the Soviet Union's collapse in 1991. The U.S. military could project power globally when it needed to without first fighting its way into an operating area. Advances in precision strike and information technologies developed during the Cold War came to fruition in the 1990s and allowed U.S. forces to achieve victories with few casualties against less capable conventional military forces during Operations Desert Storm, Allied Force, and Iraqi Freedom.

The unhindered ability of U.S. forces to move to an area of conflict enabled a small overseas military presence to protect American allies and interests. The bulk of U.S. ships, aircraft, and troops remained in and around the United States conducting training, maintenance, and peacetime constabulary missions such as countering drug trafficking or guarding against terrorist attacks. As a result, deterrence relied on the ability of U.S. forces to mobilize, potentially over months, and respond to aggression with overwhelming force to restore the status quo and punish the aggressor. Operation Desert Storm against Iraq was emblematic of this approach.

After the Cold War, the U.S. military, no longer burdened with preparing for war against the Soviet Union, redefined its purpose around deterring regional threats such as Iran and North Korea. Following the terrorist attacks of September 11, 2001, DoD expanded its priorities to include counterterrorism and counterinsurgency. Although these state and non-state actors jeopardize U.S. interests, they do not pose an existential threat to the United States or challenge the U.S. leadership of the international political and economic system in the way that the Soviet Union did.[11]

The Return of Great Power Competition

More than 25 years after the dissolution of the Soviet empire, the United States finds itself in a new and fundamentally different era of great power competition. In contrast with the bipolar contest between the United States and the Soviet Union that characterized the Cold War-era, this era is better characterized as a tripolar competition, at least in the short run, between China, the United States, and Russia.[12]

China has emerged as the long-term economic and political competitor of the United States; furthermore, they appear determined to contest U.S. leadership of an open, rules-based international order. China's economic power and its demonstrated ability to wield that power for influence or coercion largely underwrites its great power status. Not only is it the second largest U.S. trading partner but it also trades more and with a greater number of partners than the United States.

The economic interdependence between China and the United States could restrain U.S. military action against China for the fear of threatening American economic growth and stability. Exploiting this dynamic, Beijing competes against the United States in about every field—especially those in which America enjoys preeminence today, including political influence, trade, natural resource extraction, scientific innovation, finance, and military capability. This is evident in the Chinese government's attempts to undermine U.S. alliance relationships in Asia, establish sovereign major trading routes, and reshape international law.

China's efforts are focused in the East and South China Seas, where it has attempted to expand its territorial claims and influence at the expense of U.S. treaty allies Japan and the Republic of the Philippines, respectively. China continues to expand its ability to control the South China Sea by occupying disputed islands, building new ones on existing reefs, and militarizing islands gained in the past. For example, although China has controlled the Paracel Islands since 1974, in 2016 the PLA emplaced air defense systems and ASCMs there.[13] During the last 5 years, China built islands on reefs in the Spratly Islands and equipped them with runways, aircraft support facilities, radars, EW systems, and SAM launchers. These islands,

11 Peter D. Haynes, *Toward a New Maritime Strategy: American Naval Thinking in the Post-Cold War Era* (Annapolis, MD: U.S. Naval Institute Press, 2015), p. 1.

12 For how to address China and Russia, see Evan Braden Montgomery, *Reinforcing the Front Line: U.S. Defense Strategy and the Rise of China* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017); and Eric S. Edelman and Whitney Morgan McNamara, *U.S. Strategy for Maintaining a Europe Whole and Free* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017).

13 Thomas Gibbons-Neff, "New Satellite Images Show Reinforced Chinese Surface-to-Air Missile Sites Near Disputed Islands," *Washington Post*, February 23, 2017, available at https://www.washingtonpost.com/news/checkpoint/wp/2017/02/23/new-satellite-images-show-reinforced-chinese-surface-to-air-missile-sites-near-disputed-islands/?utm_term=.ac9e4c2d7152.

some of which fall in the claimed Exclusive Economic Zones (EEZ) of the Philippines and Indonesia, now regularly host PLA troops and aircraft that can threaten freedom of navigation throughout the South China Sea.[14]

The Chinese government uses a combination of civilian fishing vessels, coast guard ships, and maritime law enforcement troops to protect its island-building efforts and enforce its excessive maritime claims in a campaign of operations often characterized as gray zone warfare.[15] In addition to preventing access to islands and features to which the Chinese government has staked a claim, these paramilitary units harass and impede the maritime forces of its neighbors and the United States. Because these Chinese ships are unarmed, U.S. naval forces cannot respond against them with military force without significantly escalating the confrontation.[16]

A resurgent and active Russia seeks to recapture its great power status and regional standing, which includes restoring a sphere of influence in its near abroad to form a buffer of friendly or neutral states between Russia and potential adversaries, such as the North Atlantic Treaty Organization (NATO) alliance. To compensate for reductions in its conventional military capabilities since the Cold War and leverage new information technologies, the Russian government has also employed gray zone warfare–combining military, paramilitary, and proxy forces with political and information warfare–to undermine the stability of neighboring countries.[17] The relative success of its gray zone campaign in Ukraine in 2014–2015 may increase the possibility that Russian leaders will pursue a similar effort against other former Soviet republics such as Latvia, Lithuania, and Estonia, which are all now part of NATO.[18]

14 Mark Valencia, "South China Sea: America Needs a Better Strategy," *Straits Times*, June 30, 2017, available at http://www.straitstimes.com/opinion/south-china-sea-america-needs-a-better-strategy. For further assessments and a timeline of Chinese expansionism in the South China Sea, see Ross Babbage, *Countering China's Adventurism in the South China Sea: Strategy Options for the United States and Its Allies*, revised edition (Washington, DC: Center for Strategic and Budgetary Assessments, 2017).

15 As Hal Brands noted, "Gray zone conflict is best understood as activity that is coercive and aggressive in nature, but that is deliberately designed to remain below the threshold of conventional military conflict and open interstate war. Gray zone approaches are mostly the province of revisionist powers—those actors that seek to modify some aspect of the existing international environment—and the goal is to reap gains, whether territorial or otherwise, that are normally associated with victory in war. Yet gray zone approaches are meant to achieve those gains without escalating to overt warfare, without crossing established red-lines, and thus without exposing the practitioner to the penalties and risks that such escalation might bring. Gray zone challenges are thus inherently ambiguous in nature. . . . They represent that coercion that is, to varying degrees, disguised; they eat away at the status quo one nibble at a time." Hal Brands, "Paradoxes of the Gray Zone," Foreign Policy Research Institute, *E-Notes*, February 5, 2016, available at http://www.fpri.org/article/2016/02/paradoxes-gray-zone/.

16 Harry Kazianas, "China's Expanding Cabbage Strategy," *The Diplomat*, October 29, 2013, available at http://thediplomat.com/2013/10/chinas-expanding-cabbage-strategy/; and Nicholas Fedyk, "Russian 'New Generation' Warfare: Theory, Practice, and Lessons for U.S. Strategists," *Small Wars Journal*, August 25, 2016.

17 Michael J. Mazarr, *Mastering the Gray Zone: Understanding a Changing Era of Conflict* (Carlisle, PA: Strategic Studies Institute, 2015), p. 4, available at https://ssi.armywarcollege.edu/pubs/display.cfm?pubID=1303.

18 Olga Oliker, Senior Adviser and Director, Russia and Eurasia Program, Center for Strategic and International Studies, "Russian Influence and Unconventional Warfare Operations in the 'Grey Zone:' Lessons from Ukraine," Statement before the Senate Armed Services Committee, Subcommittee on Emerging Threats and Capabilities, March 29, 2017, available at https://www.armed-services.senate.gov/imo/media/doc/Oliker_03-29-17.pdf.

Russia has been slowly modernizing its military to implement new warfighting concepts and leverage emerging technologies. Ukraine and Syria have been testing grounds for these efforts.[19] To backstop its smaller post-Cold War conventional military and provide a degree of escalation management, the Russian government has also devoted considerable resources to modernizing its already formidable nuclear arsenal, a capability that continues to underscore its great power status and help balance the loss of the Soviet Union's massive conventional military advantage in Europe.[20]

The Counter-Intervention versus Power Projection Competition

For the first time in more than a generation, the U.S. military's ability to project power around the world is not assured. In part, the United States is a victim of its own success. Chinese and Russian leaders noted the U.S. military's ability to mobilize forces and sustain combat operations overseas in Iraq, Bosnia, Kosovo, and Afghanistan. Concerned the United States could similarly counter their efforts to expand their countries' territory or influence, the Chinese and Russian governments developed and fielded long-range precision weapons and associated sensors.[21] These sensor and weapons networks are designed to slow or stop U.S. or allied forces that may attempt to intervene in the Western Pacific or Eastern Europe on behalf of an allied country under attack.[22]

China's PLA has established a comprehensive network of counter-intervention capabilities, as shown in Figure 1, including long-range land attack and anti-ship missiles; land, air, sea, and space-based ISR systems; resilient command, control, and communications (C3) networks; cyber and EW weapons; and anti-satellite capabilities. In addition to weapons based in China, the PLA air force and navy could attack U.S. and allied forces, bases, and communications and logistical nodes throughout the Western Pacific. Within this defensive umbrella, China could project power in its near seas to blockade or attack Taiwan, seize the Senkaku Islands, or occupy features such as Scarborough Shoal.[23]

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19 Lucian Kim, "Russian Defense Minister Says His Military Has Tested 162 Weapons In Syria," *NPR*, February 23, 2017, available at https://www.npr.org/sections/parallels/2017/02/23/516895124/russian-defense-minister-says-his-military-has-tested-162-weapons-in-syria.

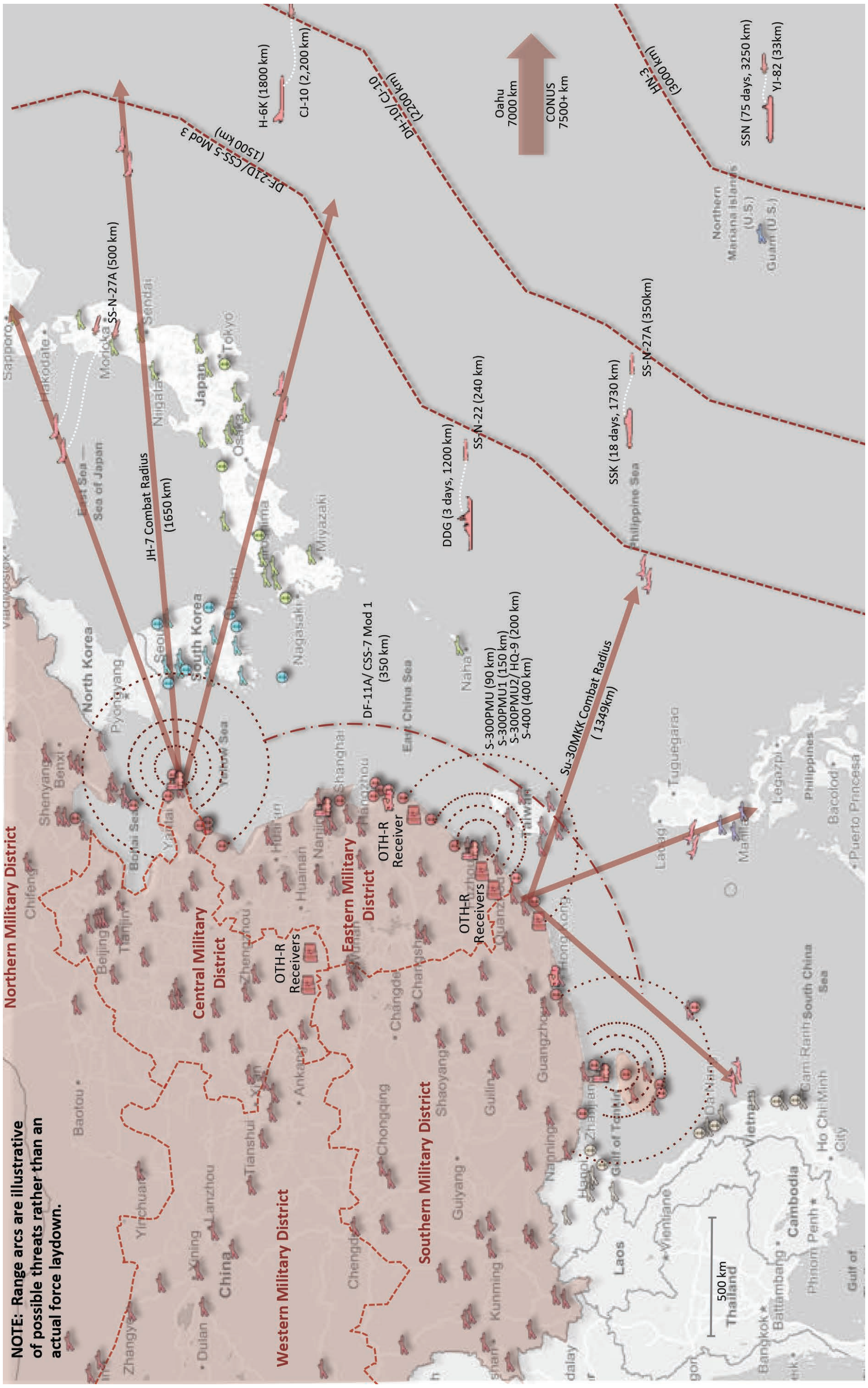
20 "Over the past decade, Russia has made nuclear weapons a predominant element of its national security strategy and military doctrine." Matthew Kroenig, *The Renewed Russian Nuclear Threat and NATO Nuclear Deterrence Posture* (Washington, DC: Atlantic Council, February 2016), p. 1, available at http://www.matthewkroenig.com/Kroenig_Russian_Nuclear_Threat.pdf. Also see Nikolai Sokov, "Russia's Nuclear Doctrine," *NTI Issue Brief*, August 2004; and Dmitry Adamsky, "If War Comes Tomorrow: Russian Thinking About 'Regional Nuclear Deterrence'," *The Journal of Slavic Military Studies* 27, no. 1, 2014.

21 See Barry D. Watts, *Six Decades of Guided Munitions and Battle Networks: Progress and Prospects* (Washington, DC: Center for Strategic and Budgetary Assessments, 2007), pp. 3–4.

22 Mary C. FitzGerald, *Marshal Ogarkov and the New Revolution in Soviet Military Affairs* (Alexandria, VA: Center for Naval Analyses, 1987); and Andrew F. Krepinevich, *The Military-Technical Revolution: A Preliminary Assessment* (Washington, DC: Center for Strategic and Budgetary Assessments, 2002).

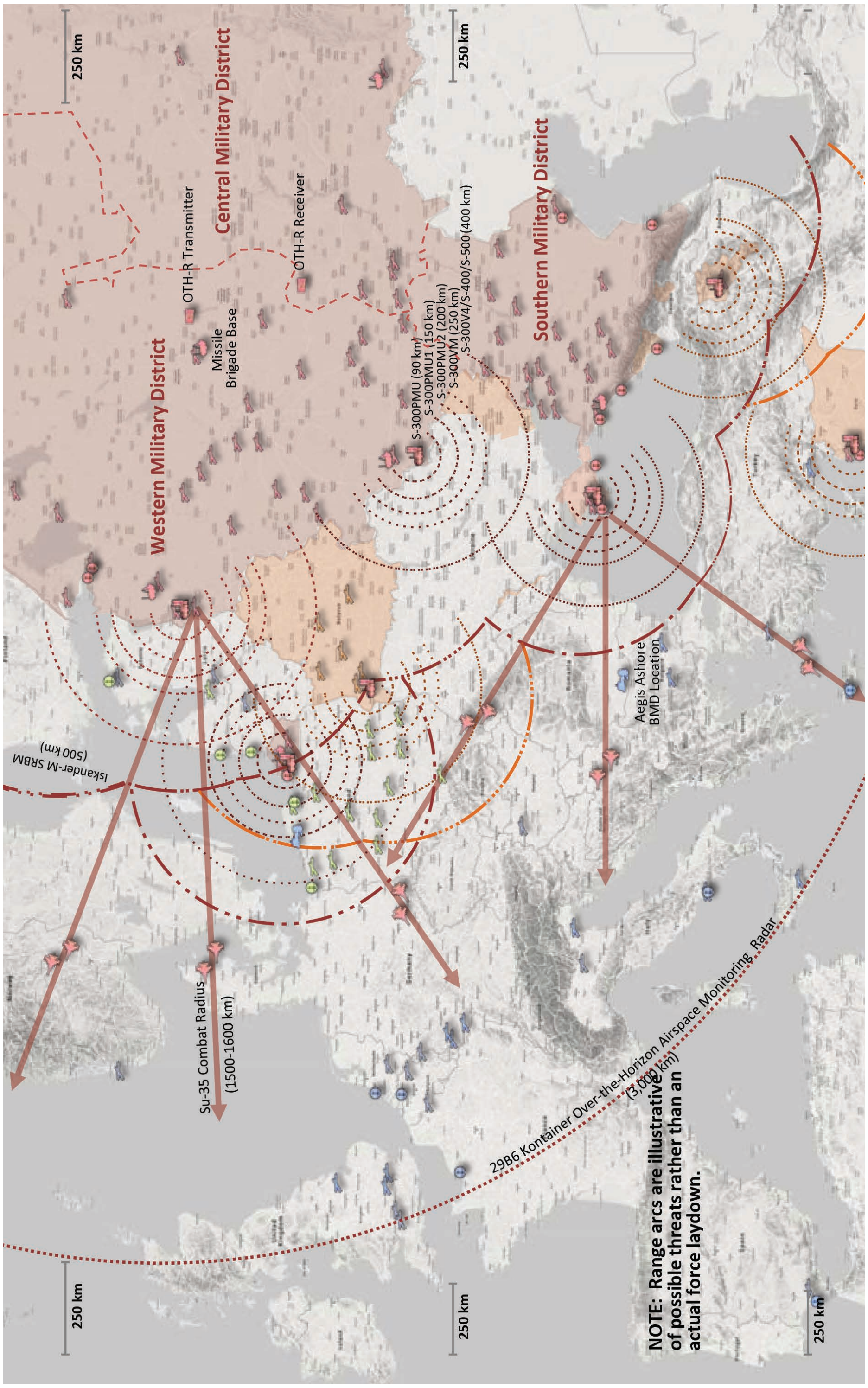
23 "Commentary: Respecting China's Core Interests is the 'Bottom Line' for Businesses," *Xinhua*, January 12, 2018, available at http://www.xinhuanet.com/english/2018-01/12/c_136891460.htm.

FIGURE 1: CHINA'S COUNTER-INTERVENTION CAPABILITIES



Office of Naval Intelligence (ONI), *The PLA Navy: New Capabilities and Missions for the 21st Century* (Washington, DC: ONI, April 9, 2015), pp. 13–25; and Office of the Secretary of Defense (OSD), *Military and Security Developments Involving the People's Republic of China 2016*, Annual Report to Congress (Washington, DC: DoD, 2016), pp. 22–29.

FIGURE 2: RUSSIA'S COUNTER-INTERVENTION CAPABILITIES



Data to build this chart was derived from IHS Jane's in January 2016.

As shown in Figure 2, the Russian military's counter-intervention capabilities cover NATO's eastern front-line states and extend into central Europe, enabling Russian forces to significantly degrade a potential NATO response. Furthermore, Russia's advanced IADS, EW systems, strike aircraft, precision fires, and heavy infantry vehicles give it military superiority over its immediate neighbors, enabling the Russian military to rapidly invade the Baltic states, Georgia, Romania, or Bulgaria. As with China, a Russian *fait accompli* such as the annexation of the Crimea in 2014 is made easier by the proximity of target nations to Russia. Moreover, like China, Russia's counter-intervention capabilities raise the cost and disruption of an attempt to eject Russian forces after their initial aggression, making it less likely the United States and international community would undertake such an action.

Russia also has interests in the Eastern Mediterranean and the Black Sea, which have seen a dramatic increase in Russian naval and air activity as the Russian government attempts to expand its geopolitical influence.[24] The Russian military has expanded its facilities in Syria and the Crimean Peninsula, including deployment of counter-intervention capabilities to extend the reach of Russian sensor and weapons networks.

Degrading and denying U.S. power projection capability is an essential element of Chinese and Russian efforts to reshape regional balances in their favor. By raising the level of escalation needed for the United States to intervene on behalf of an ally suffering Chinese or Russian aggression, these great power competitors aim to undermine the credibility of U.S. security assurances in those regions. This may not only undermine the leadership of the United States but also make regional nations more likely to accede to Chinese and Russian demands.

Russia and China also use their ability to contest the waters, land, and airspace around their territory to protect and support their gray zone operations. To respond proportionally on behalf of allies in the Western Pacific or Eastern Europe, U.S. forces would need to do so with a small, lightly armed force. Such a force would operate at high risk of attack by weapons and platforms operating in Chinese or Russian territory. To reduce that risk, U.S. and allied forces would need to either deploy in larger, better-defended formations or attack military capabilities on Russian or Chinese territory, both of which could potentially be seen as escalatory and disproportionate to the original gray zone aggression.[25] In this way, the United States could be dissuaded from intervening, which would in turn undermine U.S. extended conventional deterrence as well as the U.S. ability to reassure its allies. Chinese and Russian leaders have exploited U.S. reluctance to intervene in gray zone confrontations by carefully calibrating their aggression to remain below the level at which an overt American military response becomes necessary to preserve U.S. alliances.[26]

24 Andrea Macias, "A Detailed Look at How Russia Annexed Crimea," *Business Insider*, March 24, 2015, available at http://www.businessinsider.com/how-russia-took-crimea-2015-3.

25 This dynamic is described in detail in Bryan Clark, Mark Gunzinger, and Jesse Sloman, *Winning in the Gray Zone: Using Electromagnetic Warfare to Regain Escalation Dominance* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017).

26 See Mazarr, *Mastering the Gray Zone*; and Brands, "Paradoxes of the Gray Zone."

Furthermore, Russian and Chinese military capabilities are proliferating to nations such as Iran, North Korea, and others. Advanced land-attack ballistic missiles, anti-ship cruise and ballistic missiles, and long-range anti-air networks are providing these states with more dangerous capabilities than those fielded by North Vietnam and other Soviet proxies during the Cold War. Armed with counter-intervention systems of their own, these strategically located regional powers could threaten the interests of the United States, its allies, and trading partners.

A New Approach to Conventional Deterrence

Although not always explicitly stated, the U.S. approach to deterrence from the early 1990s until the 2018 NDS was essentially to maintain (with its allies) the credible threat of reversing the gains of an adversary's aggression, and of potentially overthrowing the aggressor's government. The United States employed this "brute force" approach during Operation Desert Storm to remove Iraqi forces from Kuwait, and it is assumed to be the planned approach for an allied response to an invasion of the Republic of Korea (RoK) by the Democratic People's Republic of Korea (DPRK).[27] In terms of U.S. posture, forward-deployed forces are used to support this strategy of an eventual response to aggression, rather than stopping the aggression outright.

The counter-intervention strategies and capabilities of Russia, China, Iran, and North Korea reduce the credibility of a brute force approach to deterrence. U.S. adversaries could complete an act of regional aggression within days, as Russia did in Crimea, using snap exercises to disguise their mobilization and military and political actions to delay U.S. and allied intervention until the operation is largely complete.[28] The level of force and costs entailed to reverse the adversary's gains would be considerable. Apart from the likely economic disruption, the number of potential U.S. and noncombatant casualties as well as the increased possibility of nuclear escalation could deter a U.S. response. Likewise, the international community and those U.S. allies that would not be threatened directly by such aggression might not support what they might see as a destabilizing U.S. conventional response to dislodge the aggressor.

During the Cold War, the United States and NATO threatened a nuclear response to stop a massive Soviet invasion of Central Europe. Such an approach lacks credibility as a response to either the PLA blockading Taiwan or Russian forces creating a frozen conflict in the territory of a NATO ally. Although these acts of aggression would undermine America's security assurances and alliance relationships, they would not pose an immediate and direct threat to the United States.

27 Yochi Dreazen, "Here's What War with North Korea Would Look Like," *Vox*, February 8, 2018, available at https://www.vox.com/world/2018/2/7/16974772/north-korea-war-trump-kim-nuclear-weapon.

28 Russian forces regularly conduct snap exercises in the Western Military District to practice likely maneuvers and habituate Eastern European NATO allies to rapid mobilizations. See Lee Litzenberger, "Beyond Zapad 2017: Russia's Destabilizing Approach To Military Exercises," *War on the Rocks,* November 28, 2017, available at https://warontherocks.com/2017/11/beyond-zapad-2017-russias-destabilizing-approach-military-exercises/.

The growing abilities of China and Russia to conduct rapid military operations against their neighbors undermines both U.S. extended deterrence and the credibility of U.S. security assurances to its allies in the Western Pacific and Eastern Europe. Leaders of Japan, Australia, South Korea, and the Philippines are concerned about China's naval buildup and increasingly aggressive behavior at sea. In response, they are modernizing and expanding their navies, particularly their submarine fleets and coast guards, and increasing coordination with U.S. naval forces.[29] In Europe, NATO allies and partners are also worried about Russia's capabilities and behavior, but their military modernization efforts have been more uneven.[30]

The U.S. military needs to develop a new model of conventional deterrence and reassurance. Given the ability of adversaries such as China and Russia to achieve a quick victory at varying levels of escalation and the disproportionate nature of nuclear retaliation, the United States should instead be prepared to deny or delay an adversary's ability to achieve its objectives or to punish aggression with proportional, conventional force.

The 2018 NDS makes this shift and states that the U.S. military will deny, degrade, or delay enemy aggression, rather than respond after the fact.[31] One implication of this strategy is the need for a robust military posture able to counter great power attacks in real time. Due to the proximity of China and Russia to their likely objectives, U.S. forces will need to be able to respond promptly and fight relatively close to enemy territory.

Ground forces can be based in allied countries, such as in the Baltic NATO states, the Republic of Korea, or Japan, enabling them to help deny or defeat aggression against those allies. U.S. Marine or Army units can be more persistent than air or naval forces, but they may be constrained in size or capability either by host nation concerns about a large U.S. footprint or by scarcity of essential capabilities such as long-range surface-to-surface missiles and air defense systems. Air forces can also be stationed in allied territory to respond promptly to aggression, but they would be vulnerable to enemy attack or limited in number or capability by host nation concerns about provoking enemies. Long-range bombers can rapidly deliver large-scale precision strikes from less-vulnerable bases outside the theater, but they may not convey the same deterrence or reassurance effect as forces based in the region.

Naval forces can complement ground and air forces by mitigating some of these limitations, and, in certain situations, they may be the primary force for early deterrence and reassurance operations. Although they have a finite capacity, naval forces can operate persistently in

29 Steven Stashwick, "Naval Buildup in the South China Sea," *The Diplomat*, July 15, 2015, available at https://thediplomat.com/2015/07/naval-buildups-in-the-south-china-sea/.

30 Eoin Micheál McNamara, "Securing the Nordic-Baltic Region," *The NATO Review Magazine,* March 17, 2016, available at https://www.nato.int/docu/review/2018/Themes/EN/index.htm#2016.

31 Donald J. Trump, *National Security Strategy of the United States of America* (Washington, DC: U.S. Government Printing Office, 2018), p. 45, available at https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf; and James Mattis, *Summary of the National Defense Strategy of the United States of America* (Washington, DC: DoD, 2018), p. 7, available at https://www.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf.

international waters near a potential area of conflict with less chance of provoking the enemy and less impact on the local population than forces based on allied territory. Ships also self-deploy, enabling the level of force to be scaled commensurate with the situation. Once in an operating area, however, they may require access to fuel and supplies from the region.[32]

Key Operational Challenges to U.S. and Allied Naval Forces

Given the potential for naval forces to deny or delay aggression, it is understandable that great power competitors and regional actors are fielding long-range sensor and weapon networks to slow or stop U.S. power projection into their near abroad. During crises or gray zone confrontations, U.S. naval forces could be held at risk when operating inside contested areas like those depicted in Figures 1 and 2. In war, U.S. naval forces would be challenged to ensure U.S. and allied access to resources, battlefields, markets, lines of production, and information in the region.[33]

To deny or delay aggression, U.S. naval forces, including CVWs, will need to be able to defend themselves while still conducting offensive operations against enemy forces attacking a U.S. ally or friend. The primary threats for naval forces to overcome will be air, missile, and undersea attacks. U.S. naval forces may also be required to help defend forces on the ground, who will face the same challenges.

Air and Missile Threats

The most significant and comprehensive threat facing the U.S. fleet is the large number of long-range air- and ground-launched anti-air and anti-ship missiles that China, Russia, and regional powers could deploy. This challenge is exacerbated by the use of gray zone tactics by Chinese or Russian forces that seek to preclude a U.S. campaign to roll back sensors and weapons on enemy territory until a conflict has escalated into a major war, at which point such operations may be infeasible. Instead, U.S. naval forces need the ability to protect themselves by only engaging weapons or airborne and naval weapons platforms.

The increasing range of foreign ASCMs is compounding the anti-ship missile threat. Today, most enemy ASCMs have maximum ranges of around 500 nm. Current and emerging LACMs, however, could be modified to have anti-ship capabilities, as the U.S. Navy is doing with Maritime Strike Tomahawk (MST). This could extend the range of ASCMs to 1,000 nm or

32 See Geoffrey Till, *Seapower: A Guide for the Twenty-First Century* (Portland, OR: Frank Cass, 2004), pp. 162–192; and Milan Vego, *Maritime Strategy and Sea Control: Theory and Practice* (New York: Routledge, 2016), pp. 18–27.

33 This challenge is described in Bryan Clark, *Commanding the Seas: A Plan to Reinvigorate U.S. Navy Surface Warfare* (Washington, DC; Center for Strategic and Budgetary Assessments, 2015), pp. 10–24.

more, although these missiles would probably be less survivable than shorter-range ASCMs that fly at higher speeds and are more maneuverable.[34]

The threat of anti-air and anti-ship missiles is especially difficult for U.S. naval forces because they are the "away team" and must bring all their offensive and defensive weapons with them, whereas an aggressor operating along its periphery is the "home team" and would be able to base its capabilities ashore or close to its shores. The numbers and sophistication of air and missile threats demand that an increasing portion of a ship's vertical launch system (VLS) magazine capacity be devoted to defensive weapons. And, as in the late Cold War, an increasing portion of the CVW's aircraft and sorties will be devoted to air defense. These defensive improvements come at the expense of the offensive weapons needed to degrade, delay, or deny enemy aggression.

As described in previous CSBA studies, U.S. naval forces need to adopt a new fleet AMD approach that increases the fleet's overall air defense capacity.[35] Naval forces could then operate at a range where U.S. air defense capacity is sufficient to at least temporarily address the salvo sizes the enemy can launch at naval forces and land bases in the vicinity. Although naval forces will lack the air defense capacity to be invulnerable or remain in the area indefinitely, this approach is intended to dissuade an adversary from expending a large number of weapons in an air attack that has a relatively high probability of being unsuccessful. The enemy may wait for a better opportunity to attack, which would give U.S. naval forces an opportunity to conduct offensive operations against the enemy.

The balance between carrier proximity to targets and the need to defend carriers from missile attack can be viewed in terms of a salvo competition.[36] In this competition, an opponent improving its short- and medium-range air defense systems increases the number or sophistication of strike weapons U.S. forces need to defeat them and reach defended targets. An opponent's long-range air defense systems complement its short-range defenses by compelling U.S. forces to launch strikes from farther away using rocket- or jet-propelled standoff weapons that are larger than a short-range gravity or glide weapon carrying a similar warhead. The fact that larger standoff weapons are carried in smaller numbers by each strike plat-

34 The U.S. Tomahawk land attack cruise missile has a range of more than 900 nm, and the Maritime Strike Tomahawk can be expected to have a similar range. The Tomahawk is a 25-year-old weapon, and it is likely the Chinese DH-10 and Russian Kalibr missiles share similar characteristics. ASCM versions of these missiles could be expected to have ranges of more than 1,000 nm. See "Tomahawk Cruise Missile," *Fact File*, U.S. Navy, updated April 26, 2018, available at http://www.navy.mil/navydata/fact_display.asp?cid=2200&tid=1300&ct=2; Jeffrey Lin and P.W. Singer, "China Shows Off Its Deadly New Cruise Missiles," *Popular Mechanics,* March 10, 2015, available at https://www.popsci.com/china-shows-its-deadly-new-cruise-missiles; and Sebastien Roblin, "Kalibr: Russia has its own 'Tomahawk' cruise missile," *The National Interest,* April 7, 2017, available at http://nationalinterest.org/blog/the-buzz/kalibr-russia-has-its-very-own-tomahawk-missile-20073.

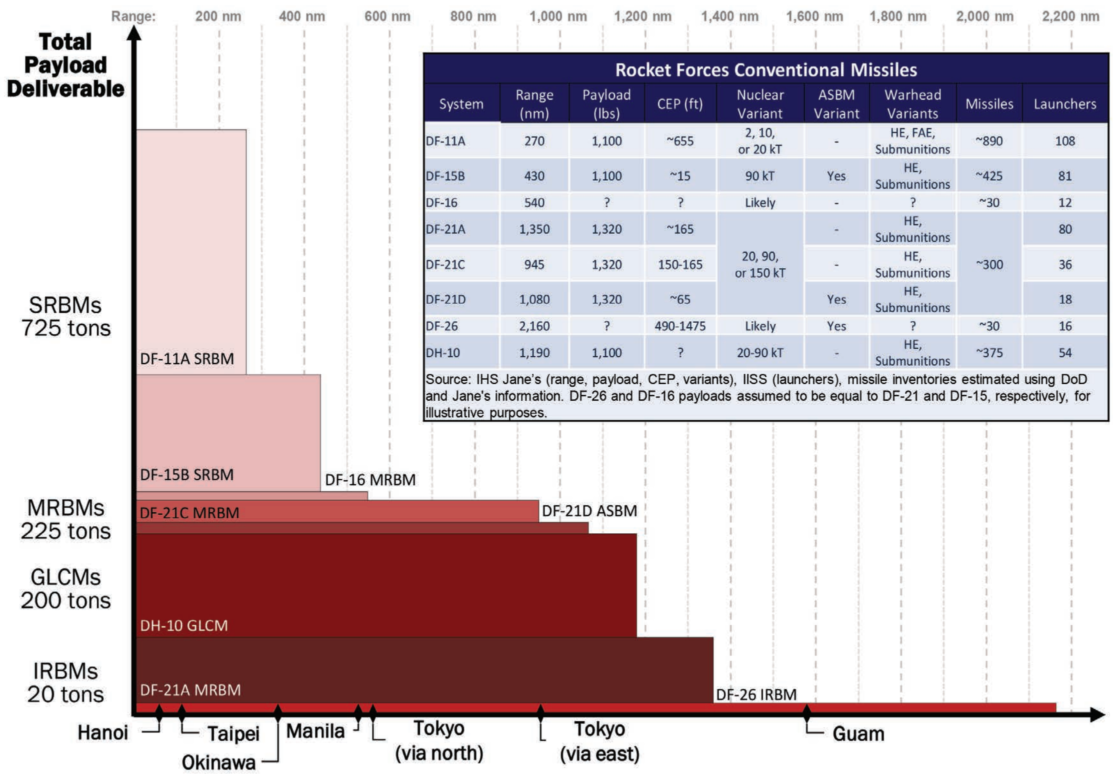
35 Clark, *Commanding the Seas*, pp. 16–22.

36 The dynamics and implications of the salvo competition are described in Mark Gunzinger and Bryan Clark, *Sustaining America's Precision Strike Advantage* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015); and Mark Gunzinger and Bryan Clark, *Winning the Salvo Competition: Rebalancing America's Air and Missile Defenses* (Washington, DC: Center for Strategic and Budgetary Assessments, 2016).

form reduces the possible salvo size from a given number of strike aircraft in U.S. and allied inventories. As in the example of carriers described above, an opponent can use long-range ASCMs to threaten U.S. carriers and compel them to operate from greater standoff distances, lowering their total aircraft sortie generation rate and further reducing the number of offensive weapons they can deliver against defended targets.

Figure 3 shows the approximate weapons payload that PLA land-based cruise and ballistic missiles could deliver at various ranges and the number of launchers able to deliver this payload. Figure 4 depicts the total payload the PLA could deliver when land-based bombers are included. Although not all of these weapons are configured for anti-ship missions, each ballistic missile has an anti-ship variant, and it is reasonable the PLA could develop an anti-ship modification to the DH-10 LACM, similar to that planned for the U.S. Navy Tomahawk cruise missile.

FIGURE 3: PLA CRUISE AND BALLISTIC MISSILE THROW WEIGHT



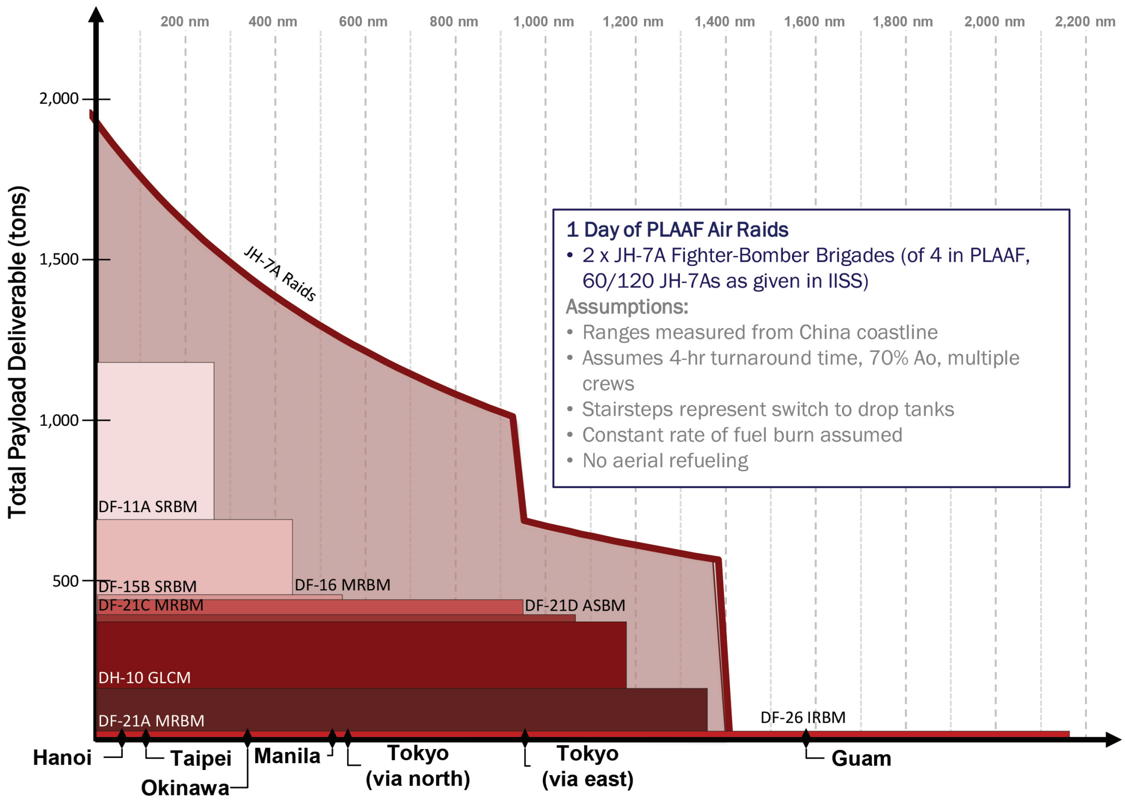
Rocket Forces Conventional Missiles

System	Range (nm)	Payload (lbs)	CEP (ft)	Nuclear Variant	ASBM Variant	Warhead Variants	Missiles	Launchers
DF-11A	270	1,100	~655	2, 10, or 20 kT	-	HE, FAE, Submunitions	~890	108
DF-15B	430	1,100	~15	90 kT	Yes	HE, Submunitions	~425	81
DF-16	540	?	?	Likely	-	?	~30	12
DF-21A	1,350	1,320	~165	20, 90, or 150 kT	-	HE, Submunitions	~300	80
DF-21C	945	1,320	150-165		-	HE, Submunitions		36
DF-21D	1,080	1,320	~65		Yes	HE, Submunitions		18
DF-26	2,160	?	490-1475	Likely	Yes	?	~30	16
DH-10	1,190	1,100	?	20-90 kT	-	HE, Submunitions	~375	54

Source: IHS Jane's (range, payload, CEP, variants), IISS (launchers), missile inventories estimated using DoD and Jane's information. DF-26 and DF-16 payloads assumed to be equal to DF-21 and DF-15, respectively, for illustrative purposes.

ONI, *The PLA Navy: New Capabilities and Missions for the 21st Century* (Washington, DC: ONI, April 9, 2015), pp. 13–25, available at http://www.oni.navy.mil/Portals/12/Intel%20agencies/China_Media/2015_PLA_NAVY_PUB_Print.pdf?ver=2015-12-02-081247-687; and OSD, *Military and Security Developments Involving the People's Republic of China 2016*, pp. 22–29.

FIGURE 4: PLA TOTAL THROW WEIGHT



ONI, *The PLA Navy: New Capabilities and Missions for the 21st Century* (Washington, DC: ONI, April 9, 2015), pp. 13–25, available at http://www.oni.navy.mil/Portals/12/Intel%20agencies/China_Media/2015_PLA_NAVY_PUB_Print.pdf?ver=2015-12-02-081247-687; and OSD, *Military and Security Developments Involving the People's Republic of China 2016*, pp. 22–29.

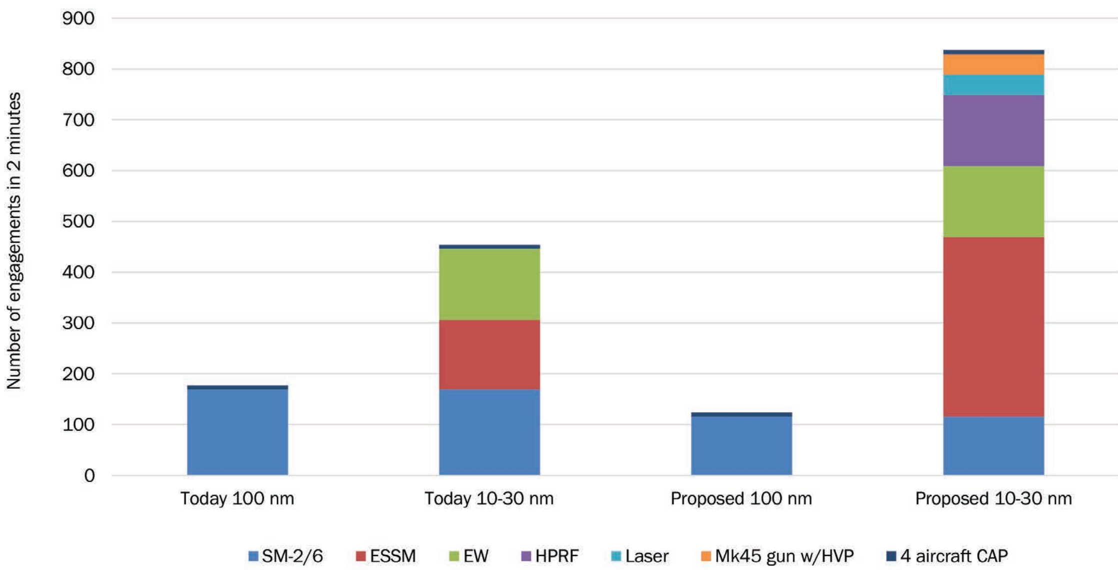
Figure 3 and 4 suggest that beyond about 1,000 nm from the Chinese mainland, U.S. naval forces would be at risk of attack primarily from DF-21 medium-range ballistic missiles (MRBM), DF-26 intermediate-range ballistic missiles (IRBM), DH-10 ground-launched cruise missiles (GLCM), and People's Liberation Army Air Force (PLAAF) bombers carrying ASCMs or bombs. Assuming each weapon is configured with a 1,000-lb warhead, Figure 4 suggests a U.S. naval force located about 1,000 nm from China could face up to 2,000 weapons over the course of a single day.[37] Factoring in cruise and ballistic missile launcher capacity constraints, this reduces the number of weapons that U.S. forces may need to defeat to about 640 weapons in a single incoming salvo.[38]

37 This includes 225 tons from DF-21 MRBMs, 200 tons from DH-10 GLCMs, 20 tons from DF-26 IRBMs, and 600 tons from JH-7A bombers for a total of 1,045 tons of ordnance, equating to 2,090 1,000-lb weapons.

38 Using the data in Figures 3 and 4, there are about 200 launchers for DH-10 GLCMs, DF-21 MRBMs, and DF-26 IRBMs. JH-7 bombers can deliver about 600 tons of ordnance per day at 1,000 nm; this assumes a 500-kt transit speed, a 1,200-nm combat radius, and that each aircraft makes about 2.7 sorties in 24 hours. These assumptions would require rotating crews, 4-hour turnaround times, and 70 percent aircraft availability. This translates into about 220 tons that could be delivered simultaneously, which equates to about 440 1,000-lb weapons.

To increase their defensive capacity, U.S. naval forces would need to employ a new AMD concept to engage enemy missiles at shorter ranges than today. Short-range interceptor SAMs such as the Evolved Sea Sparrow Missile (ESSM) or Rolling Airframe Missile (RAM) are smaller and less expensive than longer-range interceptors such as the SM-2 or SM-6, allowing more to be carried on each ship. A shorter-range AMD concept would also allow U.S. forces to use energy-based defenses instead of interceptors. Directed energy weapons such as laser, high-power microwave, and other electronic warfare weapons operate in a straight line and cannot reach a target over the horizon. With short-range interceptors and directed energy weapons devoted to defending against missiles, naval forces could use DCA patrols and larger, more expensive long-range interceptors such as the SM-6 against enemy launch platforms such as ships and aircraft. There would be fewer enemy platforms than missiles, and the cost exchange of using expensive interceptors against an enemy weapons platform is still favorable to the defender.[39]

FIGURE 5: NUMBER OF ENGAGEMENTS BY CSG AIR DEFENSES



This chart assumes a CSG composition of one CVN, one CG, and four DDGs per OPNAVINST 3501.363B. Each CG and DDG apportions its VLS cells in the current version as follows: 10 percent SM-3, 20 percent SM-6, 5 percent VL ASROC, 30 percent SM-2, 10 percent ESSM, and 25 percent TLAM; in the proposed version, 15 percent of VLS cells shift from SM-2 to ESSM, which are quad-packed four per VLS cell. Further, in the current version, each CG and DDG has a SLQ-32(V)6 EW system; in the proposed version, all CGs and DDGs also have a 300 kw laser, HPM system, and can use HVPs from one of its Mk-54 guns.

39 Clark, *Commanding the Seas*; Gunzinger and Clark, *Winning the Salvo Competition*; and Bryan Clark, Peter Haynes, Bryan McGrath, Craig Hooper, Jesse Sloman, and Timothy A. Walton, *Restoring American Seapower: A New Fleet Architecture for the United States Navy* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017), particularly pp. 17–41.

Using this new air defense approach, a normal CSG of one CVN, one guided missile cruisers (CG), and four guided missile destroyers (DDG) would have the defensive capacity depicted in Figure 5. This assumes that interceptors such as SM-2 and ESSM have a single-shot probability of kill (SSPK) of 0.7 and energy-based weapons such as SLQ-32 EW systems and lasers have a SSPK of 0.4. As the chart shows, a future CSG could defeat up to about 800 incoming weapons in 2 minutes.

The defensive capacity depicted in Figure 5 suggests a CSG with the proposed enhanced defenses could withstand the maximum salvo that PLA missiles and aircraft could deliver at 1,200 nm. Several caveats apply, however. The incoming weapons could arrive in a shorter period of time or in a disadvantageous pattern or order. They might also successfully engage air defense sensors first. Any of these situations would reduce defensive capacity. Moreover, this is the defensive capacity for a single salvo. Afterward, all of the ships' interceptors would be expended, leaving only energy weapons and DCA aircraft to protect the CSG. Within a few hours, PLA missile launchers and aircraft could be reloaded for another salvo while the CSG will have insufficient capacity to defend itself.

U.S. naval forces, and CSGs in particular, will need to reduce their dependence on kinetic interceptors in air defense to allow them to operate longer in contested areas. There are two complementary approaches available:

- Use EMW to complicate adversary targeting; and
- Shoot enemy bombers and other missile launchers before they can deliver their weapons.

EMW operations can be used to augment missile defenses in contested areas by increasing the number of potential targets the enemy must attack or assess.[40] Decoy targets would either multiply the number of weapons an adversary would need to launch for an attack to be effective or require the enemy to delay and better clarify its targeting picture.

Physical decoys in the visual and infrared (IR) portions of the electromagnetic spectrum (EMS) and radiofrequency (RF) emulators can create additional potential targets. From the enemy's perspective, each of these potential targets could have a robust defensive capacity. An enemy will have greater difficulty discerning between decoys and real targets if both are obscured by radar jammers, electro-optical (EO) and IR laser dazzlers, chaff or smoke, and camouflage. Combining decoys with obscurants or jammers would also allow each to be less sophisticated and expensive because they do not individually need to be perfect; they only need to be good enough to prevent the enemy from easily discerning real systems from decoys. To engage U.S. forces, the adversary would need to conduct a large attack with many weapons,

40 See Bryan Clark and Mark Gunzinger, *Winning the Airwaves: Regaining America's Dominance in the Electromagnetic Spectrum* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015); and Clark, Gunzinger, and Sloman, *Winning in the Gray Zone*.

which could be a more escalatory action than the enemy might be willing to undertake. Otherwise, the enemy must take time to investigate each potential target to determine if it is a decoy, potentially ceding the initiative to U.S. and allied forces.

Threats against carriers from surface ships largely manifest themselves as missile threats, because ASCMs allow surface combatants to attack a carrier at long range and with potentially large salvos. The defensive improvements described above will help address the missile threat from surface combatants, as well as degrade or defeat the enemy ISR&T supporting surface attacks. Because surface combatants could combine their attacks with those of ground and air forces or attack from less-protected sectors, U.S. carriers would need to attack surface ships before they can launch attacks, the same as with enemy bombers and ground-based missile launchers. (New CVW approaches to SUW are described in Chapter 4 that will enable the CVW to engage surface ships beyond ASCM range.)

Undersea Threats

Chinese and Russian efforts to counter the U.S. ability to project power now also extend underwater. While the United States still retains the overall advantage in undersea capabilities, its adversaries are improving. They are also taking advantage of the vulnerability of U.S. ASW platforms and the resulting reliance of the U.S. Navy on submarines for ASW operations near adversary territory. The Russian and Chinese militaries are establishing sensor networks undersea that could threaten U.S. submarine operations. Their approach uses seabed sonar arrays like the U.S. Sound Surveillance System (SOSUS) and low frequency active (LFA) sonar on ASW corvettes and frigates to find U.S. submarines. Russian or Chinese maritime patrol aircraft (MPA) could then engage U.S. submarines. Even if their attacks are unsuccessful, they could have the effect of compelling U.S. submarines to break off their operations and leave the area.[41]

Submarines are also an increasingly prominent element of Chinese and Russian efforts to counter U.S. and allied power projection. China is modernizing its submarine force, which includes both diesel and nuclear submarines. Although relatively noisy compared to U.S. submarines, the PLA Navy includes more submarines than the U.S. Navy and can focus its efforts in the Western Pacific and Indian Oceans.[42] Although its submarine fleet is much smaller than the U.S. Navy's, Russia's latest class of nuclear submarines is reportedly as quiet

41 Lyle Goldstein and Shannon Knight, "Wired for Sound in the Near Seas," *Proceedings*, April 2014, available at http:// www.usni.org/magazines/proceedings/2014-04/wired-sound-near-seas; and Kathleen H. Hicks, Andrew Metrick, Lisa Sawyer Samp, and Kathleen Weinberger, *Undersea Warfare in Northern Europe* (Washington, DC: Center for Strategic and International Studies, 2016), pp. 10–12, available at https://www.csis.org/analysis/undersea-warfare-northern-europe.

42 ONI, *The PLA Navy: New Capabilities and Missions for the 21st Century* (Washington, DC: ONI, April 9, 2015), pp. 13–25, available at http://www.oni.navy.mil/Portals/12/Intel%20agencies/China_Media/2015_PLA_NAVY_PUB_Print.pdf?ver=2015-12-02-081247-687.

as some of the newest U.S. submarines, and previous generations are on par with older U.S. submarines.[43]

The most significant threat posed by Chinese and Russian submarines is their ability to launch ASCMs before they can be detected by hull-mounted active sonars and towed passive sonars carried by surface combatants or helicopter-borne dipping sonars and sonobuoys. Moreover, U.S. ASW land-based MPA such as the P-8A Poseidon could be threatened by air defenses or fighters hundreds of miles from China's and Russia's coast, preventing MPA from protecting U.S. naval forces or allied bases from submarine attack. Consequently, the future CVW will need new ASW approaches and capabilities to protect CSGs and shore facilities from submarine attack.

U.S. naval forces, including the CVW, will also need new capabilities and concepts for mine warfare. Offensive mining, which is not a significant naval mission today, may be an option to address the threat of Russian or Chinese submarines and constrain the movement of enemy surface combatants with air defense and ASW capabilities. More urgently, however, naval forces will need to address the threat posed by enemy mines, especially those deployed by strategically located regional powers like Iran. Mine countermeasures (MCM) has not been a high priority for the Navy since the Cold War ended, and the Navy will need to modernize MCM capabilities to deter aggressors and reassure allies.[44]

Implications for the Future CVW

Degrading and defeating adversary counter-intervention concepts and capabilities will only enable U.S. naval forces to operate temporarily in contested areas. Within the resulting windows of opportunity, the fleet and its CVWs will need to be able to conduct prompt attacks against an aggressor's forces that are threatening or attacking U.S. allies. Furthermore, the growing prevalence of gray zone warfare suggests that naval forces may need to conduct proportional operations that don't start with extensive attacks on enemy sensors and weapons in their home territory. This will require CSGs to operate in areas where their defensive capacity can reliably defeat possibly multiple enemy salvos until weapons launchers or sensors are eventually neutralized. These considerations imply CVWs need to be able to operate at longer ranges and in more contested environments than they have since the end of the Cold War. CVWs will also need to restore their capability for operations such as ASW, which atrophied following the dissolution of the Soviet Union. The implications of these requirements for CVW roles, posture, operational concepts, and composition will be explored in the following chapters.

43 Hicks et al., *Undersea Warfare in Northern Europe*, pp. 10–12.

44 See Scott Truver, "Taking Mines Seriously," *Naval War College Review* 65, no. 2, Spring 2012, available at https://digital-commons.usnwc.edu/nwc-review/vol65/iss2/5; and "Littoral Combat Ships: Mine Countermeasures Mission Package," *Fact File*, U.S. Navy, updated December 6, 2016, available at http://www.navy.mil/navydata/fact_display.asp?cid=2100&tid=425&ct=2.

CHAPTER 2

Roles and Posture of the Future Carrier Air Wing

Naval forces will play an important role in competition with China and Russia because they can provide the persistence, scalability, and firepower needed to help deter and defeat aggression at various levels of escalation, including in gray zone conflicts. To address improving adversary capabilities, however, naval forces must evolve between now and 2040. Previous CSBA studies have addressed future naval operations more generally and their implications for fleet architecture.[45] This chapter will focus on the future role of carriers and their air wings, and the changes needed in their deployment patterns to address improving adversary capabilities. These changes will, in turn, inform the operational concepts as well as the type and number of aircraft needed in the future CVW.

As described in Chapter 1, instead of planning to respond to aggression after the fact, U.S. and allied forces will need the ability to deny or delay an act of aggression in order to deter. The proximity enjoyed by China and Russia to their potential targets will require that U.S. and allied forces be positioned nearby or have the ability to reach these areas quickly. Although naval forces can operate in international waters near areas of potential conflict, their posture will need to balance the benefits of this proximity against the risk from anti-ship and anti-air threats operated by great power adversaries. Specifically, CSGs need to operate in areas where the number and sophistication of threats can be countered, at least temporarily, by the capability and capacity of their defensive systems. The need to operate at longer ranges than today and against more capable threats will affect the role of carriers and CVWs in the joint force, as well as define the regions in which they are able to fulfill these responsibilities.

45 Clark et al., *Restoring American Seapower*.

Role of CVWs in the Joint Force

CVWs will probably not dramatically change the nature of their contribution to the joint force between now and 2040, although the way they provide that contribution will need to evolve considerably. Aircraft design advancements and new technologies could help CVW aircraft compensate for improving adversary threats, but it is unlikely that they would enable completely new CVW roles and missions. For example, the fundamental constraint of current and planned carrier size will prevent the Navy from significantly increasing the size of its CVW aircraft to achieve ranges, survivability, and payload that would allow them to conduct large-scale, intercontinental strike missions like land-based bombers.

The role of CVWs in current and future joint operations derives mostly from a carrier's mobility and sustainability and the CSG's defensive capacity. Unlike airfields, carriers can move to an area of operations and reposition to address new missions or counter emerging threats. Carriers are not restricted by host nations on the number or type of operations conducted from the host's territory. And carriers can be sustained on station indefinitely through underway replenishment of fuel and weapons; they can likewise move to an area of lower threat to rendezvous with logistics forces. These attributes could allow carrier-based aircraft to conduct a mission when sufficient land-based aircraft may be unavailable because of a lack of nearby airfields, because nearby airfields are being suppressed by attacks, or because those aircraft are engaged in operations elsewhere. A mission may also require specific CVW capabilities, such as ASW, EMW, or AEW&C.

Three main approaches to using CVWs emerge from a consideration of these factors and the increasingly contested operational environments previously described:

- <u>In large-scale sea control and power projection operations around the periphery of a great power</u>. The balance between proximity and effective air defense during operations against the PLA may place CSGs about 1,000 nm from significant missile threats such as air bases, ground-based missile launchers, and surface or submarine groups. This would place carriers in the eastern Philippine Sea during a conflict with China. A similar approach during a conflict with Russia in Eastern Europe would see carriers operating in the Norwegian or North Seas.

  CSGs and their CVWs can also support joint force operations by helping to defend ground forces and bases on the periphery of a great power conflict such as in Japan, Guam, the Philippines, or Australia during a confrontation with China. Although land-based fighters may be unable to launch while their bases are under attack, CVW aircraft from carriers in lower threat areas could engage enemy bombers and attack aircraft before they launch cruise missiles and bombs, reducing the number of weapons reaching short-range air defense (SHORAD) systems on the ground.

- <u>In smaller-scale missions at long range, sometimes in support of other attack platforms or fires</u>. In environments where there are no airfields located close to a conflict, or they are unavailable due to attack or host nation concerns, a carrier can provide a relatively close air base from which strike, EW, ISR&T, or counterair operations could be launched. These missions could also add capacity to or improve the effectiveness of strikes by long-range, land-based bombers that are capable of carrying large weapons payloads.

For example, to increase their salvo sizes, U.S. and allied weapons platforms could approach targets more closely and employ smaller, shorter-range weapons. With ongoing improvements to adversary air defense systems and sensors, however, attacking from close range will generally require low-observable aircraft or submarines. Currently, the U.S. Air Force has only 19 stealthy B-2 Spirit heavy bombers and is planning to build at least 100 of its replacement, the B-21 Raider.[46]

CVW aircraft could provide additional strike capacity to augment that of land-based bombers. With aerial refueling, a package of 16 to 35 F-35C strike fighters could generate salvos of 100–200 weapons against well-defended targets from carriers operating 1,000 nm away.[47] A future long-range CVW attack aircraft could likely conduct the mission without refueling. This strike capacity would likely be effective against ships and less-defended shore targets due to the relatively small number of aimpoints that need to be hit and the capacity constraints of shipboard air defense systems. Against heavily defended shore targets, CVW strike fighters may not be able to generate sufficient strike capacity on their own, but they could support land-based bomber strikes.

CVWs could also complement land-based aircraft by increasing the survivability of larger strike platforms or the weapons they carry. For example, CVW fighter and EW aircraft could escort and help protect land-based bombers from enemy DCA CAPs or jam enemy surveillance or air defense radars to improve the survivability of bomber or ship-launched weapons. CVW aircraft could also carry expendable jammers and decoys such as the Miniature Air-Launched Decoy (MALD) that reduce the effectiveness of enemy air defenses against U.S. strike weapons in flight. This effort could help reduce the number of strike weapons and platforms needed for a particular mission.

46 Aaron Mehta, "US Air Force Requests $156.3 Billion in FY19, Plans to Retire B-1, B-2 Fleets," *Defense News,* February 12, 2018, available at https://www.defensenews.com/smr/federal-budget/2018/02/12/air-force-requests-1563-billion-in-fy19-plans-to-retire-b-1-b-2-fleets/.

47 The F-35C will be the CVW's only low-observable strike aircraft once it enters operational service during the 2020s. To remain stealthy, the F-35C carries weapons in an internal bay, limiting it to two standoff weapons such as the Joint Standoff Weapon (JSOW) or eight shorter-range SDBs. Assuming the Navy's plan for two squadrons of ten F-35Cs in each CVW in the 2030s, about 16 F-35C sorties will be available at any one time, capable of delivering a total salvo of 118 SDBs. Alternatively, a combination of legacy F-18 E/Fs and F-35Cs could externally carry standoff weapons to be launched outside the range of enemy air defenses. This would result in about the same number of weapons per aircraft but would enable more aircraft to contribute to the salvo. With 19 F/A-18 E/Fs available and eight used for recovery tanking or air defense, the CVW could launch up to 206 standoff weapons in a single strike.

- In the full range of military operations against regional powers. During small-scale confrontations with North Korea, Iran, or Islamist extremists, CSGs would be able to defend themselves and operate at relatively close range to the operating area. As a result, CVWs would be able to generate more frequent sorties and larger force packages than during a great power conflict. CVW aircraft could complement or replace land-based fighters that may not be able to operate from bases in the region due to the threat of adversary attacks, host nation constraints, or the need to employ those aircraft. For example, a large fraction of land-based fighters and bombers may be needed in a great power confrontation. Carriers and CVWs would provide the ability to check opportunistic aggression by a regional power.

  This category of missions describes how CVWs are often used today. It also illustrates how the range of CVW aircraft should increase to conduct these same missions in the future. F/A-18 strike fighters operating from carriers in the Persian Gulf or Arabian Sea must travel 500 to 800 nm to reach targets in Afghanistan or Syria. These day-long missions require multiple air refuelings from land-based tankers and F/A-18 E/F recovery tankers to ensure the returning strike fighters can safely land.[48] The inefficiency of this approach results in large part from the relatively short range of CVW strike fighters, which will only modestly improve with the F-35C.[49] Since non-stealthy land-based aerial refueling tankers may not be able to operate within range of Russian or Chinese air defenses and fighters, operations against these adversaries could require CVW strike fighters to refuel 200 to 500 nm from coastal target areas.

Future Carrier and CVW Force Posture

The above mission categories suggest U.S. carriers and their CVWs should be postured in areas overseas that would allow them to maneuver quickly to the periphery of a great power during periods of heightened tension or move to theaters where they can counter regional aggressors. In the recent past, carriers in the Middle East were often used as "presence" forces that remain in a small operating area from which they can conduct sustained sorties against terrorist and insurgent forces. This employs CVNs primarily as supplemental airfields and does not exploit their main advantages: their mobility and ability to operate outside high-threat areas. Moreover, operating a carrier in close proximity to potential adversaries such as Iran can make it an attractive and hard-to-defend target for an unwarned attack.[50]

48 Douglas Jehl, "A Nation Challenged: Air Operation: Afghanistan's Distance From Carriers Limits U.S. Pilots' Flights," *The New York Times,* October 11, 2001, available at https://www.nytimes.com/2001/10/11/world/nation-challenged-air-operation-afghanistan-s-distance-carriers-limits-us-pilots.html.

49 The F-35C will have a combat radius of approximately 600 nm, compared to about 500 nm for the F-18 E/F; see "F-35 Lightning II," *Global Security*, updated December 14, 2017, available at https://www.globalsecurity.org/military/systems/aircraft/f-35-specs.htm; and "F/A-18 E/F Super Hornet," *Military Analysis Network*, Federation of American Scientists (FAS), updated November 2, 2016, available at https://fas.org/man/dod-101/sys/ac/f-18.htm.

50 Rebecca Shabad, "Iranian Admiral Says US Aircraft Carriers would be Targeted in War," *The Hill,* May 6, 2014, available at http://thehill.com/policy/international/205283-iranian-official-says-us-warships-a-target-in-case-of-war.

In contrast, carriers deployed to the Indo-Pacific region usually do not remain close to adversary territory; they instead move frequently to conduct exercises, train regional allies and partners, or augment local forces as part of a deterrence operation. This approach exploits the CSG's mobility and enables it to be positioned advantageously during periods of heightened tension. CSGs deployed to Europe can exploit their mobility as well. During the Cold War, U.S. carriers regularly employed maneuver and deception tactics in the North Atlantic and Norwegian Sea to degrade Soviet targeting.[51]

As noted in Chapter 1, the 2018 NDS emphasizes DoD efforts to address great power competition and conflict. This suggests DoD may shift its posture to focus on Europe and the Indo-Pacific region, as the Navy is already doing through its recent carrier deployments.[52] The NDS also describes a new model for military posture using forward-deployed "contact" forces to engage allies or deter adversaries and "blunt" forces to delay, degrade, or deny enemy aggression. These forward forces are supported by "surge" and "homeland" forces to manage escalation and fight a larger conflict.

In the new posture model of the NDS, Navy surface combatants, submarines, and amphibious ships would likely be incorporated into the contact force, alongside ground and air forces deployed to the region. Surface naval forces are often based in the region where they operate and conduct port calls, participate in exercises with local navies and coast guards, and counter regional problems such as trafficking or piracy.

Because they generally operate farther out to sea and can only support exercises with the most capable partners, CSGs could be considered part of the blunt force. They would not need to be continuously in contact with allies or adversaries, but could quickly maneuver to join contact forces countering an act of aggression.[53]

CSBA's 2017 fleet architecture study proposed a similar deployment model (see Figure 6) in which surface combatants and amphibious ships would be assigned to regionally focused "Deterrence Forces." CSGs based in Japan and the U.S. West Coast would form a two-CSG "Maneuver Force" deployed to the Indo-Pacific region, and CSGs based on the U.S. East Coast would deploy to the Atlantic and Europe to support Deterrence Forces there.[54] This posture requires a fleet of twelve carriers rather than today's eleven, supported by ten CVWs instead of the nine CVWs now fielded by the Navy.[55]

51 Dean Allard, "Strategic Views of the US Navy and NATO on the Northern Flank, 1917-1991," in *The Northern Mariner*, volume 11, no. 1 (Ottawa, Ontario: Canadian Nautical Research Society, 2001), pp. 11–24, available at https://www.cnrs-scrn.org/northern_mariner/vol11/nm_11_1_11to24.pdf.

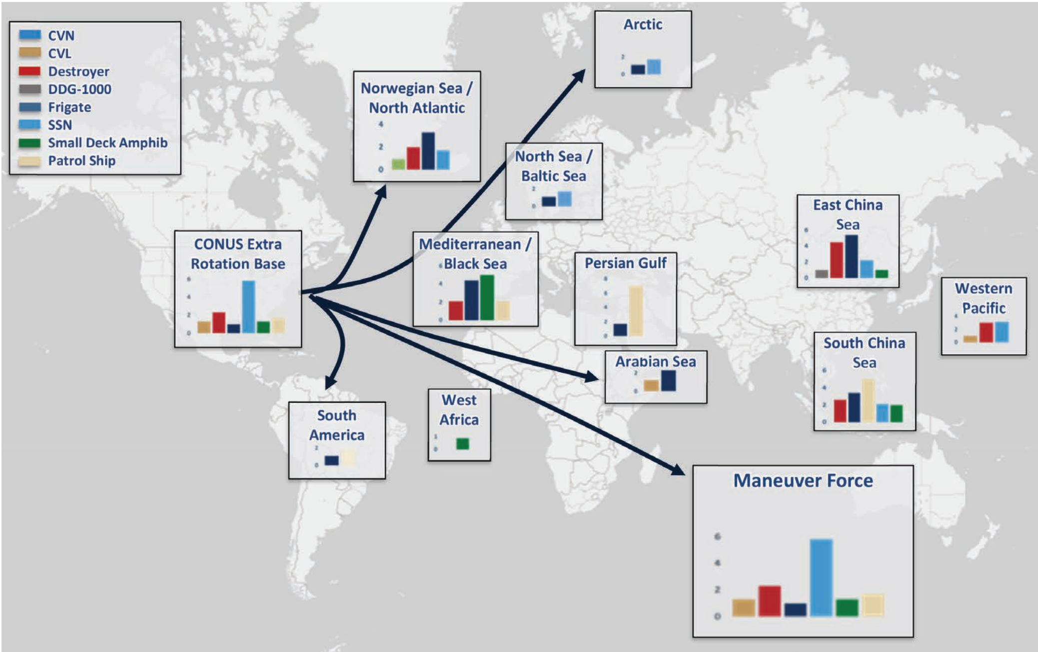
52 U.S. Naval Forces Europe Public Affairs, "USS Harry S. Truman Carrier Strike Group Begins Operations in U.S. 6th Fleet," *U.S. Navy News*, September 18, 2018, available at https://www.navy.mil/submit/display.asp?story_id=107107.

53 Mattis, *Summary of the National Defense Strategy of the United States of America* (2018), p. 7.

54 Clark et al., *Restoring American Seapower*, p. 43.

55 Meghann Myers, "Navy to Disband Carrier Air Wing in Fiscal 2017," *Navy Times,* February 9, 2016, available at https://www.navytimes.com/news/your-navy/2016/02/09/navy-to-disband-a-carrier-air-wing-in-fiscal-2017/.

FIGURE 6: NAVAL POSTURE PROPOSED BY CSBA FLEET ARCHITECTURE STUDY



Combining the two deployed carriers from the West Coast and Japan into a single Maneuver Force yields several advantages compared to today's practice of deploying carriers individually. Carrier flight deck crews are generally limited to 12 hours of operations a day in peacetime, but a two-carrier force would permit continuous 24-hour operations. During surge conditions, such as in the early stages of a conflict, two carriers could operate simultaneously to maximize the force's capacity or increase the reach of carrier aircraft by enabling aircraft to launch from one carrier and recover on another. A two-carrier force could also allow one carrier to conduct replenishment and repair operations while the other continues flight operations.

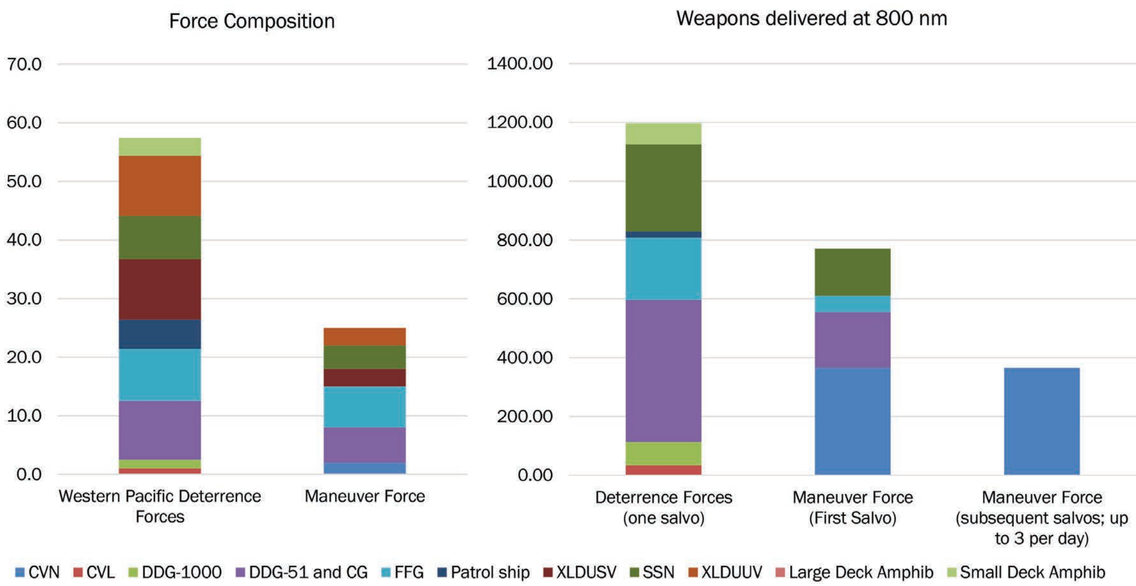
The separation of deployed naval forces into Deterrence Forces and a Maneuver Force in this proposed posture model uses different parts of the naval force for the operations and time periods in which they can be most effective. Surface combatants and submarines are more likely to be near enemy forces or objectives when a conflict starts, and they can conduct attacks predominantly using missiles and torpedoes, which can be rapidly employed in large numbers if enemy forces are already targeted. Both types of platforms, however, could quickly expend their munitions and would need to transit to a relatively secure area for reloading. These characteristics make them well suited for contact force operations in which rapid action is needed to counter an act of aggression before it can achieve a nearby objective.

Carriers, by contrast, are more likely to be operating in the open ocean and would conduct attacks using aircraft, which constrains their rate of weapons delivery to the speed at which aircraft can be launched and the number of aircraft available. To illustrate this, Figure 7 compares the number of strike weapons the CSBA South and East China Sea Deterrence

Forces could deliver in one salvo to the number that can be delivered by a Maneuver Force consisting of two CSGs carrying CVWs composed similarly to the Navy's planned CVW of 2021.

As described above, a CVW strike package of 16–35 strike fighters could deliver about 100–200 weapons in a single salvo, leaving some strike fighters free for escort or air defense operations. The aircraft would take about 10 minutes to launch, and transit to the target area would take 2 to 2.5 hours based on the likely operating distance of carriers relative to Chinese or Russian land-based missile launchers.[56] Although the proposed CVW of this study will offer dramatically improved range and survivability compared to the Navy's planned 2021 CVW, the number of weapons the CVW can deliver will not increase significantly, maintaining the validity of comparing Deterrence and Maneuver Force strike capacity.

FIGURE 7: COMPARISON OF WEAPONS DELIVERED BY DETERRENCE FORCES AND THE MANEUVER FORCE



This chart assumes surface combatants in the Maneuver Forces can devote half of their VLS magazine to strike or anti-ship weapons, whereas surface combatants in Deterrence Forces can devote 75 percent of their VLS magazines to offensive weapons because they do not need to defend a CSG. It also assumes that the CVW has an average 0.7 operational availability, the strike package includes eight escort strike fighters, and strike fighters have access to aerial refueling and do not need to use strike fighters for that purpose. Each strike fighter conducting strikes can carry eight strike or anti-ship weapons, consistent with an F/A-18 E/F LRASM/JASSM capacity or an F-35C with capacity for six standoff weapons on wing stations as well as two carried internally.

56 U.S. Navy, "Carrier: Powerhouse of the fleet," *U.S. Navy Aircraft Carriers,* accessed June 29, 2018, available at http://www.navy.mil/navydata/ships/carriers/powerhouse/powerhouse.asp.

Although the Maneuver Force would deliver fewer weapons in single salvo, it could continue delivering them several times a day indefinitely by resupplying carriers on station. Carriers are well suited, therefore, to delivering sustained fires as part of the blunt force after the contact forces expend their weapons and withdraw.

Integrating Navy and Marine Corps Air Operations

ARGs composed of amphibious assault ships (LHA/D), amphibious transport docks (LPD), and amphibious landing docks (LSD) carry Marine Expeditionary Units (MEU). Today's ARGs, of which two to three are continuously deployed overseas, carry about 2,000 Marines on one LHA/D, one LPD, and one LSD. As shown in Figure 8, the Air Combat Element (ACE) of the MEU today consists of about 25 rotary-wing aircraft and six fixed-wing AV-8B Harrier light attack aircraft hosted on an LHA/D and LPD.[57] The Navy plans to replace LSDs upon retirement with Flight II LPDs, which will provide the ARG more storage and berthing areas.[58] More importantly for naval aviation, LPDs have hangar space for MH-53 or MV-22 rotary wing aircraft, whereas LSDs do not have hangars.[59]

The F-35B will replace the AV-8B, which will improve the ACE's capability and operational availability. The six F-35Bs in an ACE, however, will still be insufficient to meet the likely demand for long-range CAS and strike during future amphibious operations. The land-based ASCM threat described in Chapter 1 will increase the risk of conducting amphibious operations within range of enemy shore-based ISR&T capabilities and ASCMs. As a result, a growing percentage of Marine expeditionary operations will need to occur from longer ranges than their surface connectors, such as Amphibious Assault Vehicles (AAV) or Landing Craft Air Cushions (LCAC), can travel in a day, requiring landing teams to move via MV-22 Osprey tilt-rotor aircraft.[60] Because the MV-22 has a combat radius of more than 400 nm, whereas that of Marine attack helicopters is less than 200 nm, Marines will need to increase their reliance on F-35Bs for CAS and strike operations to support landings or raids.[61]

57 U.S. Marine Corps, *Amphibious Ready Group and Marine Expeditionary Group Overview* (Washington, DC: U.S. Marine Corps, 2015), p. 12–13, available at https://www.hqmc.marines.mil/Portals/61/Docs/Amphibious_Capability.pdf.

58 Megan Eckstein, "Navy Designates Upcoming L(X)R Amphibs as San Antonio LPD Flight II," *USNI News,* April 11, 2018, available at https://news.usni.org/2018/04/11/navy-designates-upcoming-lxr-amphibs-san-antonio-class-lpd-flight-ii.

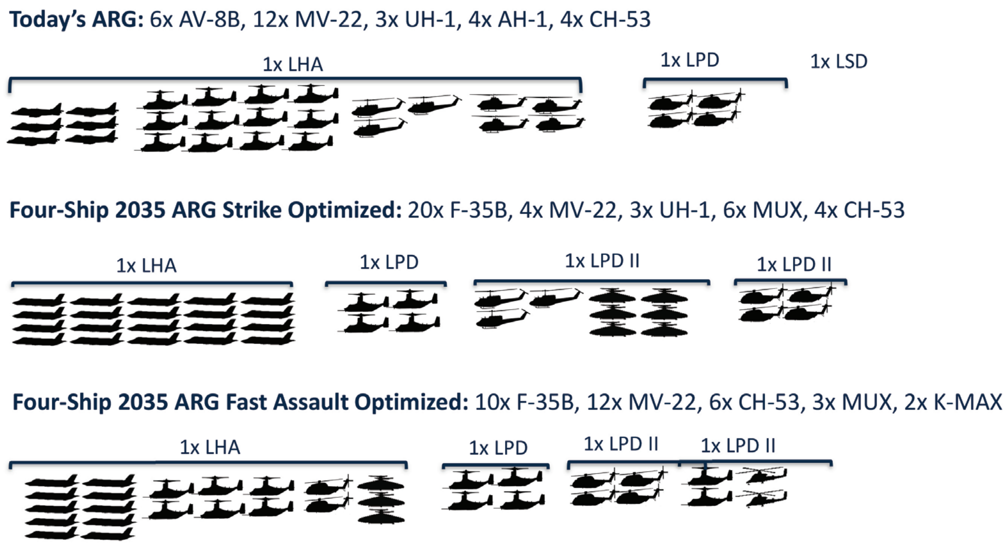
59 "Dock Landing Ship: LSD," *Fact File*, U.S. Navy, updated January 9,2017, available at https://www.navy.mil/navydata/fact_display.asp?cid=4200&tid=1000&ct=4&page=2; and "Amphibious Transport Dock: LPD," *Fact File*, U.S. Navy, updated August 3, 2018, available at https://www.navy.mil/navydata/fact_display.asp?cid=4200&ct=4&tid=600.

60 See Bryan Clark and Jesse Sloman, *Advancing Beyond the Beach: Amphibious Operations in an Era of Precision Weapons* (Washington, DC: Center for Strategic and Budgetary Assessments, 2016), p. 42–44.

61 Andy Martinez III, "Marine Helicopters Soar Farther than Before with Auxiliary Fuel Tanks," U.S. Marine Corps, *News*, March 20, 2017, available at https://www.marines.mil/News/News-Display/Article/1124024/marine-helicopters-soar-farther-than-before-with-auxiliary-fuel-tanks/.

The Marine Corps is exploring options to increase the number of F-35Bs in the ACE to provide more long-range fires for future expeditionary operations.[62] F-35Bs can only be hosted on LHA/Ds, and increasing the F-35B complement would displace MV-22s and other rotary-wing aircraft. To sustain the ARG's cargo, aircraft, and vehicle capacity, it could be expanded to four ships by adding another LPD Flight II, as depicted in Figure 8.

FIGURE 8: OPTIONS FOR AMPHIBIOUS READY GROUP AIR WINGS



These options are detailed further in Bryan Clark and Jesse Sloman, *Advancing Beyond the Beach: Amphibious Operations in an Era of Precision Weapons* (Washington, DC: CSBA, 2016), p. 42–44.

The expanded ACE portrayed in Figure 8 could operate in concert with CVWs on carriers, as well as conduct small-scale strike, CAS, SUW, or air defense operations independent of CSGs. In regions such as the Middle East or Africa where the Navy may not always have a CSG, the expanded future ARG would provide combatant commanders an option for air operations to engage terrorists and insurgents or support friendly forces that is unconstrained by host nation concerns.

62 Lee Hudson, "Marines Highlight Lightning Carrier Concept in Aviation Plan Update," *Inside Defense*, March 28, 2017, available at https://insidedefense.com/daily-news/marines-highlight-lightning-carrier-concept-aviation-plan-update.

A significant gap in the ACE's capability for independent operations, however, is its lack of AEW&C aircraft like the E-2D. This shortfall could be addressed by using shore-based E-2Ds in or adjacent to the ARG's area of operations. Alternatively, MALE UAVs such as the Defense Advanced Research Projects Agency's (DARPA) TERN could fill this role. A MALE UAV would be less capable than an E-2D, but would give the ACE an organic capability for over-the-horizon ISR&T. The Marine Corps is reviewing options like TERN for its new MUX program.[63]

In addition to the ARG and ACE, Marine Corps strike fighters are integrated into Navy CVWs. Today, two squadrons of Marine Corps F/A-18 strike fighters and crews are integrated into two Navy CVWs as part of TACAIR Integration.[64] By 2040, four Marine F-35C squadrons will be integrated with four of the Navy's nine CVWs. Marine F-35Cs are assumed to be used similarly to Navy F-35Cs in the following sections of this report.

Implications for the Future CVW

Although the future CVW will have a similar set of responsibilities as today's air wings, fulfilling them will require significant changes to how carrier aircraft operate, as well as the number and type of aircraft in the CVW. Today, CVWs are able to support all their roles with multi-mission strike fighters because carriers can operate within 500 nm of most potential threats at acceptable risk, and because enemy air defenses can be overcome with a combination of EW, radar-homing missiles, and standoff weapons. Those conditions will not endure and are already not applicable to great power confrontations. As described above, CVWs in future conflicts will need to operate up to 1,000 nm from significant threats, counter capable submarines and surface combatants, and conduct offensive operations in highly contested environments. These challenges will likely not be met by today's strike fighters, or even by a single future multi-role aircraft. The CVW will need to become more diverse, incorporate greater specialization, and improve its range and survivability to be relevant to future conflicts.

This is not the first time CVWs needed to evolve in response to new strategies, missions, or threats. During its first century, carrier aviation frequently adapted to changing circumstances, taking advantage of the carrier's flexibility and the introduction of new aircraft and mission system technologies. The ways in which CVWs changed, and how the Navy managed CVW evolution, offers several useful case studies to guide the assessment of the future CVW.

63 Megan Eckstein, "Marines Zero in on Requirements for Future MUX Unmanned Aerial Vehicle," *USNI News,* April 23, 2018, available at https://news.usni.org/2018/04/23/marines-zero-requirements-future-mux-unmanned-aerial-vehicle.

64 Deputy Commandant for Aviation, *2018 Marine Aviation Plan* (Washington, DC: U.S. Navy, 2018), p. 28, available at https://www.aviation.marines.mil/Portals/11/2018%20AvPlan%20FINAL.pdf.

CHAPTER 3

Historical Evolution of U.S. Navy Carrier Air Wings

The specific challenges facing carriers and CVWs between now and 2040 are new, but their basic character is similar to that of the threats carrier aviation has faced and addressed in the past. Over the past century, adversaries have employed long-range aircraft, submarines, and anti-ship missiles to degrade carrier mobility and striking power. These efforts compelled the Navy to balance its CVW capacity for offensive versus defensive operations and to choose between efficient multi-role aircraft and more capable specialized aircraft. The Navy's choices between these competing priorities and their implications for CVW aircraft design and composition offer useful insights and metrics that should be considered in designing the future CVW.

Carrier aviation also evolved to address changing strategies for the employment of U.S. military forces. Although each new strategy led to disruptive changes in many defense programs, carriers were able to adapt and remain relevant through these shifts by changing the size and mix of aircraft in the CVW. This evolution also offers insights to be considered in assessing the CVW of 2040.

Early Carrier Aviation (1922–1941)

Aircraft first flew from ships around 1910, but they had to land on the water using pontoons or on runways ashore because warships had small flight decks and retained their traditional topside superstructure and guns. During the First World War, the British Royal Navy sought to use aircraft as scouts for the fleet by operating them from dedicated, flat-topped ships that could both launch and recover aircraft. The Royal Navy converted a former ocean liner into the HMS *Argus,* the world's first aircraft carrier, but it was completed too late to see action in the war.

Whereas the Royal Navy pioneered carrier aviation, the U.S Navy was responsible for much of the innovation in carrier employment during the period separating the two world wars.

The U.S. Navy converted the collier USS *Jupiter* into USS *Langley* (CV-1) in 1922, which embarked eight biplanes during its first underway operations.[65] Although early U.S. carriers like the *Langley* were small, lumbering ships operating a handful of fragile scout aircraft, the Navy conducted a series of innovative, large-scale exercises known as Fleet Problems to assess operational concepts carriers could use as more capable ships and aircraft became available.[66] These exercises increased Navy leaders' appreciation for the versatility of carrier-borne aircraft and prompted follow-on efforts to expand the CVW's missions beyond merely scouting to include destroying the enemy's fleet directly.[67]

FIGURE 9: USS LANGLEY (CV-1)

The U.S. Navy aircraft carrier USS *Langley* (CV-1) underway in June 1927. U.S. Navy photo.

New carrier-based aircraft were introduced during the interwar period to carry out missions in support of the Navy's war plans. The Navy's strategy for a war with Japan, War Plan Orange, would rely on carrier-based airpower to blunt a Japanese offensive by attacking Japan's fleet and support a campaign to retake America's western Pacific territories from Japanese ground forces.[68] By 1938, CVWs included early versions of dive bombers, torpedo bombers, and fighter aircraft to attack ships, hunt enemy submarines, interdict enemy sea lines of communication (SLOC), and defend ships or troops ashore against enemy air attack. These aircraft would

65 See Thomas C. Hone, Norman Friedman, and Mark D. Mandeles, *American and British Aircraft Carrier Development, 1919-1941* (Annapolis, MD: U.S. Naval Institute Press, 1999); and Jerry Hendrix, *Retreat from Range: The Rise and Fall of Carrier Aviation* (Washington, DC: Center for a New American Security, October 2015).

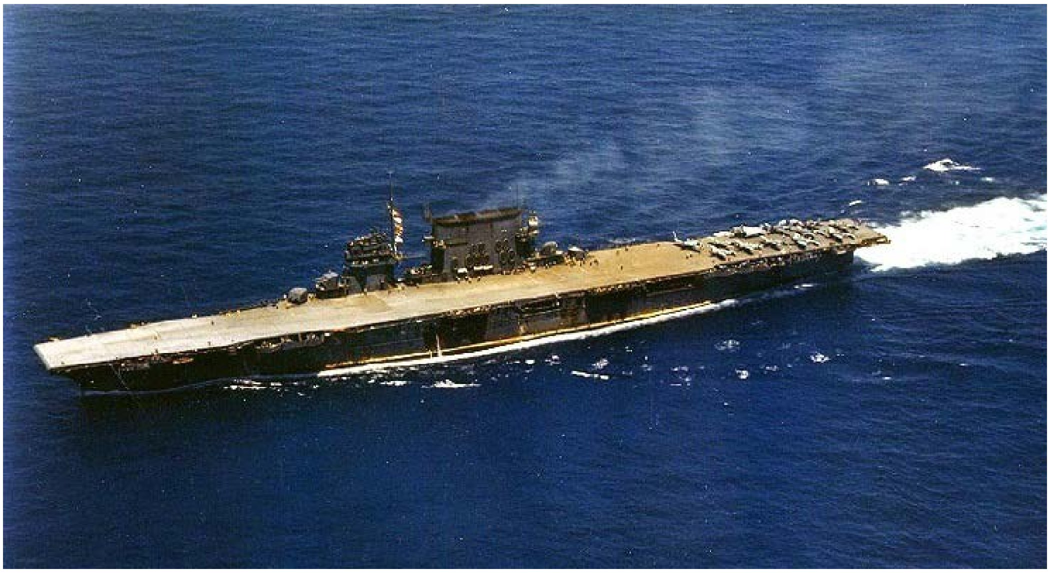
66 See Albert A. Nofi, *To Train the Fleet for War: The U.S. Navy Fleet Problems, 1923–1940* (Newport, RI: Naval War College Press, 2010).

67 For instance, Fleet Problems showed Navy leaders a carrier could establish and exploit sea control without support from land-based aircraft or other forces. Norman Friedman, *U.S. Aircraft Carriers: An Illustrated Design History* (Annapolis, MD: U.S. Naval Institute, 1983), pp. 33–35.

68 Edward S. Miller, *War Plan Orange* (Annapolis, MD: U.S. Naval Institute, 1991), pp. 21–23.

be carried on larger and faster carriers, such as the converted battle cruisers USS *Lexington* (CV-2) and *Saratoga* (CV-3), that made it possible to conduct the once-separate missions of long-range scouting, target acquisition, and weapons delivery from a single platform.[69]

FIGURE 10: USS SARATOGA (CV-3)



The U.S. Navy aircraft carrier USS *Saratoga* (CV-3), circa 1942. Planes on deck include five Grumman F4F-4 Wildcat fighters, six Douglas SBD-3 Dauntless dive bombers, and one Grumman TBF-1 Avenger torpedo plane. U.S. Navy photo.

The Second World War (1941–1945)

Early Second World War

The Japanese surprise attack on Pearl Harbor on December 7, 1941 was a vivid demonstration of the striking power and reach of aircraft carriers. Comprising two waves of more than 300 dive bombers, high-altitude bombers, torpedo bombers, and fighters launched from six carriers 220 miles away from Oahu, the raid sank or damaged almost every battleship in the U.S. Pacific Fleet.[70] In addition to this demonstration of naval aviation's capability, the losses imposed at Pearl Harbor accelerated the U.S. Navy's establishment of the aircraft carrier as its preeminent platform by sidelining its predecessor, the battleship.

69 Wayne P. Hughes, *Fleet Tactics and Coastal Combat*, 2nd edition (Annapolis, MD: U.S. Naval Institute, 2000), pp. 114–115.

70 Gordon W. Prange, *At Dawn We Slept: The Untold Story of Pearl Harbor* (New York: Penguin, 1981), pp. 490–491. The U.S. Navy's fleet carriers (CV) were out of port, out of the area, and unharmed by the attack. *Lexington* and *Enterprise* were returning from shuttling aircraft to Midway and Wake islands, respectively; *Saratoga* was in San Diego to pick up aircraft to shuttle to Oahu.

Prior to the Second World War, the U.S. Navy and Imperial Japanese Navy (IJN) had designed their fleets in line with the teachings of American maritime theorist and naval officer Alfred Thayer Mahan (1840–1914).[71] Mahan argued that the most effective way to command the sea was to construct a fleet around the battleship's offensive capabilities and destroy the opposing fleet in a decisive engagement.[72] Such a victory would ensure the winner's ability to move troops and material while denying the enemy's access to the sea, eventually resulting in a victory on the ground. After the attack on Pearl Harbor, the U.S. Navy and IJN followed this strategy using carrier-centric operations.

The early period of World War II in the Pacific was marked by large-scale confrontations between U.S. and Japanese carrier task forces as each sought a Mahanian engagement that would stop the Japanese advance or compel the United States to sue for peace. At the Battle of the Coral Sea in May 1942, the U.S. carrier task force of USS *Lexington* (CV-2) and USS *Yorktown* (CV-5) sank a Japanese light carrier. However, the *Lexington* was so heavily damaged it had to be scuttled, while USS *Yorktown* was severely damaged.[73] U.S. Navy leaders assessed that their losses resulted from a lack of fighters for air defense.[74] As depicted by the unshaded aircraft in Figure 11, the *Yorktown*'s CVW at the Battle of the Coral Sea consisted of about one-quarter F4F Wildcat fighters and three-quarters Dauntless scout dive bombers (SBD) and Devastator torpedo bombers (TBD). This balance did not provide adequate protection to the U.S. carriers. Moreover, the general parity in combat ranges between Japanese and U.S. carrier-based attack aircraft made finding and attacking the enemy first more challenging and increased the likelihood of a rapid counterattack. This situation put a premium on U.S. CVWs locating and striking Japanese carriers before being counter-targeted and on being able to defend against Japanese carrier-based bombers.[75]

Based on the lessons of Coral Sea, the U.S. Navy increased its CVW air defense capacity and implemented new tactics to counter the superior performance of Japanese Zero aircraft.[76] USS *Yorktown*, USS *Hornet* (CV-8) and USS *Enterprise* (CV-6) took their rebalanced CVWs, shown in Figure 11, into the Battle of Midway a month later in early June 1942.

71 See Alfred Thayer Mahan, *The Influence of Sea Power upon History, 1660–1783* (Annapolis, MD: U.S. Naval Institute Press, 2007).

72 Haynes, *Toward a New Maritime Strategy*, pp. 15, 17.

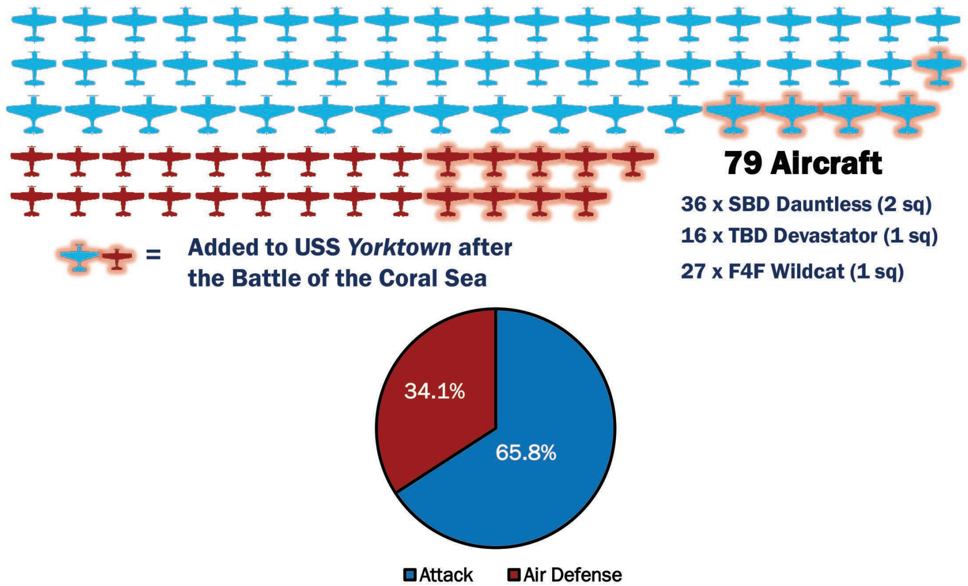
73 John B. Lundstrom, *The First Team: Pacific Naval Air Combat from Pearl Harbor to Midway* (Annapolis, MD: U.S. Naval Institute, 1984), pp. 278–279.

74 Ibid., p. 190.

75 Douglas A. Smith, *Carrier Battles: Command Decision in Harm's Way* (Annapolis, MD: U.S. Naval Institute, 2006), p. 149.

76 Lundstrom, *The First Team*, p. 301.

FIGURE 11: CVW ON USS YORKTOWN (CV-5) DURING THE BATTLE OF CORAL SEA AND CHANGES MADE FOR THE BATTLE OF MIDWAY IN JUNE 1942



During the Battle of Midway, U.S. carriers sank four Japanese carriers but lost the *Yorktown*, which was sunk by a Japanese submarine after sustaining damage during the battle. Although U.S. success in breaking Japanese codes, poor decisions by IJN leaders, and plain luck contributed to the decisive victory, the larger number of fighters in each U.S. CVW provided more protection for the fleet and imposed significant losses on Japanese CVWs, including irreplaceable experienced Japanese air crews.[77] The Japanese were left after Midway with only two large carriers and two light carriers, whereas the Americans were left with three carriers, which were soon to augmented by USS *Wasp* (CV-8) from the Atlantic Fleet. Midway marked the end of the first phase of the Pacific War. The next phase shifted the Navy's focus from blue water carrier battles to expeditionary and amphibious operations in the littoral waters of the Western Pacific.

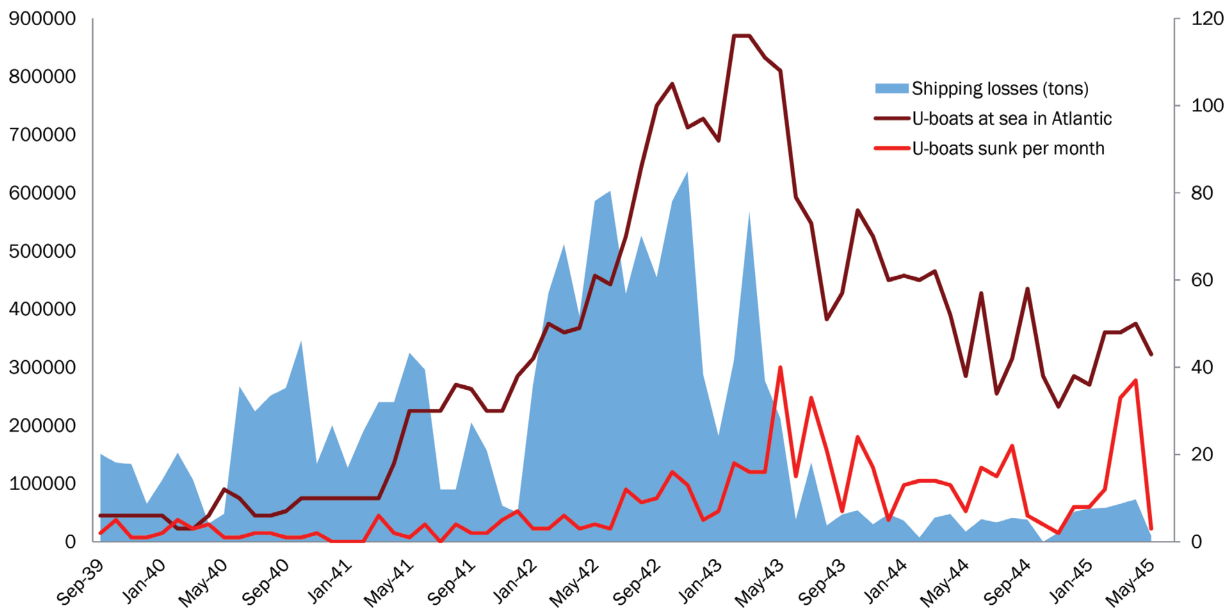
ASW Operations

The most significant challenge for ASW operations during the Second World War was the Axis submarine threat to Allied convoys resupplying Britain and preparing for the eventual invasions of Africa and Europe. Land-based aircraft were a key element of Allied ASW efforts during the resulting Battle of the Atlantic because submarines spent most of their time on the surface—at least until the snorkel's introduction late in the war. Convoys remained vulnerable, however, in the mid-Atlantic beyond the range of land-based MPA. To counter growing losses there by the middle of the war, the U.S. Navy deployed hunter-killer groups of escort carriers

77 Ibid., pp. 190, 330.

(CVE), destroyers, and destroyer escorts (DE) to cover areas land-based aircraft could not reach. CVEs were smaller than CVs and built on merchant ship hulls, enabling them to carry a smaller CVW comprised of F4F Wildcats and TBF/TBM Avengers equipped with radar and depth bombs.[78] The ISR and defensive ASW capabilities that hunter-killer groups provided enabled them to protect convoys in vulnerable areas, as well as to break off from the convoy to pursue Axis submarines after they were discovered.[79]

FIGURE 12: AXIS SUBMARINE PRESENCE AND LOSSES AND ALLIED SHIPPING LOSSES DURING THE BATTLE OF THE ATLANTIC



Samuel Eliot Morison, *The Battle of the Atlantic, 1939–1943* (New York: Little Brown, 1947), pp. 400–17; Charles Sternhell and Alan Thorndike, *Antisubmarine Warfare in World War II*, Operations Evaluation Group Report No. 51 (Washington, DC: Office of the CNO, 1946), pp. 80–90, available at http://www.ibiblio.org/hyperwar/USN/rep/ASW-51/index.html#contents, accessed June 4, 2014; Clay Blair, *Hitler's U-Boat War: The Hunters, 1939–1942* (New York: Modern Library, 2000), pp. 580–600.

The combination of MPA, CVEs, and convoy escorts were successful at reducing allied shipping losses by mid-1943, as shown in Figure 12. They achieved this result, however, not by simply sinking submarines. Axis submarine losses from 1943 to the war's end were relatively low, and submarine presence remained four to five times higher than during the early part of the war, when shipping losses were much higher. This suggests U.S. ASW forces were successful not because they eliminated submarines, but because they drove submarines away

78 Jeffrey G. Barlow, "The Navy's Escort Carrier Offensive," *Naval History Magazine* 27, no. 6, December 2013, available at https://www.usni.org/magazines/navalhistory/2013-11/navys-escort-carrier-offensive.

79 Bernard Ireland, *The Battle of the Atlantic* (Annapolis, MD: U.S. Naval Institute, 2003). In the Pacific, CVEs were abundant but were not needed as much for ASW. Instead, they complemented CVs during amphibious assaults by providing additional close air support (CAS) and air defense capacity. See Scot MacDonald, *The Evolution of Aircraft Carriers* (Washington, DC: CNO, U.S. Navy, February 1964), pp. 49–53.

from Allied convoys. When a submarine detected an Allied radar with its radar warning receiver (RWR) or saw an incoming aircraft or escort ship, the submarine crew recognized it had been detected and might be engaged by multiple escort ships with depth charges and torpedoes. The submarine would then evade. Due to its slower submerged speed, the submarine would be unlikely to catch up with the same convoy again. The ability of ASW forces to marginalize submarines through suppression is an approach that could be employed in future ASW concepts.[80]

Although neither as large nor as capable as the German and Italian submarine fleets, Japan's submarine fleet posed a threat to carriers, as evidenced by the sinking of the *Yorktown*. However, rather than focusing on cargo and personnel shipping like German or U.S. submarine forces, Japanese submarines were intended to be an adjunct to the IJN's Mahanian battle fleet. Their role was to operate in areas of expected decisive battles such as Midway Island, act as scouts for the battle fleet, and harass and attack U.S. capital ships.[81] As such, while it had larger submarines and torpedoes with longer reach than the U.S. Navy, Japan's submarine fleet lacked the capacity and speed to independently patrol the ever-expanding areas in which U.S. carrier task forces operated.[82] When Japanese submarines did encounter U.S. and allied naval forces, their slow speed and lack of an air search radar made them more vulnerable to attacks by allied destroyers and patrol aircraft.[83]

Late Second World War

At great cost to American and Australian naval forces, the Allies' success in sea battles like Midway set the stage for a new naval strategy during the second half of the war. This strategy focused on power projection ashore to eliminate the ability of Japanese forces to attack SLOCs with shore-based aircraft and their remaining fleet; it also aimed to place U.S. ground and air forces within range of Japan's home islands for an eventual invasion.

The expeditionary and amphibious operations conducted as part of the Allied "island hopping" strategy required CVWs to take on additional missions and address a more diverse and challenging set of threats. To support Marines and soldiers ashore, the U.S. Navy added more attack aircraft like the Avenger to its carriers. The Navy also operated its carriers closer to shore to enable longer on-station times for carrier aircraft flying CAS missions and generate higher sortie rates for strikes.

80 John Stillion and Bryan Clark, *What it Takes to Win: Succeeding in 21st Century Battle Network Competitions* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015).

81 Ronald H. Spector, *At War at Sea: Sailors and Naval Warfare in the Twentieth Century* (New York: Penguin, 2001), p. 286.

82 Ibid., pp. 154–155.

83 Robert W. Love, *History of the U.S. Navy, Vol. II: 1942–1991* (Harrisburg, PA: Stackpole Books, 1993), pp. 179–180.

The resulting reduction of at-sea maneuver space and proximity to enemy airfields made carriers more vulnerable to attack.[84] Land-based aircraft were especially problematic as the campaign moved toward Japan's home islands,[85] where U.S. carrier task forces came within range of hardened, well-supplied air bases on Formosa, the Philippine archipelago, and Okinawa.[86] With so much of the CVW tied up supporting operations ashore, the lack of CVW air defense capacity left carrier task forces vulnerable to what proved to be the deadliest threat to U.S. naval forces in the Second World War—*kamikaze* attacks.[87]

Kamikazes, which first appeared at the Battle of Leyte Gulf in late 1944, were an attractive asymmetric weapon for Japan. Japan faced serious pilot shortages in the final year of the war, and *kamikazes* required relatively simple maneuvers that even the most inexperienced pilots could perform.[88] *Kamikaze* aircraft did not require a return trip, which effectively doubled their range, nor did they need to be fully mission-capable. To avoid inflicting damage on U.S. ships, the *kamikazes* needed to be completely destroyed by anti-aircraft fire or fighters, which was more difficult after they began their dives.[89] As has been noted elsewhere, the *kamikazes* could be considered a forerunner of the ASCM.[90]

U.S. carrier task forces were ill prepared to address the *kamikaze* threat, particularly near the island of Okinawa, which was beyond the range of U.S. land-based aircraft that could have supported carrier task forces.[91] *Kamikazes* were launched in massive waves of up to 300 aircraft and were usually accompanied by land-based fighter escorts and bombers.[92] To address this threat, the CVW needed more fighter aircraft to sustain the large number of CAP stations necessary to protect carrier task forces and forces ashore. With a finite amount of carrier deck space, CVWs had to include fewer Helldiver and Avenger aircraft that principally supported ground operations.

To regain some attack capacity, the Navy began to incorporate multi-role aircraft into CVWs with the F4U Corsair. The Corsair was faster and more powerful than the F6F Hellcat fighter and proved to be an effective bomber. By the end of the war, CVWs were evenly split between

84 Thomas P. Ehrhard and Robert O. Work, *Range, Persistence, Stealth, and Networking: The Case for a Carrier-Based Unmanned Combat Air System* (Washington, DC: Center for Strategic and Budgetary Assessments, 2008).

85 This was generally considered at the time to be Honshu and Kyushu.

86 George W. Baer, *One Hundred Years of Sea Power: The U.S. Navy, 1890–1990* (Stanford, CA: Stanford University, 1994), pp. 266–267.

87 In addition to killing almost 5,000 U.S. sailors, Kamikazes sank 26 and damaged 164 U.S. warships. Ibid., p. 266.

88 Ronald H. Spector, *Eagle Against the Sun: The American War with Japan* (New York: Vintage Books, 1985), p. 440.

89 Ibid., p. 440.

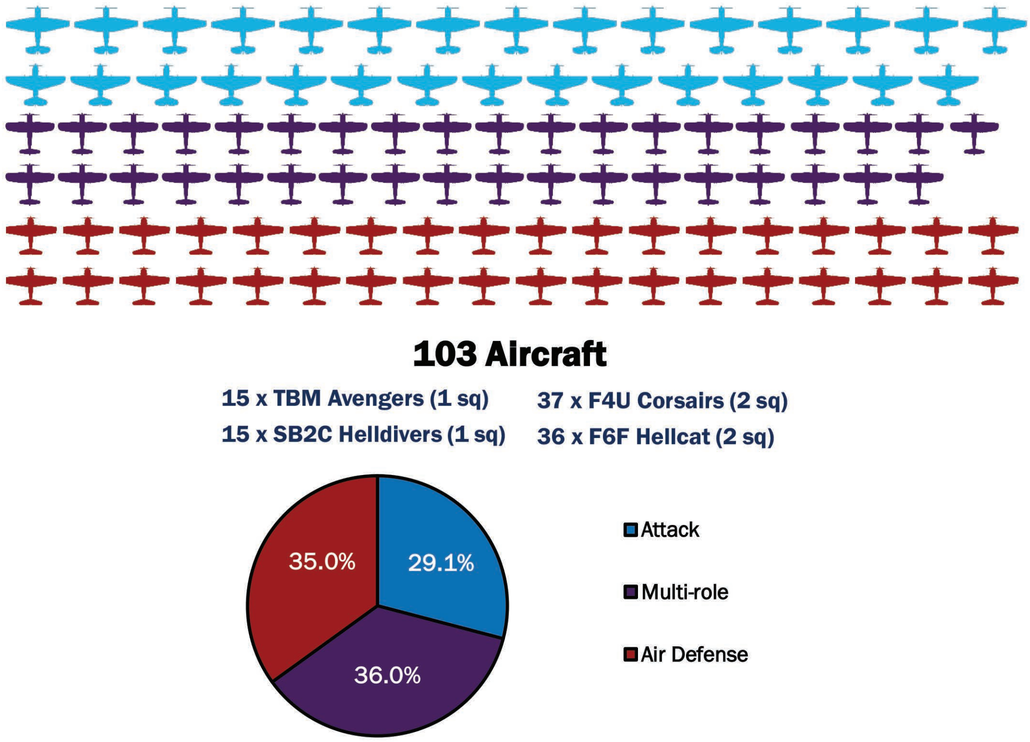
90 Andrew F. Krepinevich, *Maritime Competition in a Mature Precision-Strike Regime* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015).

91 Baer, *One Hundred Years of Sea Power*, p. 266.

92 Spector, *Eagle Against the Sun*, p. 536.

bombers, fighters, and multi-role aircraft. This was a fundamental shift from earlier in the war, when attack aircraft made up about three-quarters of CVWs.[93]

FIGURE 13: CVW ON USS LEXINGTON (CV-16) IN 1945



The Second World War transformed fleet design and naval strategy. Before the war, naval warfare was focused mostly on victory at sea. Although militaries used ships for thousands of years to move troops from one place to another, the influence of naval forces had always stopped a few miles inland. Naval strategists like Mahan argued the indirect and protracted effects of commanding the sea eventually enabled victory ashore, by denying the enemy's movement, supplies, and trade. Operations during the Second World War showed that a fleet built around carriers offered the mobility, range, and firepower to strike targets ashore at long ranges, directly affecting the outcome of ground operations. The carrier enabled naval forces to transition from achieving only victory at sea to supporting victory ashore as well.[94]

93 Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

94 Based on Haynes, *Toward a New Maritime Strategy*, p. 15. Also, see Colin S. Gray, War, *Peace and International Relations: An Introduction to Strategic History* (New York: Routledge, 2007), pp. 172–178.

The Cold War (1946–1990)

The Soviet Union emerged shortly after the end of the Second World War as a rival to the United States, and with it the threat of communist expansion became an overriding concern for U.S. foreign policy. During the early years of the Cold War, the United States' technological advantages, particularly in nuclear weapons, and the desire to reduce military spending led U.S. leaders to establish a defense strategy that would attempt to contain the spread of communism and rely on nuclear weapons to overcome the numerical superiority of Soviet and Warsaw Pact forces in the event of a war.[95] This new strategic approach called into question the relevance of aircraft carriers, which at the time were too small to operate the large, heavy aircraft capable of delivering atomic weapons over operationally useful ranges against the Soviet Union.[96] Combined with the absence of a rival at sea, the atomic bomb and the Air Force's strategic bombers threatened to marginalize not just carriers, but the Navy itself.[97]

Intent on preserving its relevance, the Navy began constructing USS *United States*, the first of a new class of supercarriers designed to host larger aircraft, and developing a carrier-based bomber capable of long-range nuclear and conventional strike.[98] The *United States* was cancelled, however, in favor of the Air Force's new B-36 strategic bomber, which was seen as a more economical approach to nuclear weapons delivery.[99] Further reductions to the carrier were forestalled by the onset of the Korean War. During the early months of the war, CVWs provided CAS, air defense, and strike to support retreating U.S. and allied troops in the absence of operable air bases on the Korean peninsula, many of which had been overrun.[100]

At the beginning of the Korean War CVWs still operated many aircraft from the Second World War. For example, 80 percent of the Navy's CAS missions during the conflict's first ten months were flown by Corsairs, which were replaced during the early 1950s by the A-1 Skyraider, shown in Figure 13. With a 726-nm combat range, 10-hour flying time, and 8,000-lb payload capacity, which exceeded other carrier aircraft of the time, the A-1 was employed in the Korean and Vietnam Wars. Twenty-two variants were eventually fielded, including versions oriented toward ASW, nuclear strike, EW, and AEW.[101]

95 Chester Patch, "Dwight D. Eisenhower: Foreign Affairs," University of Virginia Miller Center, available at https://millercenter.org/president/eisenhower/foreign-affairs; U.S. National Security Council, *U.S. Objectives and Programs for National Security* (Washington, DC: U.S. National Security Council, 1950), pp. 60–65, available at https://www.trumanlibrary.org/whistlestop/study_collections/coldwar/documents/pdf/10-1.pdf.

96 Friedman, *U.S. Aircraft Carriers*, p. 154.

97 Haynes, *Toward a New Maritime Strategy*, p. 15.

98 Friedman, *U.S. Aircraft Carriers*, pp. 240–241.

99 Ibid., pp. 251–252.

100 Ibid., p. 21.

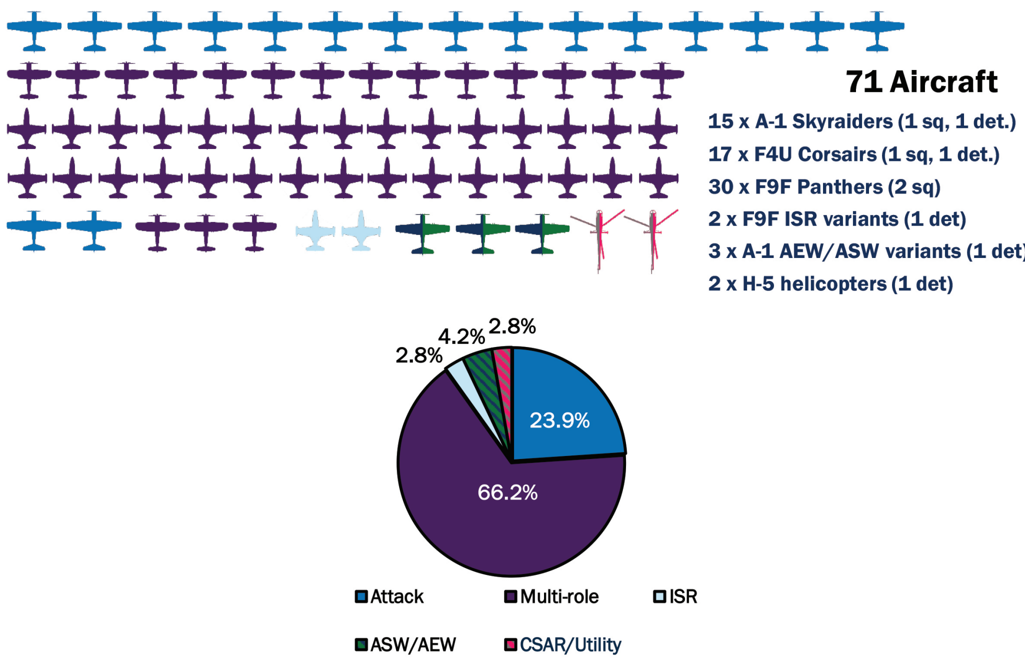
101 Martin W. Bowman, *US Naval Aviation in Camera*: *1946-1999* (New York: Sutton, 1999); and Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

FIGURE 14: A-1 SKYRAIDER

A U.S. Navy Douglas A-1H Skyraider in 1966. U.S. Navy photo.

During the Korean War, the propeller-driven A-1 was joined by the first carrier-borne jet fighters, including the F-9F Panther and, later, the nuclear-capable F-2H Banshee. Figure 14 shows the CVW on USS *Princeton* (CV-37) at the end of the Korean War in 1953, which included both propeller and jet-driven aircraft.

FIGURE 15: CVW ON USS PRINCETON (CV-37) IN 1953



Due to their lackluster performance against the Soviet swept-wing MiG-15, the straight-wing F-2H and F-9F were replaced during the mid-1950s by faster, swept-wing aircraft. These included the F-8 *Crusader*, F-3B *Demon*, and light attack aircraft such as the A-4 Skyhawk.[102]

FIGURE 16: F-8 CRUSADER

A Vought F-8E Crusader in 1965. The aircraft is armed with AIM-9D Sidewinder missiles. U.S. Marine Corps photo.

The utility of carriers during the Korean War and a sharp increase in U.S. military spending in 1951 spurred construction of the world's first supercarrier, USS *Forrestal* (CV-59). *Forrestal* and six subsequent supercarriers, including USS *Enterprise* (CVN-65), were designed to support long-range nuclear strike aircraft such as the jet-propelled A-3 Skywarrior.[103] The A-3 became central to nuclear-era CVWs thanks to its 2,600-nm combat range and 12,800-lb payload,[104] but it significantly increased the space required for CVWs between 1953 and 1960.[105]

The A-3's intended successor for nuclear strike was the supersonic A-5 Vigilante. With the introduction of the SSBN and Polaris submarine-launched ballistic missile (SLBM) in late 1959, however, carriers were superseded as the Navy's primary strategic nuclear delivery system. The A-5's role was changed to primarily photo and radar reconnaissance, and the A-3 was modified to support EW and aerial refueling.[106] Carriers retained up to one hundred tactical nuclear warheads each until the early 1990s to support fleet defense, peripheral attacks on the Soviet Union, and smaller national nuclear attack options.[107]

102 Bowman, *US Naval Aviation in Camera*.

103 "Carrier Designations and Names: Attack Carriers (CV, CVA, CVB, CVL, CVAN, CVN)," Naval History and Heritage Command, August 1, 2017, available at https://www.history.navy.mil/research/histories/naval-aviation-history/attack-carriers.html.

104 Hendrix, *Retreat from Range*; and Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

105 CSBA data; see Appendices.

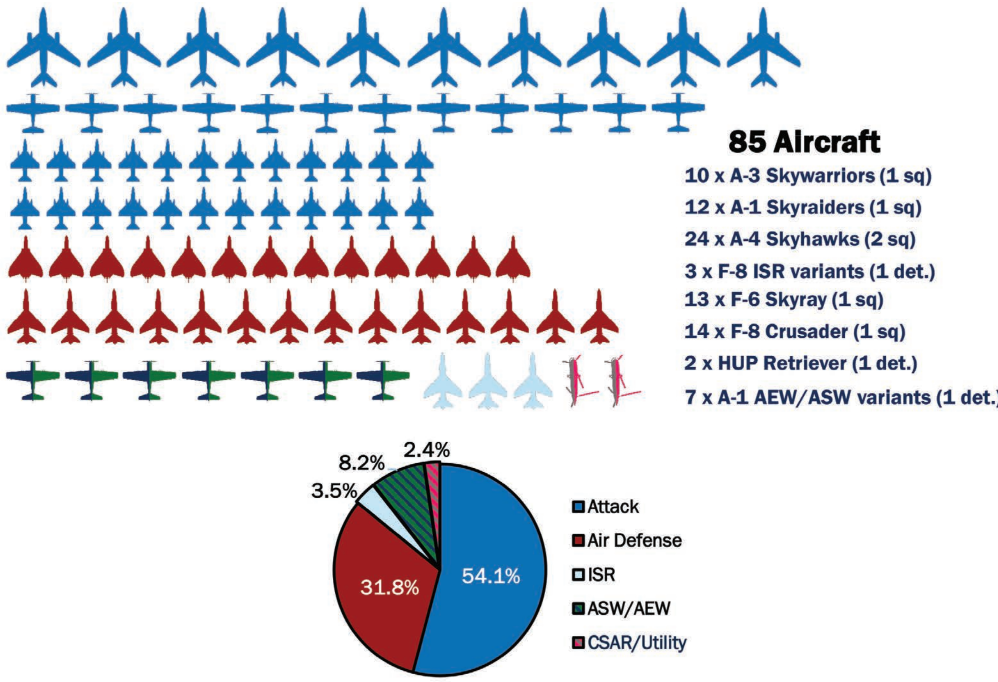
106 Hendrix, *Retreat from Range*.

107 Carriers were completely denuclearized by 1992. See Robert S. Norris and Hans M. Kristensen, "Declassified: US nuclear weapons at sea during the Cold War," *Bulletin of the Atomic Scientists*, January 8, 2016; and Timothy A. Walton, "The Evolution of the Modern Carrier Air Wing," *Center for International Maritime Security*, September 2015, available at http://cimsec.org/the-evolution-of-the-modern-carrier-air-wing/18860.

FIGURE 17: EKA-3B SKYWARRIOR (EW/TANKER VARIANT)

A U.S. Navy Douglas EA-3B Skywarrior in flight over the South China Sea in 1974. U.S. Navy photo.

FIGURE 18: CVW ON USS SARATOGA IN 1960



With SSBNs taking over the naval nuclear mission, CVWs reemphasized conventional attack and CAS, which were increasingly needed during the Vietnam War. The longer combat ranges of aircraft such as the new A-7 Corsair II and A-6A Intruder, the Navy's first all-weather precision strike aircraft, enabled carriers to provide a significant portion of U.S. air sorties in North Vietnam. They also enabled carriers to operate far enough at sea where they did not have to mount significant air defense efforts.[108] As a result, the Navy replaced the retiring F-8 fighter with the F-4 Phantom II multi-role aircraft during the 1960s to increase attack and CAS capacity.

108 Hendrix, *Retreat from Range*.

FIGURE 19: F-4 PHANTOM

U.S. Air Force photo.

FIGURE 20: A-6 INTRUDER

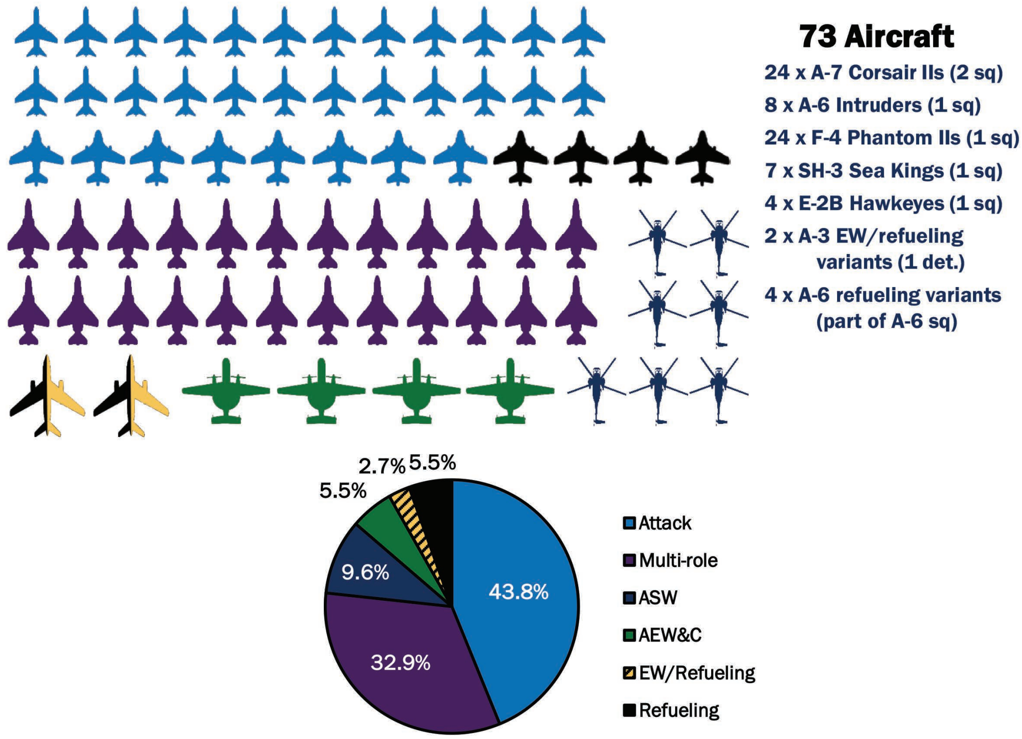
U.S. Navy photo.

New Missions Diversify the CVW

The emergence of new threats during the late 1960s and 1970s, including SAMs and ASCM-equipped bombers and submarines, necessitated the development of specialized carrier-based aircraft. Capabilities for aerial refueling, EW, AEW&C, and ASW were needed to strike targets deeper in Southeast Asia, defeat increasingly sophisticated air defenses, and counter new threats to U.S. carriers at sea. The proportion of specialized or support aircraft in the CVW, as represented by the CVW on USS *Forrestal* in Figure 21, more than doubled between 1966 and 1978.[109]

109 CSBA data; see Appendices. These new capabilities came at a price, particularly in terms of their growing deck space requirements.

FIGURE 21: CVW ON USS FORRESTAL IN 1972



Some of these new capabilities were intended to extend the CVW's reach, a continuation of efforts begun in the 1950s when the Navy started adding external fuel tanks and refueling equipment to carrier aircraft. With the shift of strategic nuclear strike missions to SSBNs, the Navy reconfigured A-3s to be tankers.[110] The KA-3 could carry 34,000 lb of fuel and was capable of keeping up with strike packages to refuel aircraft en route to their targets. Its successor, the KA-6D, was based on the Intruder airframe and could deliver 21,000 lb of fuel.[111]

Other new CVW capabilities sought to address specific threats. North Vietnamese air defenses improved throughout the war, most dramatically with the introduction of the Soviet-made and supplied SA-2 air defense system in 1965. The SA-2 created the need for a new CVW mission—suppression of enemy air defenses (SEAD).[112] Aircraft were needed in strike packages to suppress SAM systems through electronic warfare or by attacking them with the anti-radiation missiles.[113] Electronic jamming systems had been deployed on CVW aircraft since late in

110 Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

111 Ibid.

112 Stillion and Clark, *What it Takes to Win*, p. 78.

113 Alfred Price, *The History of US Electronic Warfare: Rolling Thunder Through Allied Force, 1964 to 2000* (Alexandria, VA: Association of Old Crows, 2000), pp. 79, 84.

the Second World War, usually by adding them to existing attack aircraft such as the TBM-3Q Avenger and the A-3. Introduced in 1972, the EA-6B Prowler was the CVW's first purpose-built EW aircraft.[114] Based on the A-6, the EA-6B incorporated integrated receivers, signal processing equipment, and jammer pods; it also carried three electronic countermeasures officers (ECMO) in addition to the pilot.

The Soviet Union's deployment of long-range bombers armed with ASCMs created the need for an AEW aircraft able to detect and track ships, aircraft, and ASCMs hundreds of miles from the carrier. To counter the *kamikaze* threat, the Navy had developed the first dedicated carrier-based AEW aircraft in 1945, a TBM-3W with an AN/APS-20 radar.[115] A series of A-1 AEW variants followed. After a brief period of using the E-1 Tracer for AEW&C, the Navy introduced the E-2A Hawkeye in 1964. The all-weather E-2A was the U.S. military's first purpose-built AEW aircraft, as well as the first to combine AEW and wide-area surface search with a C3 mission. The E-2A was notoriously unreliable but was quickly improved upon with the E-2B and E-2C in 1964 and 1973, respectively.[116] While the E-2C's primary mission was AEW, it could also be used to control air interdiction operations and offensive and defensive CAPs; coordinate long-range surface search and surveillance and attack missions; and coordinate strikes, CAS missions, and combat search and rescue (CSAR) efforts. [117]

The Navy began increasing the defensive ASW capacity of carrier battle groups (CVBG) during the 1950s in response to the growing Soviet attack submarine fleet, which benefited from captured German technology.[118] To prevent the ASW mission and aircraft from reducing the CVW's striking power, the Navy created dedicated ASW aircraft carriers (CVS) by repurposing smaller, older *Essex*-class carriers built during the Second World War. Each CVS carried two squadrons of fixed-wing S-2 Trackers, two squadrons of SH-3 Sea King ASW helicopters, and often a detachment of fighters for air defense.[119]

During the late 1960s, the Soviet Navy began deploying submarine-launched ASCMs to attack U.S. ships from greater distances than torpedoes, including new nuclear-powered guided missile submarines (SSGN) armed with nuclear-tipped ASCMs.[120] Given the lack of funding during the early 1970s for a new class of ASW-oriented carriers to replace the aging

114 "Airborne Electronic Attack: A Short History of U.S. Navy Airborne Electronic Attack," Prowler Association, 2013–2015, available at http://www.ea6bprowler.org/airborne-electronic-attack.

115 "Airborne Command and Control and Logistics Wing (ACCLW) History," Airborne Command and Control and Logistics Wing, official U.S. Navy web site, available at http://www.cacclw.navy.mil/history.htm.

116 Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

117 "Airborne Command and Control and Logistics Wing (ACCLW) History."

118 Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

119 Owen R. Cote Jr., *The Third Battle: Innovation in the U.S. Navy's Silent Cold War Struggle with Soviet Submarines* (Newport, RI: Naval War College Press, 2012), available at https://fas.org/man/dod-101/sys/ship/docs/cold-war-asw.htm#Fourth; and "Air Anti-Submarine Warfare," *Military Analysis Network*, FAS, updated March 14, 1999, available at https://fas.org/man/dod-101/sys/ac/asw.htm#World War II.

120 Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

Essex-class CVSs, the Navy had to once again expand CVW missions and add ASW aircraft to the already crowded flight deck of multi-mission carriers. To reduce the impact on other CVW missions, only half the ASW aircraft in the CVS air wing were incorporated into the CVW, reducing the fleet's overall ASW capacity.[121]

To improve the capacity of its smaller carrier-based ASW squadrons, the Navy introduced new dedicated ASW aircraft, including the jet-propelled S-3A Viking in 1974. The S-3A had twice the range and speed of the propeller-driven S-2, and the S-3A's sophisticated periscope detection radar and onboard acoustic sonobuoy processing tripled the area it could search for adversary submarines.[122] S-3As were upgraded to S-3Bs during the 1980s and were complemented by SH-60F Seahawk helicopters, which replaced the aging SH-3 for short-range ASW operations.

The 1980s and Outer Air Battle

The U.S. strategic failure in Vietnam and the sharp post-war drawdown in military spending starting in the mid-1970s left the Navy in a diminished state. At the same time, the Soviet Union invested in capabilities to better guard its maritime and air approaches. The centerpiece of the Soviet investment plan was to field a sophisticated network of surveillance satellites and radars that would provide targeting support to quieter SSNs and SSGNs, as well as theater-range bombers armed with long-range ASCMs.[123] This effort was meant to counter the U.S. Navy's likely use of carriers to protect SLOCs between the United States and Europe and Japan while launching strikes against the USSR's periphery, eventually articulated in the Navy's 1987 Maritime Strategy.[124]

The Soviet effort began to bear fruit during the 1980s. Soviet land-based bombers had long out-ranged U.S. carrier aircraft, but they needed to close to within a few dozen miles of a carrier in order to launch their ASCMs, which put the bombers within range of the carrier's defensive CAPs. The advent of the supersonic Tu-22M Backfire maritime bomber and its 250-nm range Kh-22 ASCM enabled Soviet forces to launch attacks beyond the range of the carrier's fighters.[125] Similarly, the SS-N-12 Sandbox and SS-N-19 Shipwreck submarine- and surface-launched ASCMs had ranges of more than 250 nm, giving Soviet submarines and ships the ability to launch attacks from beyond U.S. CVBG sensor and weapons range.

The Navy responded to the improving Soviet anti-ship threat by increasing CVW air defense capacity and adopting the Outer Air Battle doctrine, an offensive approach to CVBG air

121 LT X, "The Age of the Strike Carrier is Over," *Capability Analysis*, Center for International Maritime Security, February 22, 2017, available at http://cimsec.org/age-strike-carrier/30906; and Cote, *The Third Battle*.

122 Cote, *The Third Battle*.

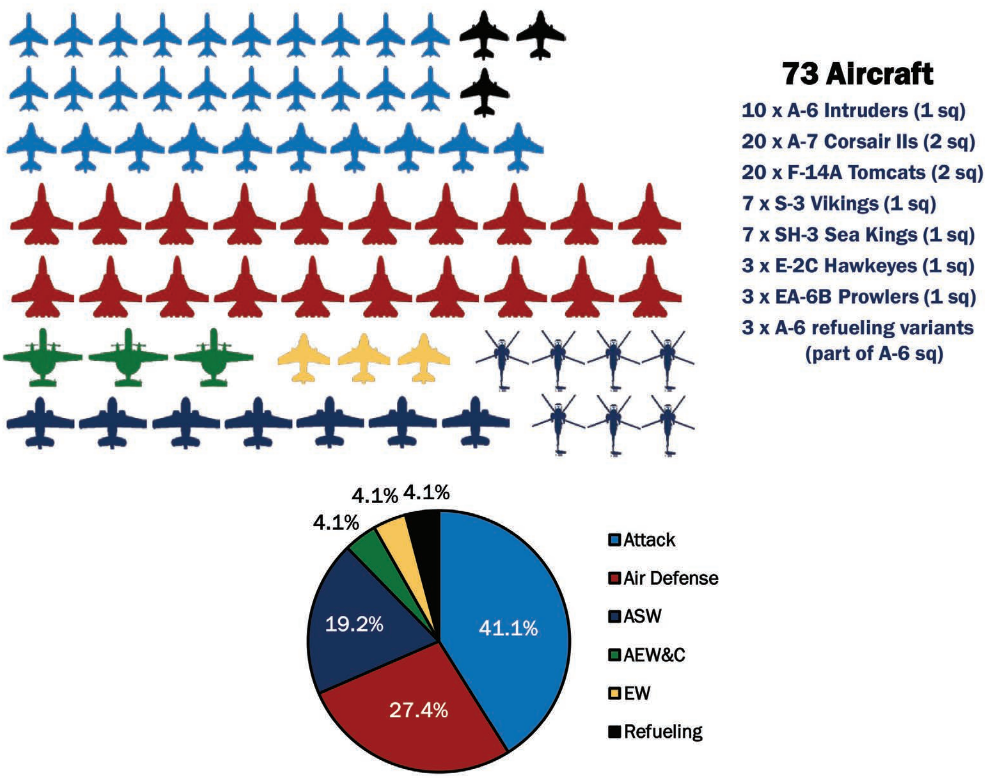
123 Krepinevich, *Maritime Competition in a Mature Precision-Strike Regime*, p. 20.

124 John Hattendorf and Peter Swartz, eds., *U.S. Naval Strategy in the 1980s: Selected Documents* (Newport, RI: Naval War College Press, December 2008); and Krepinevich, *Maritime Competition in a Mature Precision-Strike Regime*.

125 Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

defense in which CVW fighters would “shoot the archer” before it could fire its ASCM “arrow.”[126] This approach was designed to enable CVBGs to fight their way to within striking distance of the Soviet Union. The Navy fielded the F-14A Tomcat, a supersonic fighter-interceptor, in 1974 to replace the multi-role F-4 and complement the E-2C in implementing Outer Air Battle. With its AWG-9 radar and long-range supersonic AIM-54 Phoenix AAM, the F-14A was capable of engaging multiple targets simultaneously, a vast improvement in the CVW’s ability to defend the carrier. Figure 22 shows a typical CVW incorporating the F-14A. A decade later, the Navy deployed the multi-role F/A-18 Hornet strike fighter to replace the A-7 attack aircraft and further increase the CVW’s air defense capacity.[127]

FIGURE 22: CVW ON USS EISENHOWER IN 1988



Outer Air Battle relied on sustaining CAPs 400 nm from the CVBG comprised of four F-14As spread in a 90-degree arc around the expected direction of incoming Soviet bombers, as shown in Figure 23. The F-14As and their Phoenix missiles were intended to break up and thin bomber raids by destroying Backfires before they could launch ASCMs. Other F-14s and

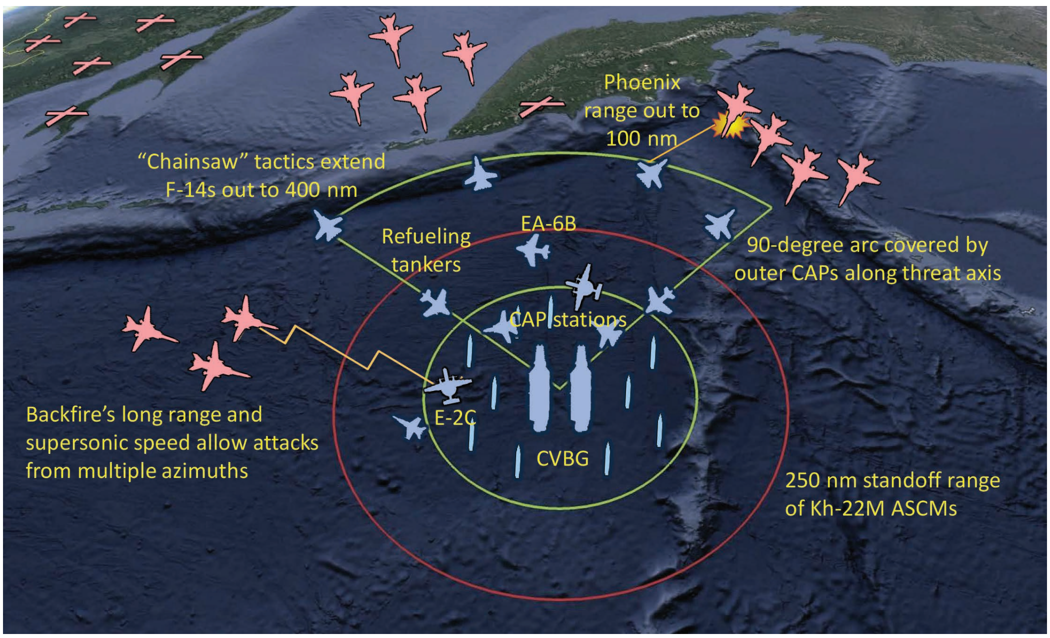
126 James A. Winnefeld, “Winning the Outer Air Battle,” *Proceedings*, August 1989, p. 1038, available at https://www.usni.org/magazines/proceedings/1989-08.

127 Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

F/A-18s maintained CAP stations 50–75 nm from the carrier to attack surviving bombers or incoming Kh-22s. The remaining ASCMs, including those launched by bombers outside the main threat axis, would be engaged by Aegis Combat Systems and SM-2 SAMs on CVBG escort ships. Outer Air Battle was supported by EA-6Bs, for detecting and jamming bomber radars and communications, and KA-6s and A-6Es, for refueling.

Although Outer Air Battle was likely the best available approach to defend CVBGs and reach striking distance of the Soviet mainland, it was difficult to sustain for more than a few days, and 24-hour operations required two carriers.[128] Outer Air Battle could also only cover a 90-degree arc. Furthermore, demands on A-6s and F/A-18s for refueling, EW, and air defense reduced capacity for strikes against Soviet targets ashore.[129] The concept was achievable in large part due to the Navy's development of Aegis cruisers, which could track hundreds of air threats with high accuracy and simultaneously engage multiple high-speed targets at long range. Without Aegis cruisers and, later, destroyers, CVBGs would not be able to adequately defend sectors not covered by F-14As.[130]

FIGURE 23: OUTER AIR BATTLE CONCEPT OF OPERATIONS



128 Ibid.

129 Krepinevich, *Maritime Competition in a Mature Precision-Strike Regime*; and Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

130 Norman Friedman, *Network Centric Warfare: How Navies Learned to Fight Smarter Through Three World Wars* (Annapolis, MD: U.S. Naval Institute Press, 2009), p. 18.

Like the Navy's approach to counter *kamikazes*, Outer Air Battle necessitated increasing the CVW's air defense capacity at the expense of its strike capacity. This compounded previous reductions in CVW strike capacity from the addition of specialized aircraft for EW, AEW&C, ASW, and refueling.[131] The overall result came close to what naval historian Norman Friedman referred to as a "self-licking ice cream cone," where the carrier's sole purpose was to defend itself.[132] Outer Air Battle was not necessarily a poor concept, but the Soviet ASCM threat and available CVW aircraft forced the U.S. Navy to choose between two undesirable options: 1) attempt to project power via strike missions, but do so with reduced capacity and at high risk; or 2) keep carriers safe and out of range of Soviet bombers, but trade significant strike capacity to ensure local sea control. The future CVW will likely also face this choice.

Post-Cold War (1991–Present)

The collapse of the Soviet Union in 1991 saved the Navy from having to contend with the growing vulnerability of its carriers. Until recently, the post-Cold War era was marked by an absence of great power rivalry and overwhelming U.S. military superiority.[133] Despite the more permissive environment, U.S. post-Cold War operations demonstrated the value of carrier-based aviation against regional powers and transnational terrorist threats.

When U.S. and NATO forces initiated Operation Enduring Freedom (OEF) in Afghanistan in October 2001, there were few suitable airfields for U.S. land-based tactical aircraft. Carrier-based strike fighters and land-based bombers, supported by AEW&C and tanker aircraft, provided essentially all the airpower to OEF until airfields were constructed in Afghanistan starting in 2002. During the war's first three months, carrier strike aircraft flew 75 percent of all U.S. strike sorties and delivered 50 percent of the precision munitions deployed by U.S. forces.[134] Operation Iraqi Freedom (OIF) in 2003 was supported by six carriers. This was partly a reflection of the Navy's desire to be involved in the invasion and partly to address host nation constraints placed on the use of airfields in the Middle East and Turkey.[135]

131 Krepinevich, *Maritime Competition in a Mature Precision-Strike Regime*.

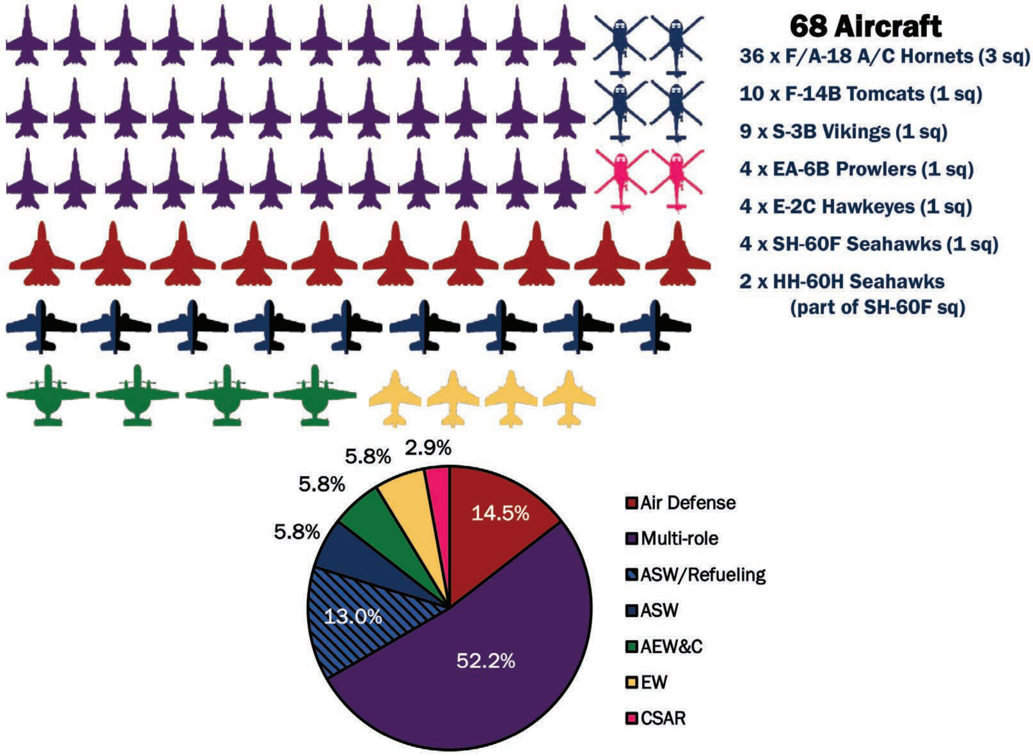
132 Norman Friedman, *Seapower and Space: From the Dawn of the Missile Age to Net-centric Warfare* (Annapolis, MD: U.S. Naval Institute Press, 2000); and Krepinevich, *Maritime Competition in a Mature Precision-Strike Regime*.

133 Brands and Edelman, *Why is the World so Unsettled?*

134 Paragraph based on Haynes, *Toward a New Maritime Strategy*, pp. 151–152; and Benjamin S. Lambeth, *American Carrier Air Power at the Dawn of a New Century* (Santa Monica, CA: RAND Corporation, 2005), p. 28.

135 Haynes, *Toward a New Maritime Strategy*, p. 152

FIGURE 24: CVW ON USS THEODORE ROSSEVELT IN 2002



Without the Soviet challenge to drive U.S. defense spending during the 1990s, the Navy reduced spending for its CVWs. When the A-6 retired in 1997, its intended replacement, the stealthy but expensive A-12 Avenger II, had already been cancelled. Instead of the A-12, the Navy bought the more affordable multi-role F-18 E/F Super Hornet. Although the Super Hornet had an 800-nm-shorter range than the A-6, carriers could operate closer to targets and adversaries or use land-based tankers, and the F/A-18 E/F was developed for about half the cost of an entirely new aircraft.[136] When F-14s began retiring during the mid-2000s, the Navy replaced them with more F/A-18 E/Fs.[137] By 2006, the CVW had transformed from a force of long-range interceptors and attack aircraft built for great power conflict to a CVW of relatively short-range multi-role fighters intended for operations against regional powers and irregular adversaries.

The post-Cold War era also saw a precipitous decline in CVW organic refueling and ASW capabilities. The KA-6D tanker left the air wing when the A-6 retired in 1997, shifting the burden of organic air refueling to the less capable S-3B ASW aircraft, which did not have the speed to

136 Haynes, *Toward a New Maritime Strategy*, pp. 116–117; and William Flannery, "On the Line–McDonnell and the Navy are Counting on the Super Hornet," *St. Louis Post-Dispatch*, September 25, 1995.

137 Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

refuel strike fighters en route. As a consequence, S-3Bs were instead used as recovery tankers to support carrier landings.[138] The S-3B then retired in 2009 without a replacement.[139] The carrier's organic tanking capability today consists of F/A-18 E/Fs carrying external fuel tanks, which reduces the number of CVW aircraft available for offensive missions on any given day. The S-3B's retirement also left the SH-60F Seahawk helicopters as the only remaining ASW-capable aircraft on the carrier, which was replaced with the improved MH-60R Seahawk during the 2000s. A second squadron of helicopters, which fly the multi-mission MH-60S Seahawk, was added to the CVW starting in 2002.[140]

Despite the fiscal constraints and permissive operational environments of the 1990s, the Navy developed some new capabilities in anticipation of a more challenging future. The EA-18G Growler, an EW aircraft based on the F/A-18 E/F, replaced the E/A-6B and will be equipped with the NGJ during the 2020s.[141] The E-2D Advanced Hawkeye is also joining CVWs to replace E-2Cs. The E-2D's new AN/APY-9 radar incorporates AESA technology, giving it greater range, accuracy, and jam resistance than its E-2C predecessor. Starting in 2020, E-2Ds will also be capable of being refueled in flight, allowing them to operate farther from their carriers for greater periods of time.[142] Lastly, the C-2A Greyhound, the primary carrier onboard delivery (COD) aircraft since the mid-1960s, will be replaced by the CMV-22B Osprey starting in 2020.[143]

Figure 25 depicts the current CVW configuration on the Japan-based USS *Ronald Reagan*.

138 Ibid.

139 Hendrix, *Retreat from Range*.

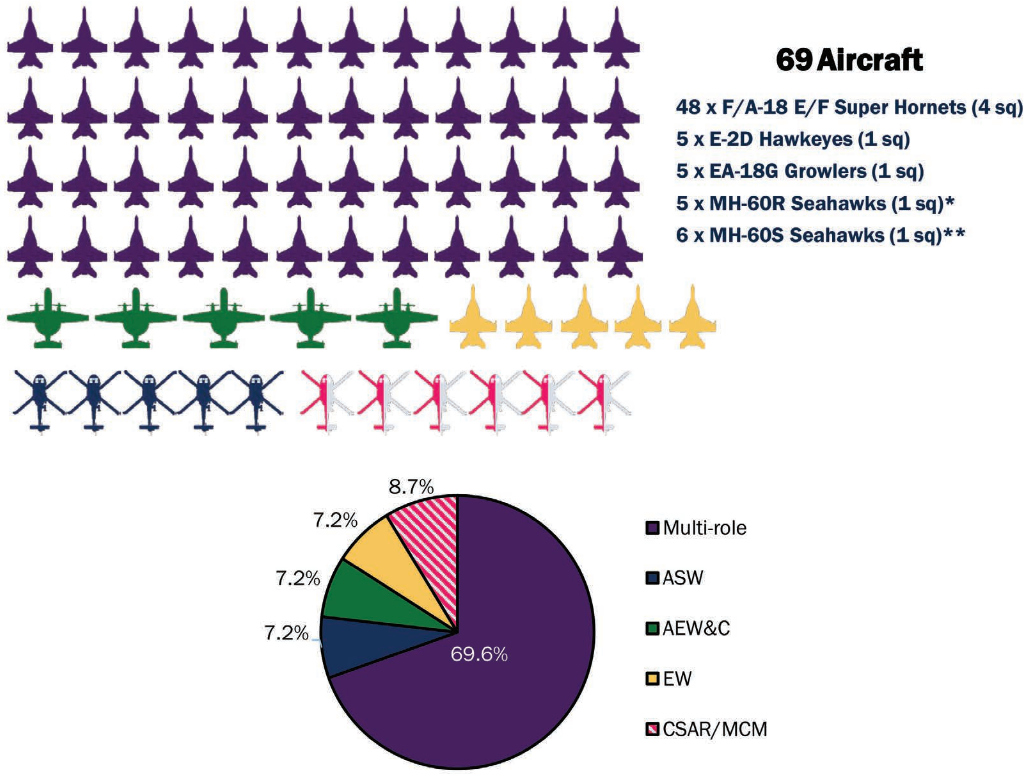
140 Sam LaGrone, "The Basics: Inside the Carrier Air Wing," *USNI News,* April 28, 2018, available at https://news.usni.org/2016/04/28/the-basics-inside-the-carrier-air-wing.

141 "A Short History of U.S. Navy Airborne Electronic Attack"; Kris Osborn, "Navy Moves Next-Gen Jammer Electronic Warfare to Next Phase," *Defense Systems*, July 10, 2017, available at https://defensesystems.com/articles/2017/07/10/next-gen-jammer-navy.aspx.

142 "E-2 Hawkeye Early Warning and Control Aircraft," *Fact File*, U.S. Navy, updated January 5, 2018, available at http://www.navy.mil/navydata/fact_display.asp?cid=1100&tid=700&ct=1.

143 Megan Eckstein, "Navy Transition From C-2A to CMV-22B Will Span 2020 to 2026; Location of Training Squadron Undecided," *USNI News*, January 3, 2018, available at https://news.usni.org/2018/01/03/navy-transition-c-2a-cmv-22b-span-2020-2026-still-deciding-location-training-squadron.

FIGURE 25: CVW ON USS RONALD REAGAN IN 2018



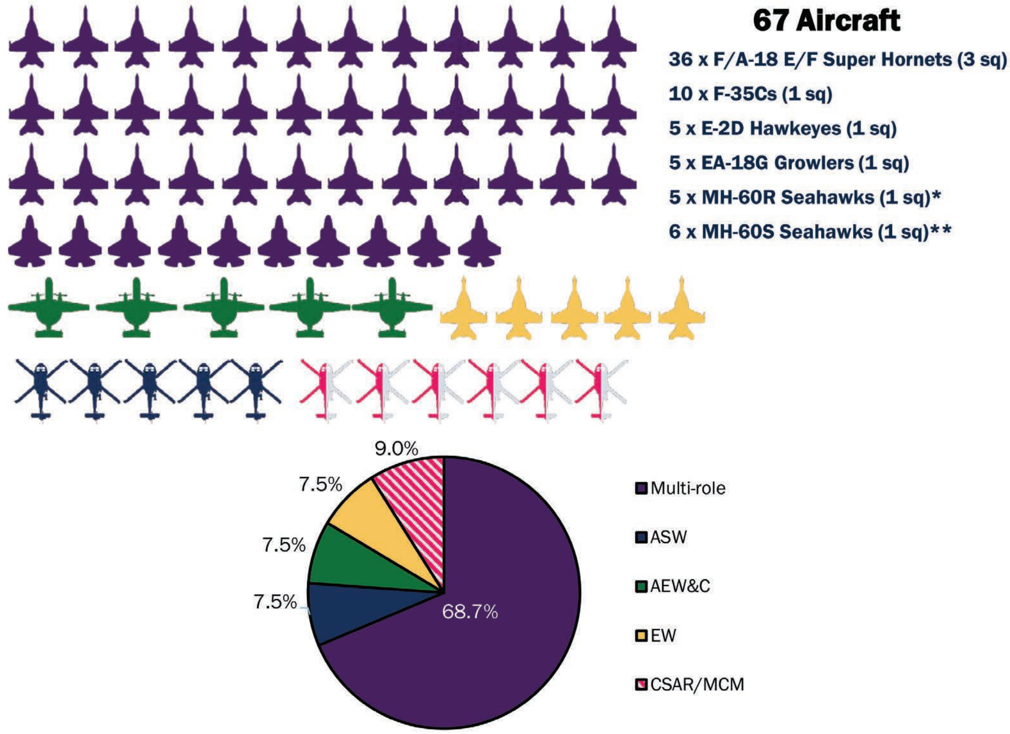
*Helicopter Maritime Strike (HSM) squadrons are typically comprised of eleven MH-60Rs spread across the CSG, approximately five of which are based on the carrier.
**Helicopter Sea Combat (HSC) squadrons are typically comprised of eight MH-60Ss spread across the CSG, approximately six of which are based on the carrier.

The F-35C Lightning II Joint Strike Fighter is expected to achieve initial operational capability (IOC) in 2019, when it will begin replacing F/A-18 A-Ds throughout the Navy and Marine Corps. The F-35C will be the first low-observable aircraft in the CVW, which will improve CVW survivability against sophisticated adversary IADS. However, since the F-35C is more expensive to buy and maintain than the F/A-18 C/D, F-35C squadrons will have fewer aircraft than the F/A-18 squadrons they replace.[144] Figure 26 depicts the projected CVW on USS *Carl Vinson* (CVN-70) in 2021, which is expected to be the first carrier to deploy a F-35C squadron.[145]

144 Walton, "The Evolution of the Modern Carrier Air Wing."

145 Ben Werner, "Schedule at Risk for Navy F-35C Fighters to be Combat Ready by End of Year," *USNI News,* March 29, 2018, available at https://news.usni.org/2018/03/29/current-schedule-risk-navy-f-35c-fighters-combat-ready-end-year.

FIGURE 26: PLANNED CVW IN 2021



* Helicopter Maritime Strike (HSM) squadrons are typically comprised of eleven MH-60Rs spread across the CSG, approximately five of which are based on the carrier.
** Helicopter Sea Combat (HSC) squadrons are typically comprised of eight MH-60Ss spread across the CSG, approximately six of which are based on the carrier.

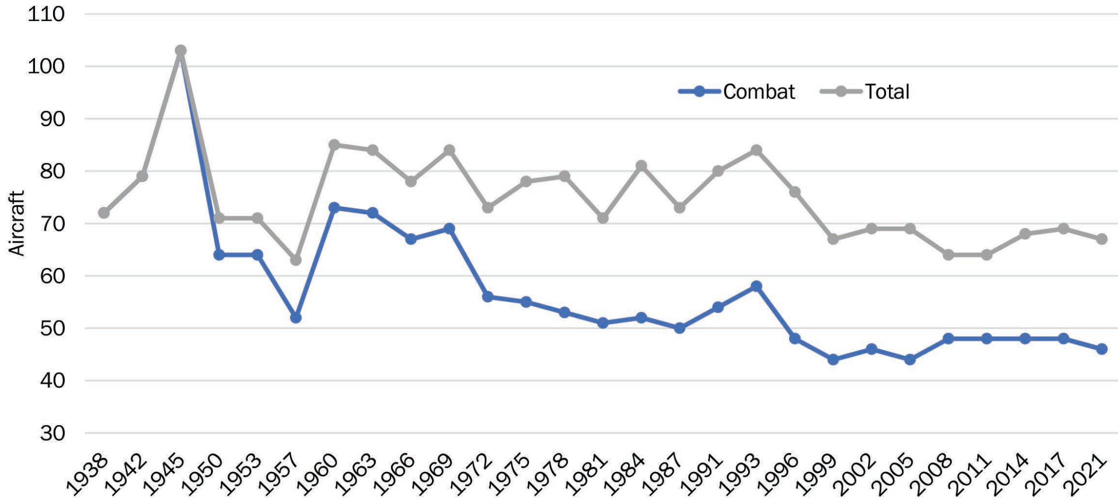
Trends in CVW Composition and Capabilities

Reduction in Number and Variety of Combat Aircraft

Ever since carrier aviation's inception a century ago, the Navy has regularly changed CVW missions, operational concepts, aircraft, and configurations to address emerging threats and enact new U.S. strategies. An assessment of this evolution reveals several important trends. Most significantly, the diversity and number of CVW combat aircraft steadily decreased, especially since the end of the Cold War, as shown in Figures 27 and 28. Where there once was a variety of combat aircraft—fighters, interceptors, and heavy, medium, and light-attack aircraft—there is now only the multi-role F/A-18 in its Hornet, Super Hornet, and Growler configurations.[146] Although this trend likely made the CVW more efficient to operate, it also reduced its capability for specific missions like ASW or air defense.

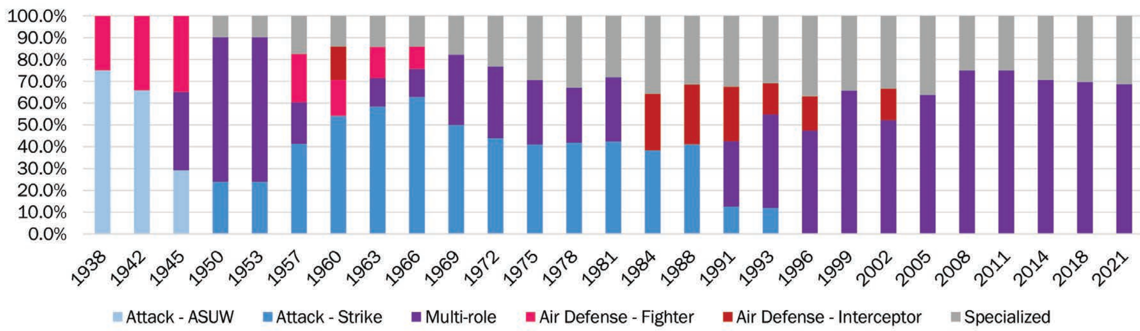
146 Walton, "The Evolution of the Modern Carrier Air Wing."

FIGURE 27: NUMBER OF CVW AIRCRAFT



CSBA data; see Appendices.

FIGURE 28: PROPORTION OF CVW AIRCRAFT BY MISSION



CSBA data; see Appendices.

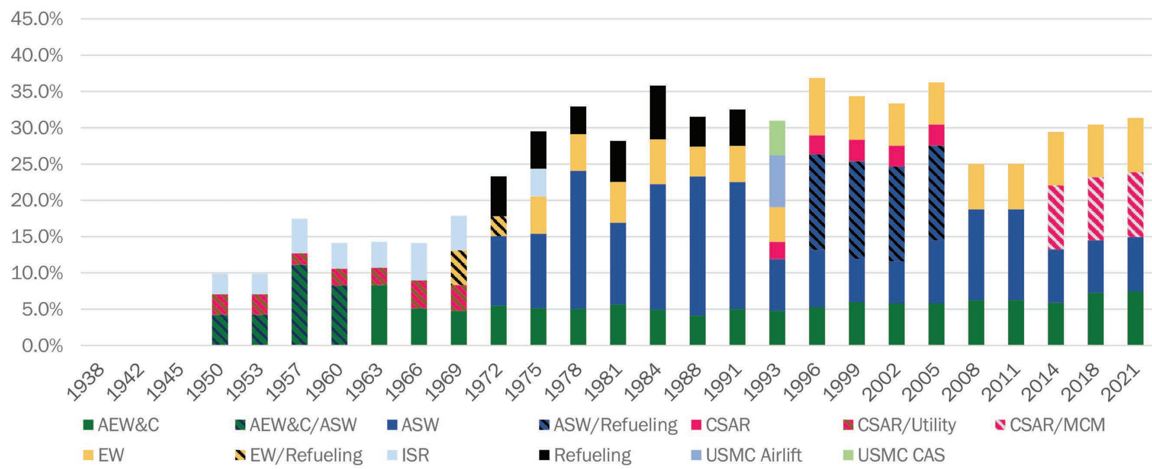
Increase in Capacity for Air Defense Specialized Missions

Another trend shown by Figure 28 is the shift toward increasing the air defense capacity of the CVW when new threats emerge, followed by a return to strike and CAS when threats recede. To counter *kamikazes* during the late Second World War, the Navy replaced bombers with multi-role aircraft and fighters.[147] At the end of the war, fighters were replaced with multi-role aircraft to support ground operations in Korea. The advent of new Soviet fighters required the addition of more F-6 and F-8 fighters during the late 1950s to mid-1960s, which were replaced by the multi-role F-4 during the late 1960s to support ground operations in Vietnam.

147 Clark G. Reynolds, *The Fast Carriers: The Forging of an Air Navy* (Annapolis, MD: U.S. Naval Institute Press, 1992), pp. 288–290.

By the late Cold War, the threat posed by Soviet Backfire bombers carrying long-range ASCMs prompted replacement of the multi-role F-4 with the F-14 air defense interceptor. When the Soviet threat dissolved at the end of the Cold War, F-14s were replaced with multi-role F/A-18s.

FIGURE 29: COMPOSITION OF CVW SPECIALIZED AIRCRAFT



CSBA data; see Appendices.

As the number and variety of CVW combat aircraft decreased, the number of specialized aircraft dedicated to what had been considered support missions—ASW, EW, AEW&C, ISR, and refueling—also increased, as depicted in Figures 28 and 29. This evolution toward missions other than strike and anti-air warfare is often pointed to as an example of the carrier's decreasing relevance and inability to contribute to power projection.[148] The shift toward a diverse set of missions, however, may also suggest that aircraft carriers are becoming increasingly important to the joint force, particularly for ASW; command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR); and counter-C4ISR operations.

For example, the Navy's adoption of operational concepts that improve the offensive capability of ships and submarines, such as Distributed Lethality, may require CVW aircraft to provide targeting information and relay communications between sensor platforms and shooters.[149] As

148 Justin Bachman, "How America's Aircraft Carriers Could Become Obsolete," *Bloomberg Business,* June 28, 2017, available at https://www.bloomberg.com/news/articles/2017-06-28/how-america-s-aircraft-carriers-could-become-obsolete.

149 Distributed Lethality and related concepts are designed to make more ships able to conduct anti-ship and strike operations and to expand the multi-mission capability of ships that already have offensive capabilities. See Thomas Rowden, Peter Gumataotao, and Peter Fanta, "Distributed Lethality," *Proceedings*, January 2015, available at http://www.usni.org/magazines/proceedings/2015-01/distributed-lethality; and Kris Osborn, "The Navy's Aircraft Carriers Have a Neat Trick to Kill More Enemy Ships," *National Interest*, June 13, 2018, available at http://nationalinterest.org/blog/the-buzz/the-navys-aircraft-carriers-have-neat-trick-kill-more-enemy-26244.

the ability to rapidly collect, analyze, and disseminate data becomes more central to warfare in general, CVW C4ISR and counter-C4ISR capabilities will also be needed by the joint force. This will be particularly true when land-based AEW&C aircraft such as the E-3 Sentry and E-8 Joint Surveillance Target Attack Radar System retire over the coming decade.[150]

CVW Aircraft Designs Have Led to Tradeoffs

Because a carrier possesses a finite amount of deck and hangar space, changes in CVW aircraft size have prompted tradeoffs in CVW composition. These tradeoffs were delayed during the first half of the Cold War because the amount of deck space on new carrier designs increased, accommodating more and larger aircraft. When the carrier's deck space stabilized with the introduction of *Nimitz*-class of carriers during the 1970s, further increases in the size of CVW aircraft required more efficient use of hangar space or reductions in the total number of aircraft in CVWs.

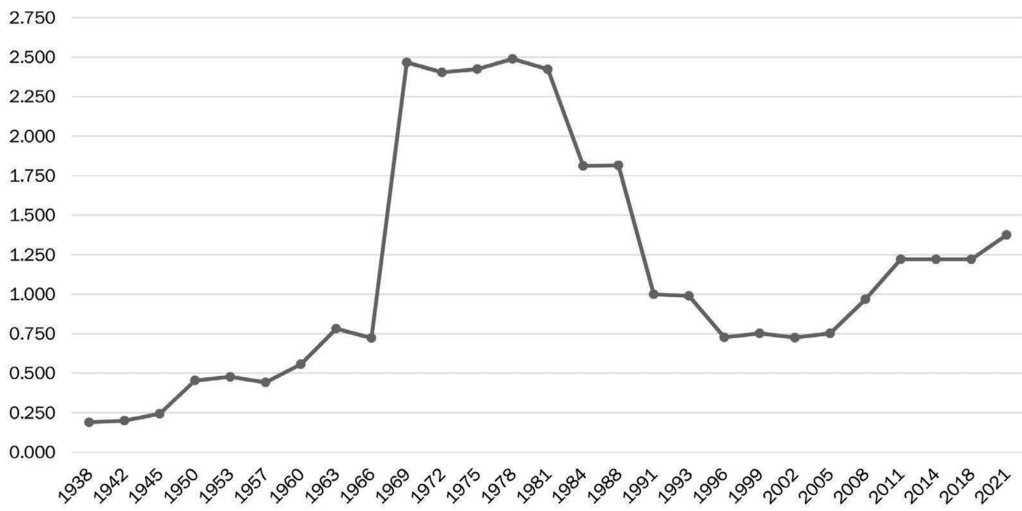
The designs of carrier aircraft themselves also led to significant capability tradeoffs. For any given airframe, adding weapons or sensors generally reduces the amount of fuel the aircraft can carry. The most obvious example of this relationship is that an aircraft can carry either weapons or external fuel tanks on wing station hard points.[151] Because an aircraft's range and weapons payload are related, the combination of its maximum range (using internal fuel) and its maximum combat payload can be a useful performance metric to compare different airframes. Furthermore, the maximum combat range x maximum payload per unit surface area can quantify how efficiently a single aircraft, or the entire CVW, is using a carrier's available space. The area unit often used to represent the size of CVW aircraft is their "spot factor." A spot factor of 1.0 is defined as the approximate surface area taken up by an F/A-18 A-D Hornet.

In terms of range and payload per spot factor, carrier combat aircraft today are lower performing, on average, than their late-Cold War brethren, as shown in Figure 30. The reduction in combat efficiency, however, is not due to decreasing payload capacity. The average maximum payload of CVW attack, multi-role, and air defense platforms, depicted in Figure 31, increased consistently from before the Second World War to the introduction of the A-6 and A-7 at the end of the 1960s. Although it declined slightly with the replacement of the A-6 and A-7 by the F/A-18 A-D, the introduction of the F/A-18 E/F Super Hornet in the mid-to-late 2000s returned total potential CVW payload capacity to a comparable level with its Cold War high.

150 "JSTARS Replacement: Competition Opened Wide," *Defense Industry Daily,* January 11, 2018, available at https://www.defenseindustrydaily.com/jumped-up-jstars-mp-rtip-technology-for-ground-surveillance-planes-05156/.

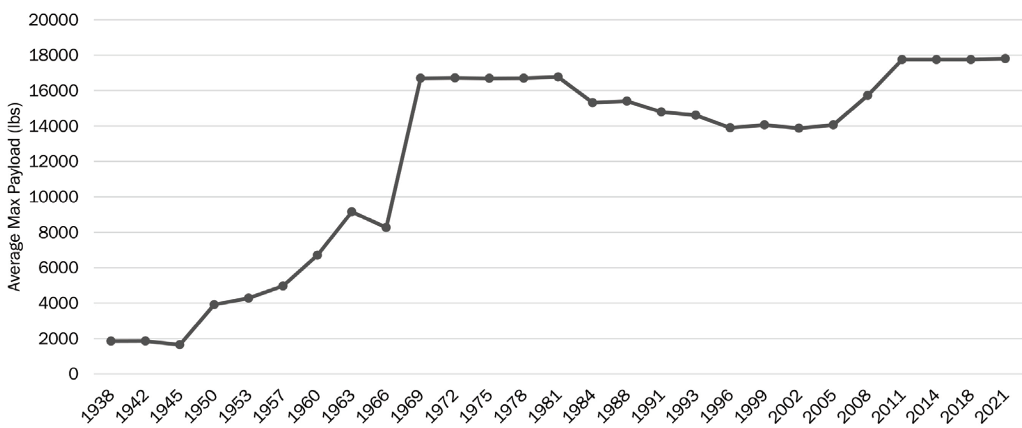
151 Ehrhard and Work, *Range, Persistence, Stealth, and Networking*.

FIGURE 30: CVW COMBAT AIRCRAFT EFFICIENCY (RANGE X MAX PAYLOAD/SPOT FACTOR)



CSBA data; see appendices.

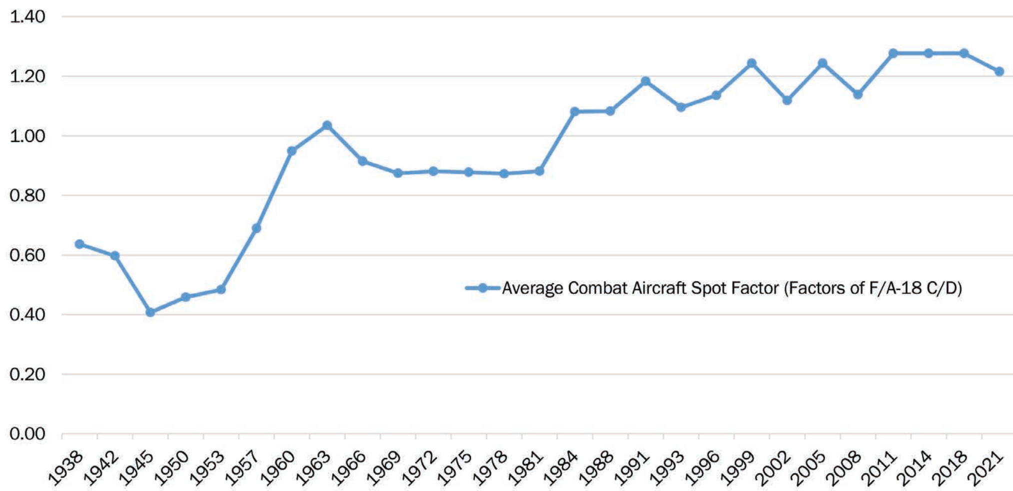
FIGURE 31: CVW COMBAT AIRCRAFT AVERAGE PAYLOAD



CSBA data; see appendices.

Increases in the size of CVW aircraft and reductions in their range were the major factors that drove reductions in CVW performance and combat efficiency. During the 1950s and early 1960s, the need to support the nuclear strike mission demanded aircraft with large payloads, which resulted in larger aircraft, as shown in Figure 32. Many of these aircraft, such as A-1 or A-3, were repurposed to other missions when nuclear strike faded in importance as a CVW mission. When the A-1 and A-3 retired, the average size of CVW aircraft decreased until introduction of the F-14. It has grown slowly since, with the transition from the F/A-18 C/D to the larger F/A-18 E/F contributing.

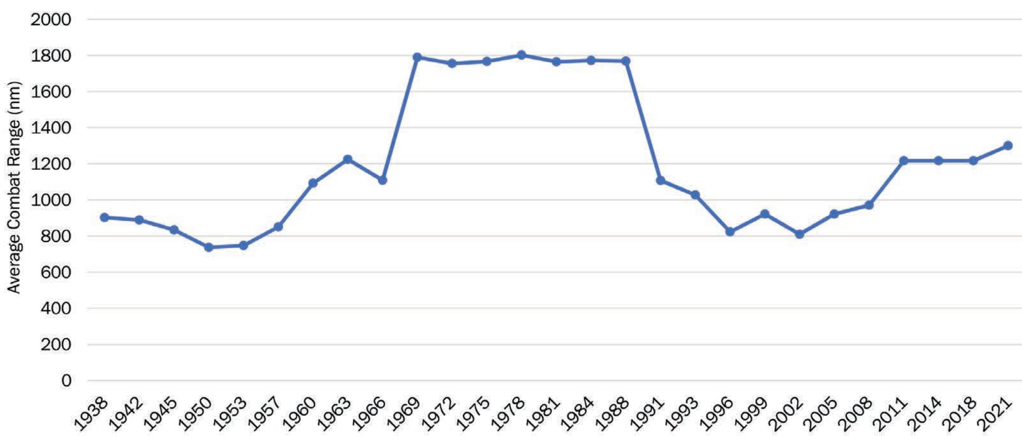
FIGURE 32: CVW COMBAT AIRCRAFT AVERAGE SIZE



CSBA data; See appendices. CSBA's approximation of "spot factor" is calculated by the length and wingspan (folded, if applicable) of carrier aircraft relative to the spot factor of the F/A-18C Hornet.

Although payloads have remained relatively constant and aircraft have grown slightly since the end of the Cold War, CVW combat aircraft range has decreased significantly. This could be attributed, in part, to the CVW's shift from specialized attack and air defense aircraft toward multi-role F/A-18s. The design features that enabled F/A-18s to achieve the speed and maneuverability needed for air warfare may have reduced their fuel efficiency and range. As a result, the average range of CVW combat aircraft, shown in Figure 33, is as low today as it was in the early 1960s.

FIGURE 33: CVW COMBAT AIRCRAFT AVERAGE RANGE

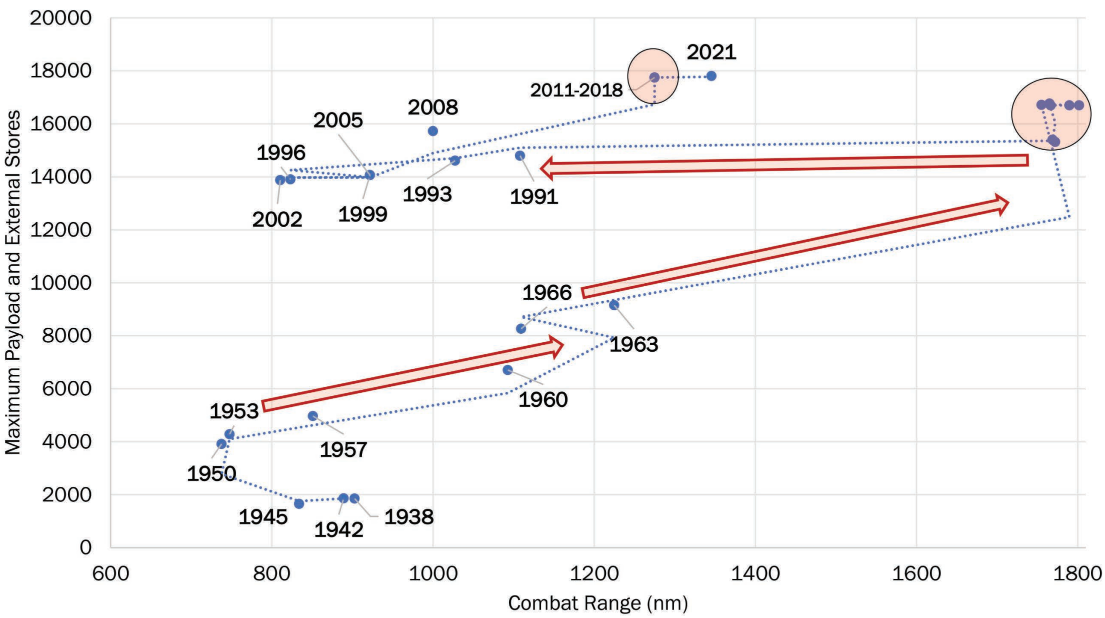


CSBA data; See appendices.

With the return of great power competition, land- and carrier-based aircraft capable of long-range operations will become more important to deterring and countering aggression. As in the past, tradeoffs may be required between CVW aircraft range, size, speed, and payload. (These potential tradeoffs will be discussed in Chapters 4 and 5.)

The evolution of CVW average range, payload, and aircraft size is summarized in Figure 34. As aircraft and aircraft carriers grew in size during the first half of the Cold War, CVWs were able to increase both their range and payload. With the adoption of a single class of *Nimitz*-class aircraft carriers during the 1970s, large increases in both range and payload were no longer possible without reducing the number of aircraft in the CVW. As a result, average CVW payload and range stabilized until the end of the Cold War. With the more permissive environments of the post-Cold War period, range was traded for the efficiency of multi-role aircraft. Range and payload have improved slowly since then with the introduction of new aircraft design features and improved propulsion technologies.

FIGURE 34: AVERAGE CVW RANGE AND PAYLOAD



Imperatives for the Future CVW

The CVW of 2040 will require new aircraft and a different composition than that planned for the CVW of 2021, which is centered on F/A-18 E/Fs and F-35Cs. The design and development of the F-35C began during the 1990s and 2000s.[152] In the years since the F-35C program began, the ranges of ASCMs and ASBMs have increased to more than 500 nm and 800 nm,

152 "History," *The F-35 Lightning II*, Joint Strike Fighter Joint Program Office, updated October 25, 2018, available at http://www.jsf.mil/history/his_jsf.htm.

respectively.[153] Both can be delivered from platforms and launchers protected by long-range SAMs with ranges of more than 200 nm. Shooting the "archer" instead of the "arrow" will require operating at long range and penetrating sophisticated air defenses to find and engage mobile and relocatable ASCM or ASBM launchers at sea and ashore.

However, if the carrier remains at a safe distance from an adversary's mainland, then even survivable aircraft like the F-35C will not have the range to strike anti-ship launchers and platforms. If the F-35C uses external fuel tanks to extend its range, it loses the stealth that may enable it to penetrate enemy IADS. Land-based refueling tankers must remain outside the range of enemy air defenses and require bases that may also be vulnerable to attack. A dedicated squadron of carrier-based aerial refueling tankers could help CVW aircraft engage enemy targets at sea or ashore at ranges where the carrier can remain far enough away to reduce its vulnerability to acceptable levels.

The Navy is pursuing the development of such a tanker.[154] However, this is not the only mission for which the CVW needs new capabilities. Capabilities for longer-range and higher-capacity ASW and air defense, penetrating EW and strike, and C4ISR will also be necessary to support offensive operations in the face of sophisticated enemy sensors and weapons. In short, the Navy will need to evolve the operational concepts, aircraft, and composition of the CVW if it is to contribute to future operations against great powers.

153 OSD, *Military and Security Developments Involving the People's Republic of China 2016*, pp. 22–29.

154 Sam LaGrone, "Navy Releases Final MQ-25 Stingray RFP; General Atomics Bid Revealed," *USNI News,* October 10, 2017, available at https://news.usni.org/2017/10/10/navy-releases-final-mq-25-stingray-rfp-general-atomics-bid-revealed.

CHAPTER 4

Missions and Operational Concepts of the Future CVW

As described in Chapter 2, the future CVW will continue to focus on three main types of operations:

- In large-scale sea control and power projection operations around the periphery of a great power;
- In smaller-scale missions at long range, often in support of other attack platforms or fires; and
- In the full range of military operations against regional powers or during heightened tensions with great powers.

The 2040 CVW will need to conduct several specific missions within these general categories of operations. Although similar to those conducted by current and past CVWs, the relative importance of each mission and the operational concepts used to conduct them will need to change to address the improved capabilities that America's great power adversaries are fielding. (Chapter 5 will address implications of these missions and concepts for the characteristics of CVW aircraft and overall configuration of future CVWs.)

This chapter will outline new or modified operational concepts the future CVW will need to conduct. These concepts are described in the context of the two carrier Maneuver Force, but could be executed by single carriers as well. Multiple carriers enable larger operations, long-term continuous operations, or more flexible force packaging compared to a single carrier. When conducted by a single carrier, the operational concepts described below may be sustained at smaller scales or for shorter periods, or they may require additional deck crew personnel to sustain continuous operations.

Future IAMD and ISR&T

A fundamental challenge for U.S. joint forces countering great powers will be mounting a credible capability to survive and operate in contested areas long enough to conduct offensive operations that could deny, delay, or degrade aggression. A key element of improving joint force survivability is increasing the air defense capacity of naval forces and bases ashore. CVW aircraft can make a decisive contribution to air defense of the fleet and nearby land bases and at the same time create an ISR&T and communications network that can support the joint force in the region.

Today, the primary platforms conducting naval IAMD are surface combatants that possess limited sensor range and weapons capacity. The U.S. surface fleet is improving its air defense capacity by increasing its use of smaller, shorter-range SAMs like the Block II ESSM, four of which can be loaded into each VLS cell, and fielding more multi-mission missiles that can conduct both air defense and surface attack. This will allow more VLS cells to potentially support air defense operations without decreasing strike or SUW capacity.[155]

The Navy is also accelerating the development and fielding of gun-based air defense using hypervelocity projectiles (HVP);[156] non-kinetic systems such as the SLQ-32 Surface EW Improvement Program (SEWIP) Block 2 and 3 systems; and shipboard lasers and HPM weapons, whose defensive capacity is only limited by time and available power.[157] The air defense capacity of these systems could be sufficient to enable a CSG to counter the size of a potential salvo of Chinese anti-ship missiles that could be delivered 1,000 nm from the Chinese coast. This will hardly make the CSG invulnerable, but it could persuade the attacker to not strike the CSG until a more advantageous situation emerges. An aggressor like China could choose instead to defeat a CSG's air defense capacity in several ways, even if the CSG is operating 1,000 nm away:

- Launch multiple salvos to deplete the air defense interceptors on CSG surface combatants, which would then need to leave the area to reload. This would be costly for the aggressor and reduce weapons inventories for subsequent operations, but the cost exchange of damaging or sinking several major combatants and an aircraft carrier would still be in China or Russia's favor.

155 Thomas Rowden, "Sea Control First," *Proceedings*, January 2017, available at https://www.usni.org/magazines/proceedings/2017-01/commentary-sea-control-first.

156 Sydney J. Freedberg Jr., "$86,000 + 5,600 MPH = Hyper Velocity Missile Defense," *Breaking Defense,* January 26, 2018, available at https://breakingdefense.com/2018/01/86000-5600-mph-hyper-velocity-missile-defense/.

157 John Keller, "Navy Asks General Dynamics to Provide SEWIP Block 1B3 Shipboard Electronic Warfare (EW) Systems," *MilitaryAerospace.com*, May 4, 2018, available at http://www.militaryaerospace.com/articles/2018/05/contract-for-shipboard-electronic-warfare-ew.html.

- Use the mobility of ships and aircraft to attack the CSG from azimuths that would allow ASCMs to avoid some CG and DDG defensive systems and allow some weapons to slip through; and

- Employ highly survivable weapons, such as hypersonic missiles, that would significantly lower or negate the effectiveness of U.S. air defenses, or incorporate jammers or decoys into attack salvos.

CVWs could augment ship and ground-based air defenses to reduce the ability of adversaries to conduct successful attacks against U.S. and allied forces at sea and ashore. The most effective contribution CVW aircraft could make would be to destroy some or all enemy weapons platforms before they launch their weapons. As a result, SUW, ASW, and DCA operations also contribute to IAMD. CVW aircraft could also thin out salvos by shooting down enemy weapons before they reach CSG or air base defenses.

Attacking the Archers

Attacking the archers before they launch their arrows is a well-known missile defense approach. During the Cold War, U.S. carrier-based fighters planned to defend naval forces by attacking Soviet bombers before they could launch their ASCMs at U.S. CVBGs.[158] The combat radius of Cold War-era F-14A Tomcats, including patrol time on station, was about 500 nm; this allowed them to engage Soviet bombers before the bombers could launch ASCMs, which at that time had ranges of 200–250 nm.[159] The 1,000 nm ranges of current or projected future LACMs and ASCMs would make a similar approach very challenging, considering today's CVW strike fighters have about the same unrefueled combat radius as an F-14A.

To address the increasing range of enemy ASCMs and LACMs, future CSGs could implement a 21st Century version of Outer Air Battle, as shown in Figure 35, to defend U.S. and allied forces at sea and ashore. Although two CSGs, as in the proposed Maneuver Force, would be able to execute this concept continuously by taking 12-hour shifts, a single CSG could also implement this approach by surging deck crews for extended operations or bringing on additional flight deck and air crew personnel to enable continuous operations. However, two carriers operating simultaneously could enable aircraft to launch from one carrier and recover on the other, expanding the area aircraft can cover or allowing carriers to maneuver in a way that reduces their vulnerability to detection.

Like the Cold War version, the new Outer Air Battle would use CVW aircraft and CSG escort ships to attack ASCM-equipped enemy ships and bombers before they could launch missile

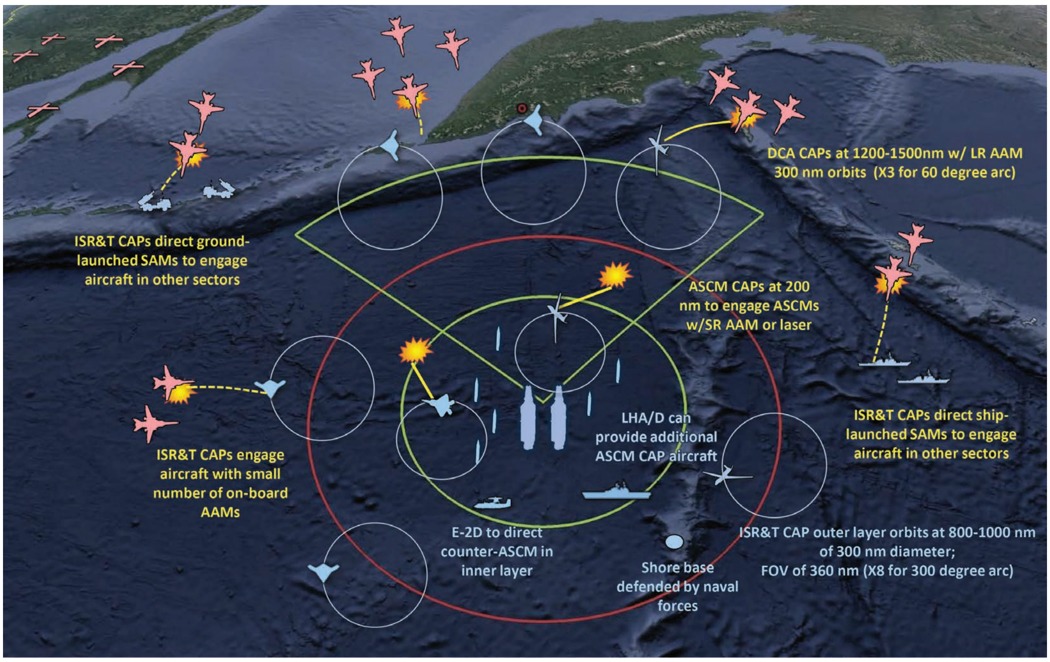
158 Michael Smith, *Antiair Warfare Defense of Ships at Sea* (Alexandria, VA: Center for Naval Analysis, September 1981); and James A Winnefeld, "Winning the Outer Air Battle," *Proceedings*, August 1989, p. 1038, available at https://www.usni.org/magazines/proceedings/1989-08.

159 Carlo Kopp, "Soviet/Russian Cruise Missiles," *Air Power Australia,* August 2009, available at http://www.ausairpower.net/APA-Rus-Cruise-Missiles.html; and "F-14 Tomcat," *Globalsecurity.org,* July 7, 2011, available at https://www.globalsecurity.org/military/systems/aircraft/f-14-specs.htm.

attacks. As described below, this new air defense scheme would use DCA CAP aircraft to position sensors and weapons where they can engage enemy bombers before they can launch ASCMs and LACMs. The concept complements DCA CAPs with ISR&T CAPs to position sensors where they can detect enemy aircraft coming from other directions and direct engagements by surface combatant SAMs.

To counter bombers, DCA CAP orbits would be established about 1,000 nm from the carrier or the defended land base in those sectors from which enemy bombers, having the longest-range LACMs and ASCMs, are most likely to arrive. Three DCA CAP orbits of 300 nm in diameter would be able to cover a 60-degree arc at this range using medium-range AAMs, assuming DCA CAP aircraft are at an altitude of 40,000 feet and the enemy bombers are at 20,000–40,000 feet.[160]

FIGURE 35: 21ST CENTURY VERSION OF OUTER AIR BATTLE



DCA CAP missions would ideally be 12 or more hours in duration, considering the 2-hour transit time to and from the CAP orbit, which would require two aircraft per DCA CAP station. DCA CAP aircraft would likely need to be refueled on their way to their stations, and while on station could be refueled if the threat environment was permissive enough for land-based tankers to support the mission.

160 Distance to Horizon = . Therefore, if an aircraft is at 40,000 feet, it can see 200 nm to the horizon; if the enemy aircraft is at 20,000 feet, it can see 160 nm to the horizon. The two aircraft can see each other up to 360 nm away.

Today's strike fighters could conduct 12-hour DCA CAPs 1,000 nm from a carrier, but it would require frequent refueling while on station, and the mission duration could test the limits of human pilots. A more efficient approach would be to use long-endurance, optionally manned or unmanned aircraft. These aircraft would likely be slower and less maneuverable than today's strike fighters or the F-14s used in the Cold War. In the 21st Century Outer Air Battle, however, longer-range AAMs and passive sensors could enable CAP aircraft to detect and engage bombers without themselves being detected. This would reduce the need for DCA CAP aircraft to be fast and maneuverable.

Current and future Russian and Chinese bombers and ASCMs will have the endurance to circumvent the most likely threat sectors and could approach CSGs from other azimuths. The new version of Outer Air Battle would address enemy air threats in these other sectors using a distributed air defense approach that combines ISR&T CAPs at 800–1,000 nm from the CVN or defended target with SAM launchers. ISR&T CAP aircraft would be equipped with long-range passive and active RF, EO, and IR sensors. Their primary role would be to detect enemy bombers and provide targeting information via Cooperative Engagement Capability (CEC) or similar high-bandwidth LOS datalinks to surface combatants, ground-based launchers, or unmanned surface vessels (USV) that would engage the bombers with SAMs.[161] ISR&T CAP aircraft would carry AAMs to engage enemy bombers if needed, provided the payload devoted to weapons does not affect the aircraft's sensor capability.

To provide full coverage of the 300-degree sector outside of the 60-degree sector covered by DCA CAPS would require eight ISR&T CAP orbits of 300 nm in diameter at an altitude of 40,000 feet, again assuming enemy bombers are at 20,000 feet or higher. Assuming 12-hour missions and a 2-hour transit time each way, the eight ISR&T CAP orbits would require 16 aircraft, which would likely need to be refueled on their way out to their CAP stations. Commanders could reduce the sector covered or the continuity of coverage to lower the number of aircraft needed. As with DCA CAP aircraft, long-range ISR&T CAPs would be more efficiently implemented by long-endurance unmanned or optionally manned aircraft rather than today's strike fighters.

Thinning ASCM Salvos

Even if fully implemented, the air defense scheme shown in Figure 35 would not necessarily engage every enemy ASCM platform before it could launch its weapons payload. CVW CAP aircraft may run out of weapons, and friendly surface combatants, submarines, or DCA aircraft may be out of position to engage enemy platforms. To defeat ASCMs, the 21st Century Outer

161 Cooperative Engagement Capability (CEC) is a high-bandwidth datalink designed to allow Navy surface combatants to share sensor data and contact information. In contrast to datalinks like Link-16 that share data via discrete messages, CEC shares raw data from one combat system to another, enabling ships to evaluate each other's operational pictures. CEC has now been installed on E-2Cs and E-2Ds as part of the Navy Integrated Fire Control-Counter-Air (NIFC-CA) capability. This enables ships to use sensor data from E-2s, which have a much more distant horizon, to target long-range SAMs such as the SM-6.

Air Battle would rely on planned improvements to surface fleet air defense, augmented with an inner air defense layer of ASCM CAPs and E-2Ds located about 200 nm from the carrier.

CVW aircraft flying ASCM CAPs could engage ASCMs using short-range AAMs or, preferably, laser or HPM weapons such as the Air Force Self-protect High Energy Laser Demonstrator (SHiELD) program.[162] The power of lasers, and to a lesser degree HPM, is reduced by attenuation in the atmosphere, lowering the amount of energy directed on and damage to the target. By shooting down at ASCMs through thinner air at higher altitudes, instead of shooting up at ASCMs from a ship through thicker air saturated with water vapor, a fighter can damage or defeat an ASCM using much less laser power than a ship would require. By using directed energy weapons to defeat ASCMs, air defense fighters would have a deeper magazine than fighters carrying only AAMs.

A wider variety of CVW and ARG ACE aircraft could be used for ASCM CAPs compared to DCA and ISR&T CAPs. Today's relatively short-range CVW F/A-18 and F-35C strike fighters can support ASCM CAPs with organic refueling because the patrols are closer to the carrier. Engaging ASCMs instead of enemy aircraft also reduces the risk to non-stealthy CVW aircraft performing this mission and would enable F/A-18s or F-35Cs to carry more external weapons, providing them greater counter-ASCM capacity. Similarly, ACE F-35Bs could complement F-35Cs in ASCM CAPs.

E-2Ds could coordinate engagements against ASCMs by CVW CAPs and surface combatants, and they would likely receive cueing of incoming ASCMs from ISR&T and DCA CAPs. By being able to look down at incoming ASCMs, which normally approach their targets at low altitudes, CVW ASCM CAP aircraft and E-2Ds would be better able to overcome stealth features and countermeasures that are often oriented toward the front and side of ASCMs to defeat ship-based air defenses.

In addition to extending the range of CSG air defense, this distributed air defense concept would more efficiently employ the air defense capacity of naval formations. Surface launchers in the outer air defense layer can carry more weapons than airborne platforms. And in the inner, counter-ASCM layer, surface combatants would be better able to use shorter-range air defense weapons such as ESSM, lasers, and HPM because they would have cueing and targeting from ISR&T CAPs and E-2D sensors.

CVW ISR&T

CVW DCA and ISR&T CAPs would provide the blunt or Maneuver Force organic ISR&T for the air and surface within 1,000 nm of CSGs, and they could relay data from other sensors such as sonar arrays and electromagnetic detectors on unmanned vehicles, the sea floor, or the

162 Gideon Grudo, "Lasers Coming to USAF Fighter Jets by 2021," *Air Force Magazine,* November 7, 2017, available at http://www.airforcemag.com/Features/Pages/2017/November%202017/Lasers-Coming-to-USAF-Fighter-Jets-By-2021.aspx.

shore. This could allow deployed commanders to conduct SUW, strike, or ASW despite a loss of communications with theater headquarters ashore and joint or national C4ISR capabilities. CVW ISR&T aircraft could also be employed by the joint force to support attacks from land or long-range strikes from shore-based bombers and strike fighters.

Inorganic ISR&T capabilities, however, will be important and necessary for naval operations because fiscal and space constraints will prevent devoting 22 or more CVW aircraft to sustain continuous 360-degree ISR&T coverage around a carrier, such as when a single CSG is operating independently. Naval forces could use theater ISR&T assets such as MQ-4 Triton high-altitude long-endurance (HALE) UAVs to fill gaps in CVW ISR&T coverage, given the Navy's plans to maintain five continuous MQ-4 orbits around the world.[163] Emerging commercial and military space capabilities could also fill gaps in ISR&T and communication relay coverage by CVW CAPs. For example, the DARPA Blackjack program intends to build a constellation of low earth orbit (LEO) satellites that would augment or eventually replace the larger and more expensive geosynchronous orbit (GEO) satellites that DoD now uses for C4ISR. Blackjack's goal is to provide worldwide ISR&T and high-bandwidth communications by hosting military sensor and communication payloads on commercial satellites.[164]

In addition to supporting SUW, strike, and ASW, long-range airborne and space-based ISR&T will be essential to defeating hypersonic ASCMs.[165] Travelling at more than five times the speed of sound, these weapons may be able to speed past most air defense SAMs, while their flight paths could exploit seams between current U.S. high-altitude ballistic missile defense (BMD) systems and lower-altitude AMD systems. CVW CAPs, supported by space-based sensors, could provide naval forces a way to detect hypersonic ASCMs in flight.[166] Hypersonic ASCM intercepts will be challenging, but may be possible by CVW aircraft using high-performance AAMs designed to intercept supersonic aircraft.[167]

The characteristics needed to support CVW ISR&T and DCA CAPs will favor the use of a survivable, long-endurance UAV with a payload on par with CVW attack aircraft. ISR&T and DCA CAP aircraft will, by design, operate close to enemy forces to enable targeting and

163 Sam LaGrone, "Navy: First Operational MQ-4C Tritons Will Deploy to Guam By Year's End," *USNI News,* April 10, 2018, available at https://news.usni.org/2018/04/10/navy-first-operational-mq-4c-tritons-will-deploy-guam-years-end.

164 John Keller, "DARPA Asks Industry to Develop Small, Secure Military Satellites to Operate in Low-Earth Orbit (LEO)," *Military Aerospace.com,* April 20, 2018, available at https://www.militaryaerospace.com/articles/2018/04/military-satellites-secure-low-earth-orbit-leo.html.

165 Aaron Mehta, "As Putin Touts Hypersonic Weapons, America Prepares its Own Arsenal. Will It Be in Time?" *Defense News,* March 4, 2018, available at https://www.defensenews.com/pentagon/2018/03/02/as-putin-touts-hypersonic-weapons-america-prepares-its-own-arsenal-will-it-be-in-time/.

166 Sydney J. Freedberg Jr., "Space-Based Sensors Needed For Missile Defense Vs. Hypersonics: MDA," *Breaking Defense,* March 9, 2018, available at https://breakingdefense.com/2018/03/space-based-sensors-needed-for-missile-defense-vs-hypersonics-mda/.

167 Oriana Pawlyk, "StratCom Chief Worries Amid Claims of 'Unstoppable' Russian Missile," *Military.com,* March 20, 2018, available at https://www.military.com/daily-news/2018/03/20/stratcom-chief-worries-amid-claims-unstoppable-russian-missile.html.

engagement of platforms before they can launch ASCMs. Enemy bombers and ships may also operate under the cover of shore-based air defenses up to 200 nm offshore.[168] As a result, ISR&T and DCA CAP aircraft will need to either have low observability to defeat enemy sensors or be able to defend themselves from enemy SAMs and AAMs. To reduce the number of aircraft needed to sustain these long-range operations, CAP aircraft should also be able to conduct 12-hour missions or longer, which will likely require a long-endurance aircraft that is either unmanned or optionally manned. The payload of ISR&T and DCA CAP aircraft will need to support a robust sensor package such as an AESA radar, passive sensors like those on the F-35, and a weapons payload of four or more AAMs, comparable to today's strike fighters.

Future Surface Warfare and Strike Operations

CVWs currently provide most of the Navy's strike and SUW capacity because U.S. surface ships or submarines are constrained by their VLS or torpedo room capacity, which must be shared between weapons for multiple missions. Surface combatants and submarines are also limited in their SUW capability by the relatively short ranges of current SUW weapons, including the >67-nm range AGM-84 Harpoon ASCM and >5-nm range Mk-48 torpedo.[169]

The Navy's new Distributed Lethality concept is designed to increase the offensive capacity and capability of individual ships, as well as to make more ships able to conduct offensive operations.[170] Planned upgrades to SM-2 and SM-6 SAMs will enable CGs and DDGs to conduct SUW and strike missions more than 100 nm away without impacting the ship's air defense capacity.[171] Surface combatant strike capacity will be further increased by the new multi-mission MST or a VLS-compatible version of the Long-Range Anti-Ship Missile (LRASM), which will enable SUW or strike more than 500 nm away with greater survivability

168 The Russian-designed S-400 series of air defense systems has a reported range of about 200 nm, while newer S-500 systems are reportedly able to reach 250 nm away. The air-launched Kalibr LACM has a range of up to 1,500 nm. See Dave Majumdar, "S-500: Russia's Super Weapon That Could Kill the B-2, F-22, or F-35?" *The Buzz* blog, The National Interest, April 10, 2017, available at http://nationalinterest.org/blog/the-buzz/s-500-russias-super-weapon-could-kill-the-b-2-f-22-or-f-35-20107; and Sebastien Roblin, "Kalibr: Russia Has Its Own 'Tomahawk' Cruise Missile," *The Buzz* blog, The National Interest, April 7, 2017, available at http://nationalinterest.org/blog/the-buzz/kalibr-russia-has-its-very-own-tomahawk-missile-20073.

169 Starting in 2018, U.S. submarines began carrying torpedo tube launch (TTL) Harpoon missiles. See David Larter, "The US Navy's Upgraded Harpoon Ship-Killer Missile is In Line for a Boost from Congress," *Defense News,* July 28, 2018, available at https://www.defensenews.com/naval/2018/07/28/the-us-navys-upgraded-harpoon-ship-killer-missile-in-line-for-a-boost-from-congress/; "Harpoon Missile," *Fact File*, U.S. Navy, updated March 10, 2017, available at http://www.navy.mil/navydata/fact_display.asp?cid=2200&tid=200&ct=2; and "Mk-48: Heavyweight Torpedo," *Fact File*, U.S. Navy, updated December 6, 2013, available at http://www.navy.mil/navydata/fact_display.asp?cid=2100&tid=950&ct=2.

170 Thomas Rowden, Peter Gumataotao, and Peter Fanta, "Distributed Lethality," *Proceedings*, January 2015, available at http://www.usni.org/magazines/proceedings/2015-01/distributed-lethality.

171 The SM-6 and SM-2 SAMs are being modified to enable them to conduct surface attack as well. See Sydney J. Freedberg Jr., "Anti-Aircraft Missile Sinks Ship: Navy SM-6," *Breaking Defense*, March 7, 2016, available at https://breakingdefense.com/2016/03/anti-aircraft-missile-sinks-ship-navy-sm-6/.

than today's weapons.[172] For submarines, the MST would also enable SSNs to carry up to twelve SUW/strike missiles in their VLS cells and approximately 30 missiles or torpedoes in their torpedo rooms. SSGNs could carry up to 154 SUW/strike missiles but will retire by the mid-2020s; their replacements, Block V *Virginia*-class SSNs with Virginia Payload Modules (VPM), will be able to carry 40 missiles in VLS cells as well as about 30 missiles or torpedoes in their torpedo rooms.[173]

The different characteristics of CVW aircraft, surface combatants, and submarines make each best suited for SUW and strike operations in different situations. For example, a surface action group (SAG) is more likely to be in an engagement area when a confrontation begins, enabling it to rapidly respond. Following an initial response, however, a SAG may need to go offline for several days to reload at a port or anchorage outside the conflict area. Submarines could engage small numbers of surface combatants in highly contested environments where their torpedoes could circumvent a ship's air defenses, or they could attack targets with missiles from unexpected directions that are not as well defended. Similar to a SAG, however, submarines that expend their payloads must return to a port facility to replenish.

Although CVW aircraft may not be in the area where a confrontation begins, they could sustain SUW and strike operations indefinitely once they reach the area, assuming CVNs are able to replenish at sea. As assessed in the following paragraphs, however, future CVW strike and SUW operations will need to occur from longer ranges than today to manage the threat to carriers from enemy ASBM or ASCM attack. These operations will also need to launch more weapons or more survivable weapons to counter improving enemy air defense systems.

Longer-Range Attacks

Today, CVWs conduct strikes against targets in Iraq and Syria from carriers located only a few hundred miles away in the Eastern Mediterranean or the Persian Gulf. By the 2030s, improving and proliferating sensor and missile threats will require CVNs to attack defended targets from farther offshore to keep the anti-ship missile threat within the capacity of their CSG's defenses. In addition to improving CSG survivability, reducing the volume of incoming weapons would enable a CSG to shift more of its aircraft from defensive to offensive missions.

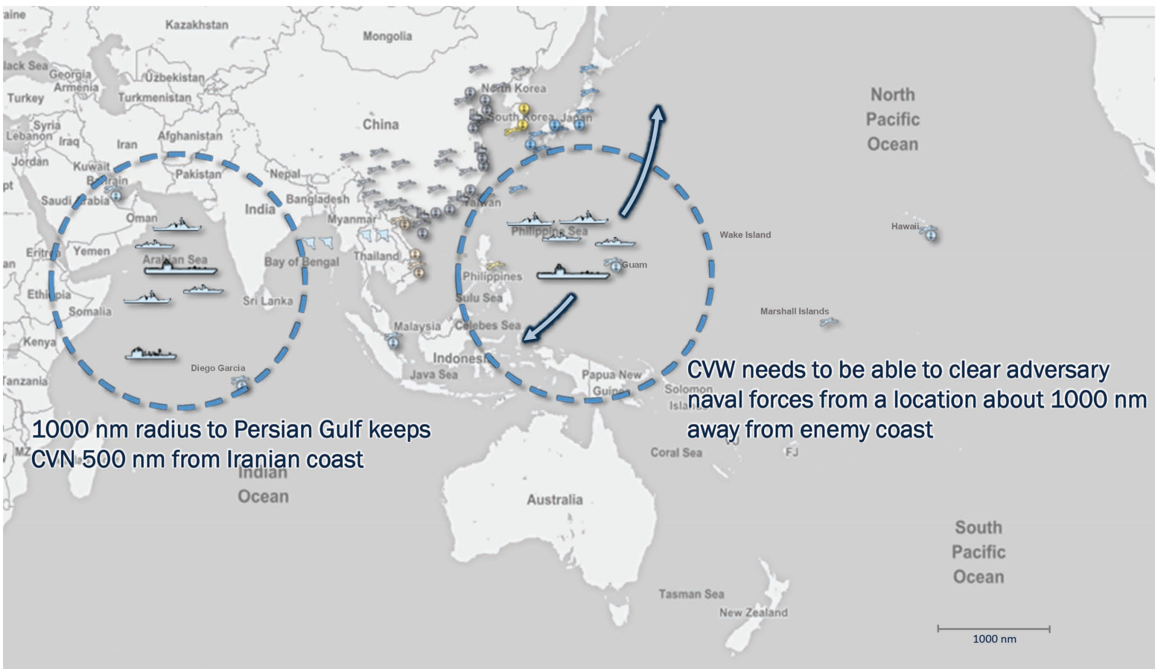
172 Although MST and LRASM are primarily anti-ship weapons, in theory they could also be used to attack ground targets using GPS coordinates or could be made strike-capable with minor modifications. See Sebastien Roblin, "LRASM: The Navy's Game Changer Missile Russia and China Should Fear?" *The Buzz* blog, The National Interest, April 21, 2018, available at https://nationalinterest.org/blog/the-buzz/lrasm-the-navys-game-changer-missile-russia-china-should-25490.

173 Weapons capacities are from "Attack Submarines: SSN" *Fact File*, U.S. Navy, updated April 27, 2017, available at https://www.navy.mil/navydata/fact_display.asp?cid=4100&ct=4&tid=100; "Guided Missile Submarines: SSGN," *Fact File*, U.S. Navy, updated November 9, 2015, available at https://www.navy.mil/navydata/fact_display.asp?cid=4100&tid=300&ct=4; and Kris Osborn, "Navy Wants 28 More Tomahawks on *Virginia*-Class Submarines Sooner," *Military.com*, March 16, 2015, available at https://www.military.com/daily-news/2015/03/16/navy-wants-28-more-tomahawks-on-virginia-class-submarines-sooner.html.

The CSG could also avoid undertaking maneuvers that may preclude carrier aircraft launch operations, which generally require a steady course heading into the wind.

Against regional powers such as Iran or North Korea that lack significant air or naval forces, CVWs will likely be able to conduct attacks against enemy targets within 500–1,000 nm of their carriers, as shown in Figure 36. Even in the event these adversaries have Russian or Chinese ASCMs with ranges of about 1,000 nm, it is unlikely that they will have the ISR&T infrastructure or capacity to launch and coordinate large salvos that could overcome the CSG's defensive capacity. However, in the event of conflict against great powers, enemy ships are likely to be operating up to 500 nm from Russian or Chinese territory to stay within range of their own shore-based sensors and aircraft. This may require U.S. CSGs to initially operate more than 1,000 nm from an enemy's coastline, depending on the number of enemy ships and their potential weapons capacity, until the CVW defeats the enemy surface combatants.[174]

FIGURE 36: CVW OPERATIONS AT PERIPHERY OF GREAT POWER CONFLICT AND AGAINST REGIONAL POWERS

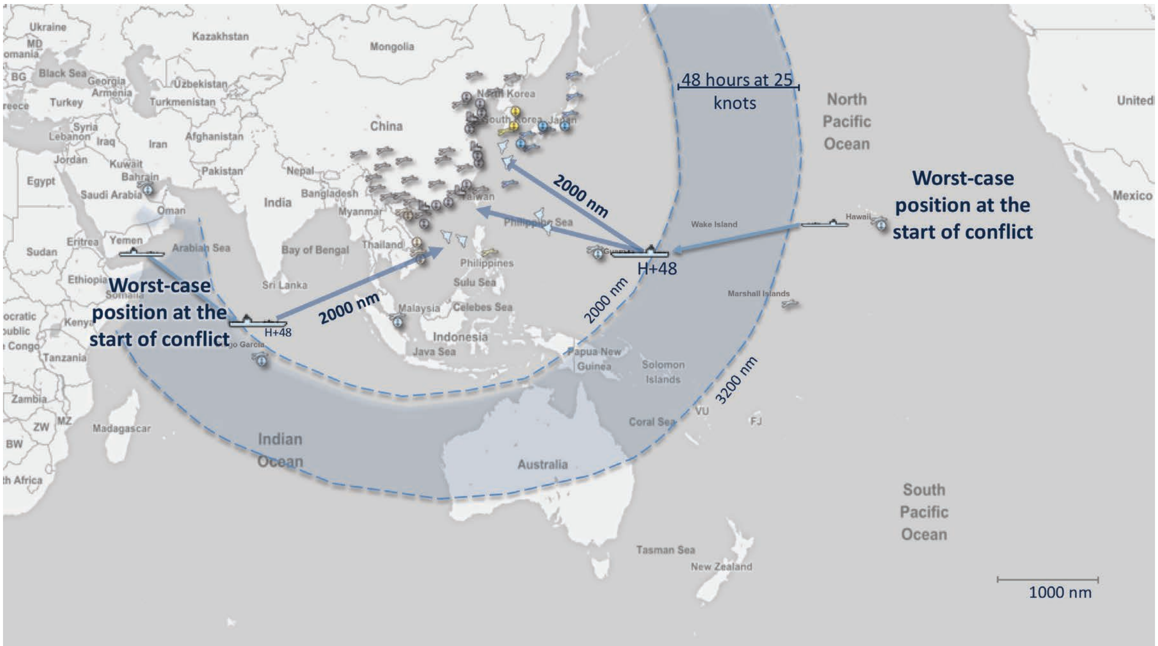


The most stressing situation for CVW strike or SUW range would be a conflict emerging with China when the blunt or Maneuver Force is far from the conflict area and land-based aircraft are unable to assist immediately. Although the conflict may start as a gray zone confrontation, U.S. and allied air bases in the region may be threatened or attacked by PLA cruise and

174 See Majumdar, "S-500"; and Roblin, "Kalibr."

ballistic missiles as it intensifies. This could suppress air operations or coerce the host nation into not allowing air operations from its territory. In this situation, the small inventory of U.S. long-range bombers may be allocated to attack high-priority targets such as Chinese C4ISR systems and air bases, leaving them unavailable for attacks at sea or against coastal and island targets.

FIGURE 37: LONG-RANGE CVW STRIKE OPERATIONS

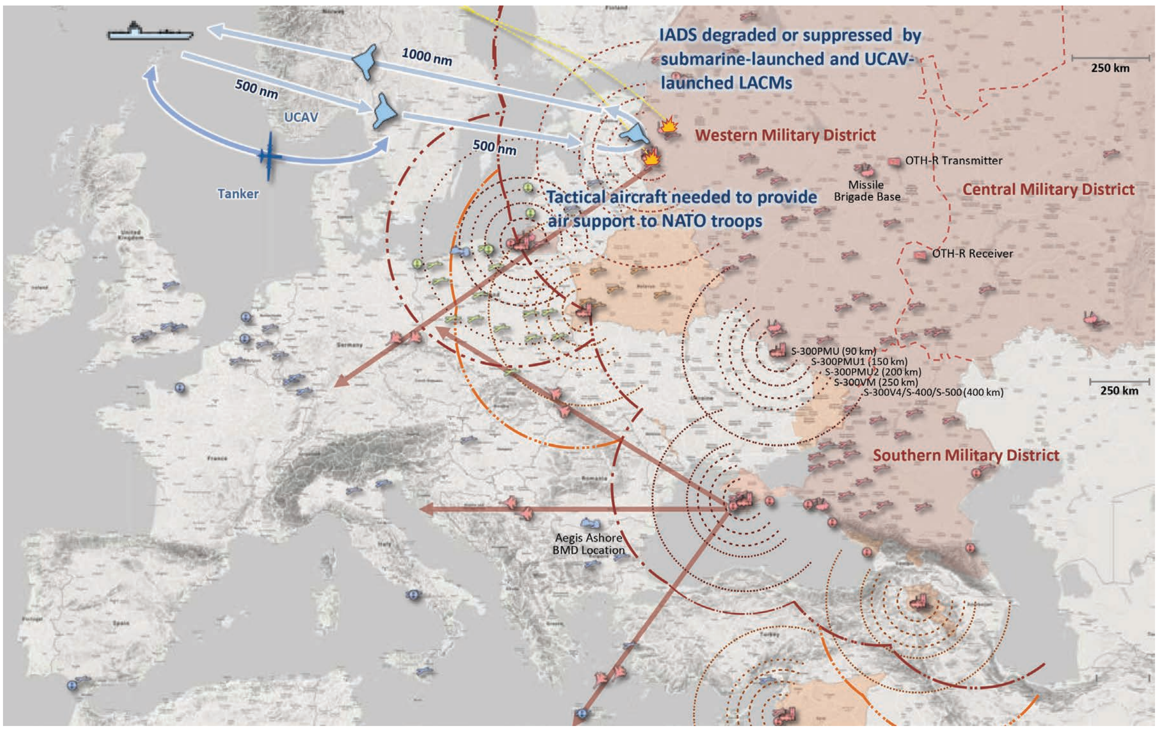


In this scenario, U.S. Navy contact or Deterrence Forces composed of submarines, amphibious ships, and surface combatants would conduct initial attacks against Chinese naval and coastal- or island-based forces until they run out of weapons or are destroyed, which would likely take one to two days. As Figure 37 shows, within one to two days Maneuver Force carriers could deploy from a remote location to within 2,000 nm of confrontation areas in the South and East China Seas. To support withdrawing contact forces, CVW aircraft would need to fly sorties over this range, and they would likely need to continue SUW and strike operations from more than 1,000 nm away from engagement areas until enemy air and missile threats are reduced.

Very long-range attacks like those needed in this scenario may be beyond the capability of current and planned manned CVW aircraft. A mission against targets located 2,000 nm from a CVN would likely take 10 to 12 hours to complete, including travel time for the 4,000-nm round trip, refueling operations, and the time to conduct attacks. Generally, air missions are limited to 6.5 to 12 hours due to pilot fatigue.[175] Therefore, the CVW will need aircraft for long-endurance missions that are unmanned or, like the Cold War-era A-3, have multiple pilots. Strike and SUW missions against targets 2,000 nm from a CVN will also require aerial refueling to some degree. Today's strike fighters with unrefueled ranges of 1,200–1,400 nm would require multiple air refueling events, whereas a long-endurance aircraft may need only one refueling.

In the posture model proposed above, CSGs could also periodically deploy from the U.S. East Coast to Europe as part of Deterrence Forces in the Northern Atlantic or Mediterranean. This would apply in a scenario involving Russian aggression against an Eastern NATO ally and a failure by NATO to respond due to a lack of consensus. U.S. leaders could view the attack as an attempt to establish a Russian-controlled enclave, as happened in Crimea, and choose to respond unilaterally in support of the affected NATO ally. The only forces able to counter the Russian effort may be those of the ally and U.S. forces based there or at sea.

FIGURE 38: CARRIER STRIKE OPERATIONS IN AN EASTERN EUROPE SCENARIO



175 "Daily flight time should not normally exceed three flights or 6.5 total hours flight time for flight personnel of single-piloted aircraft. Individual flight time for flight personnel of other aircraft should not normally exceed 12 hours. Flight times listed do not include ground time for pre-flight and post-flight duties." Office of the CNO, *NATOPS General Flight and Operating Instructions Manual*, CNAF M-3710.7 (Washington, DC: U.S. Navy, August 15, 2018), p. 8-14, available at https://www.public.navy.mil/airfor/vaw120/Documents/CNAF%20M-3710.7_WEB.PDF. See also Secretary of the Air Force, "General Flight Rules," Air Force Instruction 11-202V3, August 10, 2016, updated October 2, 2018, available at http://static.e-publishing.af.mil/production/1/af_a3/publication/afi11-202v3/afi11-202v3.pdf.

In this scenario, depicted in Figure 38, submarines or surface combatants in the Norwegian Sea could launch LACMs against fixed targets such as air defense systems in Kaliningrad, Belarus, or Russia's Western Military District protecting the Russian regular, paramilitary, and proxy troops conducting the aggression. Cruise missiles may not be appropriate, however, for attacking moving and rapidly relocatable targets such as vehicles and ground units. They may also be unable to provide CAS to allied security forces defending their nations' sovereignty. Manned or unmanned CVW attack aircraft could provide the persistence and responsiveness needed for these missions, flying from carriers 1,000 nm away in the Norwegian Sea. During these missions, CVW aircraft would likely need to be refueled in flight one or more times from land (if available) or carrier-based tankers, depending on the type of strike aircraft used and the time on station needed to support allied ground operations.

Improved Salvo Size and Survivability

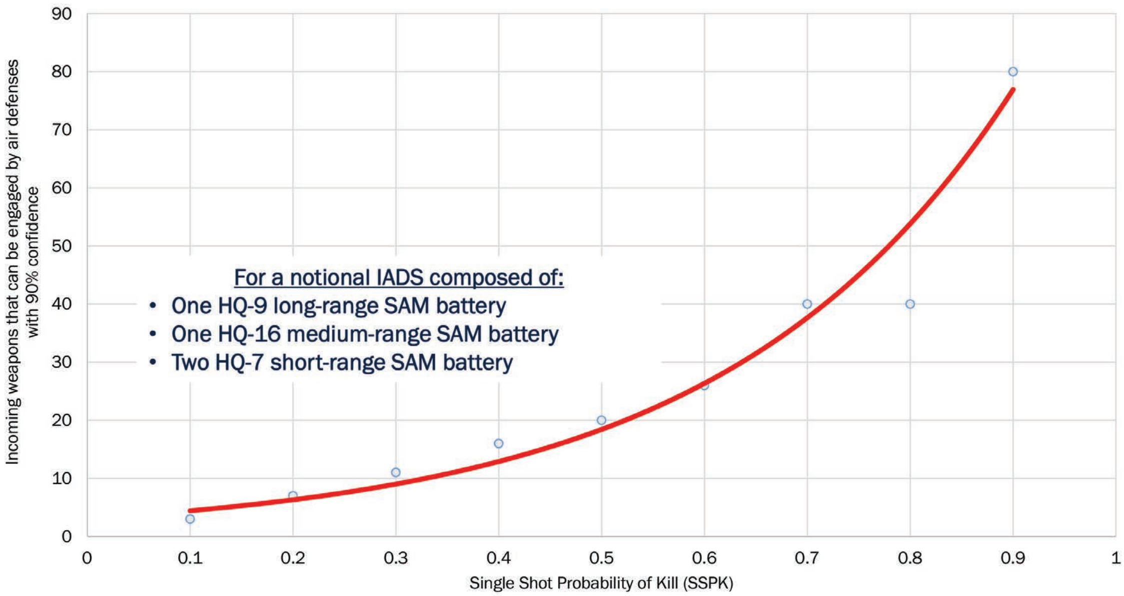
The advances in sensors and precision weapons technologies and their proliferation will intensify the salvo competition between strike capabilities and air defenses during future conflicts. CVW aircraft could use one or more of the following approaches to counter the increased range, capacity, and lethality of advanced air defense systems:

- Employ standoff weapons, which will be more expensive and less numerous than smaller, short-range weapons, to remain outside the range of air defense threats;
- Employ short-range weapons that are smaller and increase a platform's salvo size, which will require low-observable aircraft, EW, or both to closely approach targets; or
- Employ more survivable weapons, which use stealth design features, EW, maneuver and other measures to hit the same number of aimpoints with a smaller salvo compared to less survivable weapons.[176]

The future CVW will likely need to use a combination of these approaches. For example, as shown in Figure 39, an enemy air defense complex consisting of short-, medium-, and long-range SAMs and associated radars could have the capacity to engage up to about 80 strike weapons in a single salvo. Even if survivability features of CVW strike weapons reduce the enemy air defenses' SSPK to 0.3, a strike salvo would need to include up to ten weapons for each aimpoint until the defenses are depleted or destroyed. This would require two or more F-35C strike fighters, depending on the weapon used and the range of the attack. This may be acceptable against small targets, such as a C2 center. If multiple aimpoints are to be struck, the number of aircraft needed would grow significantly, depending on the orientation of the aimpoints and enemy air defenses.

176 These approaches to address the salvo competition are detailed in Gunzinger and Clark, *Sustaining America's Precision Strike Advantage*.

FIGURE 39: SALVO SIZE NEEDED TO OVERCOME TYPICAL IADS COMPLEX



A more effective approach to strike multiple targets defended by an air defense complex may be to use highly survivable standoff weapons to attack enemy air defense radars first. Depending on the presence of enemy fighters, less-stealthy aircraft could be used to deliver these strikes. CVW aircraft carrying smaller and less expensive short-range weapons could then engage other targets. These attacks would probably be best delivered by low-observable aircraft due to both the likely presence of enemy fighters and potential deployment of new radar resources to the area following the initial attack.

Future Anti-submarine Warfare

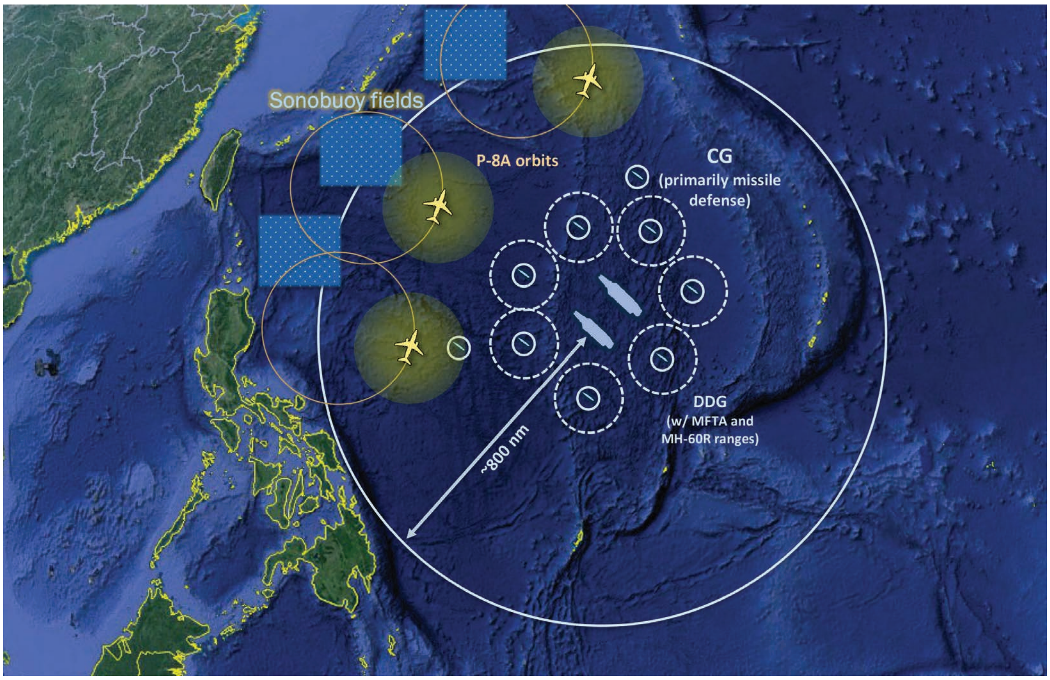
ASW will become an increasingly important CVW mission as adversary submarine forces increase in their size, sophistication, and ability to attack targets ashore and at sea using highly survivable long-range weapons.[177] The increasing range of submarine-launched cruise missiles may result in CVW aircraft being the only platforms able to defend civilian and other military shipping as well as high-value U.S. and allied targets ashore from submarine attack.[178]

177 ONI, *The PLA Navy*, pp. 18–20; and ONI, *The Russian Navy: A Historic Transition* (Washington, DC: U.S. Navy, 2015), pp. 16–19, available at http://www.oni.navy.mil/Intelligence-Community/Russia/.

178 Jeffrey Lin and P.W. Singer, "China Shows Off Its Deadly New Cruise Missiles," *Popular Mechanics,* March 10, 2015, available at https://www.popsci.com/china-shows-its-deadly-new-cruise-missiles; and Lee Willet, "Game Changer: Russian Sub-launched Cruise Missiles Bring Strategic Effect," *Janes International Defense Review,* 2017, available at http://www.janes.com/images/assets/147/70147/Game_changer_Russian_sub-launched_cruise_missiles_bring_strategic_effect_edit.pdf.

Submarine-launched ASCMs, such as the Chinese YJ-18 or Russian SS-N-19 and SS-N-27, allow submarines to conduct attacks more than 250 nm from their targets. This is beyond the practical search radius of the MH-60R, which has a total range of 275 nm.[179] The long range of submarine-launched ASCMs also expands the ASW search area around a U.S. carrier, reducing the ability of CSG surface combatants and a squadron of ten helicopters to search all the potential threat areas. And, as with aircraft and surface combatants, China and Russia are likely to exacerbate these Navy ASW shortfalls by fielding submarine-launched ASCMs with ranges on par with their submarine-launched LACMs, some of which can strike targets approximately 1,000 nm away.

FIGURE 40: CURRENT ASW OPERATIONS USING P-8A PATROL AIRCRAFT AND HELICOPTERS



Fixed-wing P-8 Poseidon ASW aircraft are intended to conduct wide area ASW operations in support of CSGs. The P-8A relies on passive and active sonobuoys to detect and track submerged submarines. P-8As remain in the area of the sonobuoy field to engage submarines with air-dropped Mk-54 torpedoes or add sonobuoys as they drift away from submarines, their batteries are expended, or targets move out of detection range. As a large patrol aircraft

179 Jacob Gleasun, "3M-54 Klub (SS-N-27 Sizzler)," *Missile Defense Advocacy Alliance,* May 2017, available at http://missiledefenseadvocacy.org/missile-threat-and-proliferation/missile-proliferation/russia/ss-n-27-sizzler/; ONI, *The Russian Navy*, pp. 33–36; ONI, *The PLA Navy*, p. 19; and "MH-60R Seahwak," *H-60 Helicopters*, Navy Sea Systems Command, June 2016, available at http://www.navair.navy.mil/index.cfm?fuseaction=home.displayPlatform&key=230E736F-D36A-4FB8-BDD3-372CD723D22C.

built on the Boeing 737 airframe, however, the P-8A may be vulnerable to detection by enemy early warning radars within several hundred miles of an enemy's coastline.[180] It could then be attacked by enemy fighters using a new generation of long-range (200 nm) AAMs designed to attack large ISR&T, AEW&C, and C2 aircraft like the P-8A.[181]

Distributed Hunter-Killer ASW

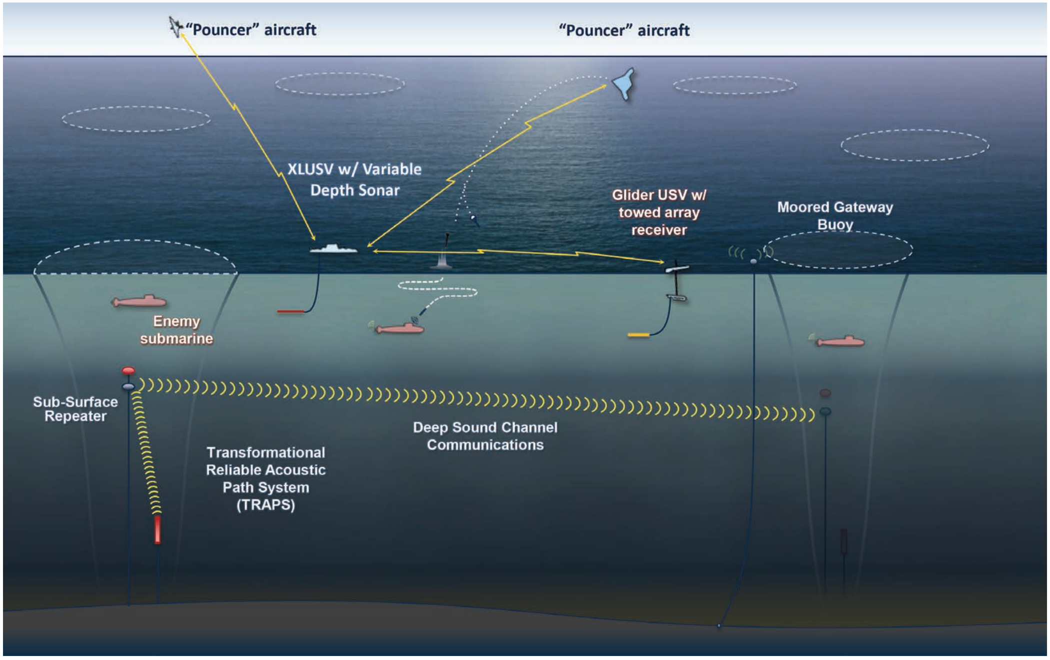
The limiting factors for theater ASW are wide-area search and engagement. To find enemy submarines before they can launch ASCMs, P-8As would need to search 250 nm or more from a carrier or other defended target. As enemy ASCM ranges increase, this tactic could place P-8As in areas where they would be vulnerable to attack from enemy shore or airborne air defenses. The Navy could mitigate this vulnerability using distributed unmanned sensors to find and track enemy submarines at long ranges and over wide areas. CVW aircraft and surface combatants with long-range vertical launch ASROC (VLA) could then act as "pouncers," quickly dropping weapons on submarines to suppress their operations as in the Battle of the Atlantic, rather than attempting to sink every submarine. This new form of hunter-killer operations leverages the low cost and endurance of unmanned search systems and exploits the fundamental speed and self-defense vulnerabilities of submarines.

Figure 41 depicts this updated version of hunter-killer operations. The Navy is fielding several unmanned sensor systems that could help detect submarines within 1,000 nm of a CSG or other defended assets such as U.S. and allied bases. In addition to SOSUS, which is installed around U.S. and allied coasts, systems such as the Transformational Reliable Acoustic Path System (TRAPS), USVs with LFA sonars or passive towed arrays, and unmanned undersea vehicles (UUV) carrying Multistatic Acoustic Coherent (MAC) sonobuoy sensors could be used to search for submarines in areas of interest and along approaches toward CSGs or defended bases.

180 As noted above, the S-500 air defense systems has a maximum range of 250 nm. Chinese OTH backscatter radars have ranges of up to 1500 nm depending on frequency and atmospheric conditions. See Bin-Yi Liu, *HF Over-the-Horizon Radar System Performance Analysis*, thesis (Monterey, CA: U.S. Naval Postgraduate School, 2007), p. 74, available at http://www.dtic.mil/dtic/tr/fulltext/u2/a474069.pdf.

181 Douglas Barrie, "It's Not Your Father's PLAAF: China's Push To Develop Domestic Air-To-Air Missiles," *War on the Rocks,* February 21, 2018, available at https://warontherocks.com/2018/02/not-fathers-plaaf-chinas-push-develop-domestic-air-air-missiles/. The PLAAF J-16 fighter has a range of 1,600 nm. See "Shenyang (AVIC) J-16 (Red Eagle)," Military Factory, available at https://www.militaryfactory.com/aircraft/detail.asp?aircraft_id=1157.

FIGURE 41: UPDATED HUNTER-KILLER OPERATIONS



Stationary passive unmanned sensors like TRAPS are placed on or anchored to the sea floor and listen for submarines using a vertical sonar array that extends toward the surface. The resulting search area becomes a cone with a radius of dozens of nautical miles, depending on the water depth and acoustic conditions. TRAPS and similar passive acoustic sensors can recognize threat submarines by specific sound frequencies they emit and transmit contact reports or raw sensor data to other naval forces through a fiber optic cable connection or acoustic communications. Reports are then transmitted to commanders through shore networks, satellite phone, or LOS datalink.[182] Systems like TRAPS could be placed by CSG aircraft at chokepoints through which enemy submarines are likely to approach CSGs or defended areas, or through which enemy submarines must exit to reach the open ocean, such as the Luzon Strait or the Greenland-Iceland-United Kingdom (G-I-UK) gap. Because they use little electrical power, passive sonar systems like TRAPs can operate for several months or more without battery replacement.

Mobile unmanned sensors could complement stationary sensors by covering larger search areas and relocating in response to changing threat locations and CSG movement. Larger, powered USVs such as the Navy Sea Hunter could tow LFA sonars similar to those carried by the Navy's Littoral Combat Ship (LCS), other NATO navies, and the U.S. Navy's Surveillance

182 Tim Broderick, "Underwater Sensors Bolster Anti-Submarine Capabilities," *Defense Systems*, October 31, 2016, available at https://defensesystems.com/articles/2016/10/31/drape2.aspx; Cheryl Pellerin, "Tech-in the Future at DARPA, Wait, What?" *Armed With Science,* September 14, 2015, available at http://science.dodlive.mil/2015/09/14/tech-ing-the-future-at-darpa-wait-what/; and Lisa Zurk, "Passive Detection in Deep Water Using the Reliable Acoustic Path," *Journal of the Acoustical Society of America* 125, no. 4, April 8, 2009, available at https://doi.org/10.1121/1.4783790.

Towed Array Sensor System (SURTASS) Ships.[183] LFA sonars can achieve detection ranges of more than 30 nm and, if combined with passive receiving arrays on other platforms, conduct bistatic and multistatic sonar operations over wide areas. High-power active sonars can also cause an enemy submarine to turn away to avoid detection, which may prevent it from conducting its intended mission.[184]

Smaller, unpowered glider USVs, such as Liquid Robotics Sensor Hosting Autonomous Remote Craft (SHARC), could carry passive towed sonar arrays as LFA receivers or to conduct independent passive sonar searches in threat areas.[185] USVs could conduct onboard processing and automated target recognition of passive sonar detections, as with TRAPS and other unmanned systems, and transmit contact reports and some raw sensor information to other naval forces using a satellite phone or LOS datalink. Similarly, MAC-equipped UUVs could find submarines using multistatic active sonar, in which one UUV transmits and one or more receiver buoy listens for returns to search an area for submerged submarines. Contact reports could then be transmitted by the receiver UUVs to other naval forces via LOS datalink.[186]

Distributed ASW sensors such as TRAPS, glider USVs, and UUVs can be placed by surface combatants or support ships if the threat environment allows doing so. When rapid deployment or redeployment of sensors is needed, larger aircraft like the P-8A or C-17 Globemaster could be used to deploy unmanned systems. In highly contested areas, low-observable attack aircraft or UAVs could deploy these systems. Larger unmanned sensors such as Sea Hunter could self-deploy and operate in concert with CSGs.

Figure 42 shows one operational concept for ASW hunter-killer operations by unmanned sensors and carrier-based aircraft. TRAPS are deployed by CVW attack aircraft, and may remain in place for several months, along chokepoints through which People's Liberation Army Navy (PLAN) submarines may transit. Large USVs operating in concert with the CSG use LFA sonar to search for submarines or drive them away from the carriers. The LFA sonar reflections are detected by DDG Multi-Function Towed Arrays (MFTA) and by glider USVs deployed by CVW aircraft and surface combatants. A MAC field is deployed in the area of previous CSG operations to search for trailing submarines.

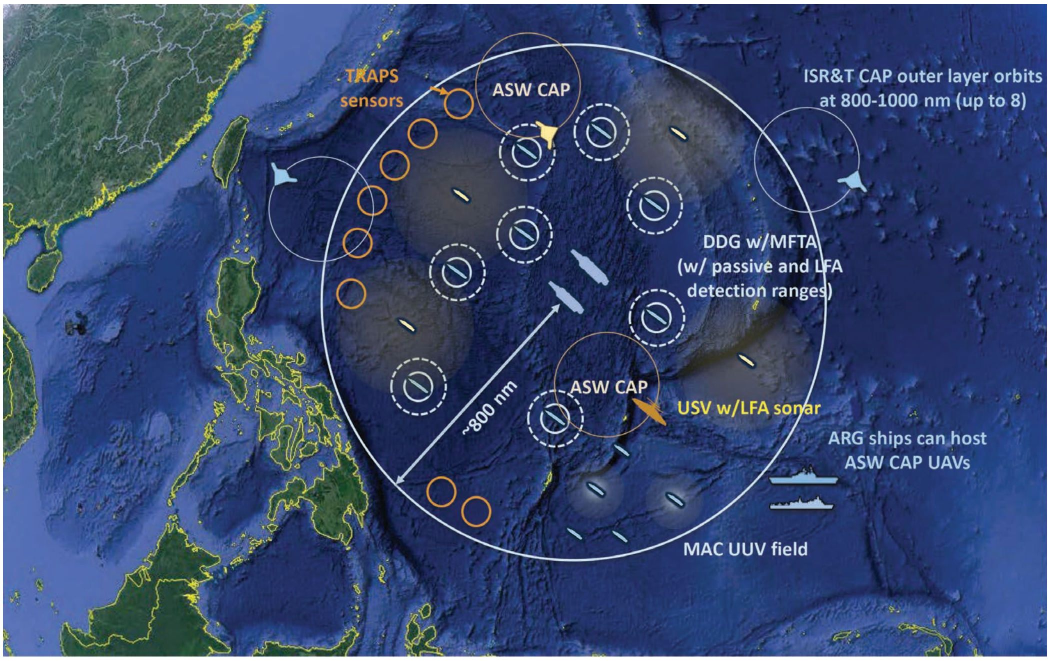
183 "Surveillance Towed Array Sensor System (SURTASS)," and "Compact Low Frequency Active (CLFA) Sonar," in Director, Operational Test and Evaluation (DOTE), *FY 2014 Annual Report* (Washington, DC: DoD, January 2015), p. 253, available at http://www.dote.osd.mil/pub/reports/FY2014/pdf/navy/2014surtass_clfa.pdf; "ACTUV 'Sea Hunter' Prototype Transitions to Office of Naval Research for Further Development," *DARPA News and Events,* January 30, 2018, available at https://www.darpa.mil/news-events/2018-01-30a; and Gordon Tyler, "The Emergence of Low-Frequency Active Acoustics as a Critical Antisubmarine Warfare Technology," *Johns Hopkins APL Technical Digest* 13, no. 1, 1992, available at http://www.jhuapl.edu/techdigest/views/pdfs/V13_N1_1992/V13_N1_1992_Tyler.pdf.

184 This dynamic occurs because the active sonar sound must travel two ways and be attenuated twice for a reflection to be detected at the receiver, whereas it only needs to travel one way to be heard by the target submarine.

185 Justin Manley and Graham Hine, "Unmanned Surface Vessels (USVs) as Tow Platforms: Wave Glider Experience and Results," conference paper, Oceanology International, September 2016.

186 "Multi-Static Active Coherent (MAC) System," in DOTE, *FY 2014 Annual Report*, p. 263, available at http://www.dote.osd.mil/pub/reports/FY2015/pdf/navy/2015mac_system.pdf.

FIGURE 42: PROPOSED FUTURE CVW ASW HUNTER-KILLER OPERATIONS



When possible, submarine contacts could be detected by distributed sensors, and contact reports and some raw sonar data could be sent via satellite radio link to the ASW CSG command center and to ASW CAP aircraft orbiting above the CSG. If satellite communications are degraded, unmanned sensors will send contact information via LOS datalink to a communication relay package on the ISR&T CAP or DCA CAP aircraft orbiting above the operating area, similar to the Battlefield Adaptive Communications Network (BACN) or future Distributed Airborne Reliable Wide-Area Interoperable Network (DARWIN).[187] Contact classification and identification may be done onboard the sensor itself for passive sonar detection, or it could be done by location and depth for active sonar detection, assuming friendly submarines are not operating in the same area.

The ASW commander will direct the platform with the shortest response time to engage the enemy submarine. This could be a DDG equipped with a new longer-range VLA or an ASW CAP aircraft from a carrier, amphibious ship, or surface combatant deploying Compact Rapid Attack Weapons (CRAW).[188] Although small, short-range air-launched torpedoes are unlikely

187 "Robust Communications Relay with Distributed Airborne Reliable Wide-Area Interoperable Network (DARWIN) for Manned-Unmanned Teaming in a Spectrum Denied Environment," *Navy SBIR*, U.S. Naval Air Systems Command, January 8, 2018, available at https://www.navysbir.com/n18_1/N181-007.htm; and "Battlefield Airborne Communications Node (BACN)," Northrop Grumman, 2018, available at http://www.northropgrumman.com/Capabilities/BACN/Pages/default.aspx.

188 Edward Walsh, "Naval Systems: Torpedo-Defense Weapon Eyed for LCS Antisub Use," *Proceedings* 140, no. 1, August 2014, p. 138, available at https://www.usni.org/magazines/proceedings/2014-08/naval-systems-torpedo-defense-weapon-eyed-lcs-antisub-use.

to destroy an enemy submarine, they would alert the submarine that it has been counter-detected and would likely continue to be attacked. Having lost its main advantage of stealth, the submarine would break off its operation and leave the area. As in the Battle of the Atlantic case study, over time this approach would likely suppress submarine attacks.

The ASW scheme shown in Figure 42 uses two orbits of ASW CAP aircraft focused on sectors not covered by surface combatants or P-8As and those that are closest to enemy threats. ASW CAPs at these locations could enable engagement of possible submarines within 30 minutes of detection. With typical submarine transit speeds of 5–15 knots, the target would have moved less than 10 nm between the detection and attack. As with DCA and ISR&T CAPs, aircraft may launch from one carrier in the Maneuver Force and recover on the other to extend their endurance or enable the launch carrier to reposition. Each CAP would require two to three aircraft to sustain it, depending on how long they can patrol, their available refueling capacity, and how many weapons they use. These attributes suggest an attack aircraft with large payload and endurance would be well suited to this mission, although other aircraft could be used for ASW CAPs with less efficiency.

Future Offensive Counterair (OCA) and Electromagnetic Warfare (EMW) Operations

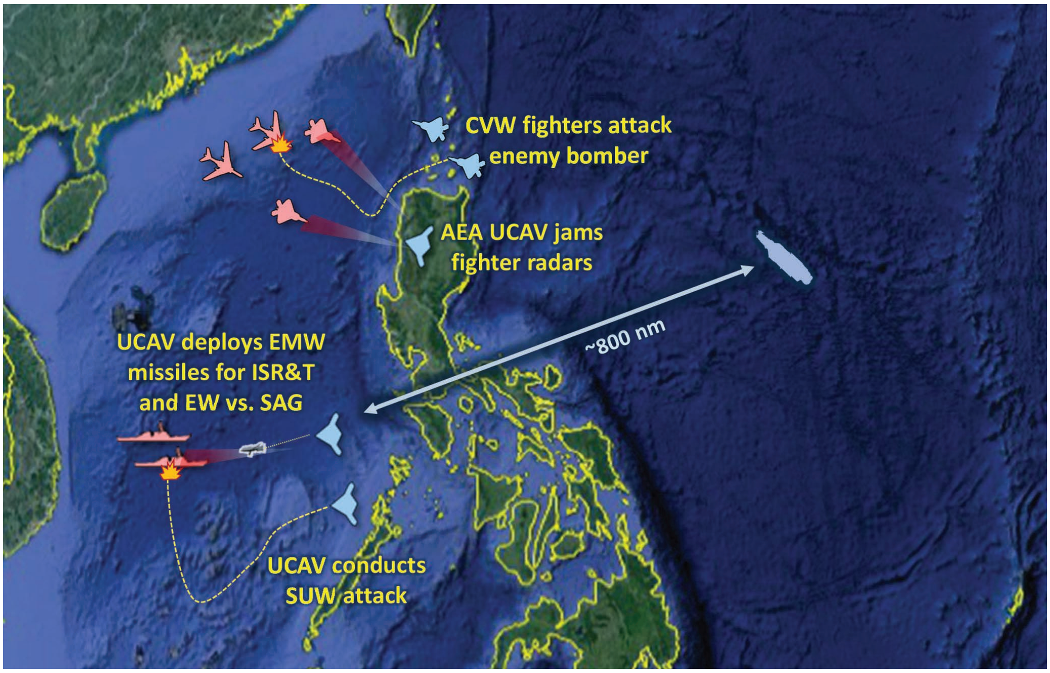
Future SUW and strike operations will face a growing array of challenges. In contrast to U.S. post-Cold War operations in Iraq, Afghanistan, or Syria, future adversaries are likely to employ a combination of DCA aircraft and ground-based air defense systems to shoot down strike weapons or aircraft; EW to prevent accurate targeting by attacking U.S. forces; and camouflage, decoys, and hardening to protect targets. CVW aircraft will be needed to help naval strike and SUW missions overcome these challenges. Moreover, the mobility and defensive capacity of a CSG may make it a more reliable source of escort aircraft for land-based bombers than airbases near target areas that could be suppressed by enemy attacks.

OCA operations by CVW aircraft would help prevent capable, 4^{th} and 5^{th} generation enemy fighters from engaging U.S. attack aircraft. Using expendable payloads or onboard systems, EMW operations can provide updated ISR&T to strike aircraft or weapons and conduct short-range jamming and decoy operations against enemy early warning and air defense radars. By degrading and confusing shipboard air defenses and improving targeting, EMW operations improve the likelihood weapons reach their intended targets, effectively increasing the size of the SUW attack.

Figure 43 depicts one potential scenario for OCA and EMW operations. A PLA SAG is operating in the South China Sea to extend the range of mainland-based air defense systems in support of a bomber attack making its way toward Australia. CVW UCAVs deploy EMW expendables to determine the SAG's size and composition because one of the enemy ships is operating passively, using cueing from the other's active radar. The EMW expendables also decoy the passive sensors and jam the active radars of the SAG to protect an SUW attack by

CVW UCAVs. The SUW operation removes some protection for the enemy strike package moving south over the South China Sea. A UCAV using onboard EW systems jams the radars and communications of the strike package's fighter escorts, and CVW fighters then attack the bombers with long-range AAMs.

FIGURE 43: FUTURE CVW OCA AND EMW OPERATIONS

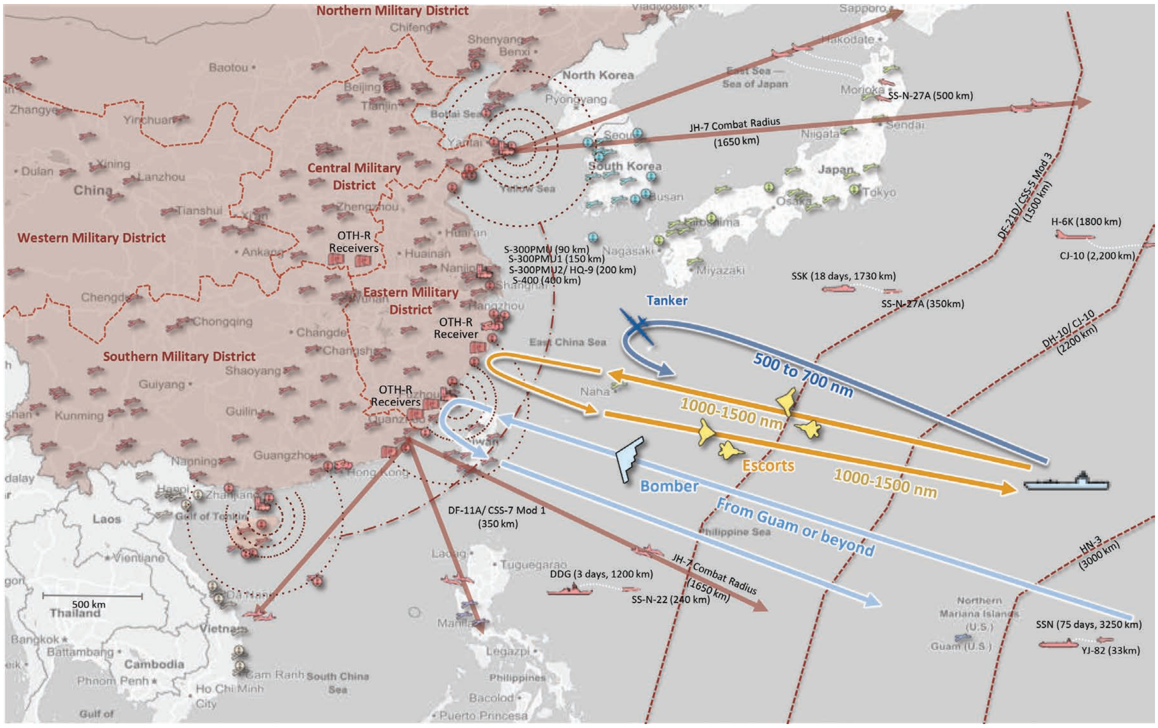


CVW escorts could also be beneficial in support of large, land-based bombers, which have unrefueled combat radii of more than 4,000 nm and can conduct missions lasting more than 24 hours.[189] Land-based fighters cannot match a bomber's reach without refueling multiple times in flight and exceeding the endurance of pilots. Fighter airfields located within unrefueled fighter range of target areas may not be available due to enemy attacks or host nation constraints.

Carrier-based aircraft could enable bombers to make the most efficient use of their large payload capacity, as shown by the depiction of a notional CVW escort mission in Figure 44. Carriers operating 1,000–1,500 nm offshore could launch attack aircraft and fighters to degrade enemy early warning sensors, suppress air defenses, and engage DCA CAPs in support of intercontinental bombers arriving from outside the theater.

189 David Evans, "B-2's 'Global Reach' Pushes Its Crew to Limits of Endurance," *Chicago Tribune,* June 26, 1992, available at http://articles.chicagotribune.com/1992-06-26/news/9202260357_1_crew-members-whiteman-air-force-base-saudi-arabia.

FIGURE 44: FUTURE CVW ESCORT MISSION IN SUPPORT OF LAND-BASED BOMBERS



Offensive Counterair Operations (OCA)

Since the end of the Cold War, U.S. strike and SUW operations have faced only modest challenges from enemy air forces. That will not be the case in future confrontations with great power competitors. Similar to U.S. operational concepts, enemy DCA aircraft should be expected to threaten U.S. strike aircraft 500–1,000 nm away from enemy bases, and enemy bombers could strike U.S. and allied forces at intercontinental ranges. Although Russia and China's air forces lack significant aerial refueling capacity, their fighters will be operating from bases on home territory and may be numerous enough to maintain robust airborne patrols. Furthermore, both countries are establishing outlying airfields such as those on the Spratly Islands for China or in Kaliningrad for Russia that increase the reach of their air operations.

CVW OCA aircraft will be needed to neutralize or destroy DCA CAPs and fighter escorts in advance of U.S. attacks on enemy ships, land targets, or high-value aircraft to protect CVW attack aircraft and enable shorter-range attacks that can increase salvo size and effectiveness. Even if CVW OCA aircraft are unable to shoot down enemy fighters, they could be delayed or suffer a "mission-kill," enabling U.S. attacks to proceed. Because the escort mission is intended primarily to enable attacks rather than attrite enemy fighters, the mission systems and weapons on escort aircraft should prioritize weapons capacity and aircraft range over their ability to achieve a destructive kill. Two main approaches emerge from this priority:

- Escorts could employ directed energy weapons and small short-range AAMs to maximize their weapons capacity and rely on passive detection and targeting sensors like Infrared Search and Track (IRST) to reduce their risk of being detected. This combination of capabilities would improve the escort's ability to defend itself against enemy DCA CAPs. In this approach, escort aircraft may need to be more maneuverable fighters to reduce their risk of being shot down; they may also need to be optionally manned to reduce the risk of losing pilots in highly contested environments. If unmanned, escort aircraft may be more constrained in what they are allowed to engage to reduce the risk of fratricide.

- Escorts could carry medium- and long-range missiles and engage enemy DCA fighters from standoff distance. Instead of using expensive and sophisticated AAMs such as the AIM-120D, however, these operations could employ less sophisticated missiles or missile-like UAVs that either emulate AAMs or are simply less kinematically capable weapons. DCA CAP aircraft would need to honor the threat of these weapons and evade, which may open up time and space for strike aircraft to reach their targets. In this approach, escort aircraft may need to conduct multiple OCA attacks to enable the strike package to reach the target. Higher-endurance UAVs could make multiple engagements possible per vehicle, or larger escort aircraft may be needed for greater weapons capacity. CVW attack aircraft could fulfill this requirement, as they could for CVW DCA operations, where their weapons capacity and sensor capability enable longer-range engagements that compensate for their lower speed and maneuverability compared to fighters.

OCA operations will also be used to destroy high-value enemy aircraft, such as bombers and ISR&T or AEW&C aircraft. These targets are likely to be protected by DCA CAPs, and CVW escort aircraft could engage them as described above. Against the high-value target aircraft, U.S. OCA attacks may need to occur from longer standoff range than possible with today's medium-range AAMs to improve the survivability of the U.S. OCA aircraft, lower the warning time for the target aircraft, and improve the complexity of the attack.[190] OCA attacks on high-value aircraft will also likely need to rely on passive sensors such as IRS&T, as described above against DCA aircraft.

EMW Operations

EMW will be an essential element of future CVW strike, SUW, and OCA missions, including sensing, communicating, jamming, and deceiving through the EMS. Today, U.S. strike and SUW operations rely on targeting from space-based or aerial sensors, which are vulnerable to attack or could have their communications jammed. The satellite networks that provide long-distance communications could be similarly degraded during hostilities.

190 Kyle Mizokami, "The Pentagon is Working on a New Air-to-Air Missile," *Popular Mechanics,* November 2, 2017, available at https://www.popularmechanics.com/military/weapons/news/a28883/new-air-to-air-missile-amraam/.

Jamming and deception for CVW offensive operations are provided today by the E/A-18G AEA aircraft, which largely employs longer-range effects generated from outside the range of enemy air defenses. As SAMs and AAMs increase in range and passive sensors improve in range and accuracy, the power required to jam sensors and communications from beyond air defense range may exceed what an aircraft can support, and the counter-detection risk associated with using high-power emitters may become too great. Because it is not a low-observable platform, the E/A-18G may not be able to generate EW effects within enemy AAM or SAM range in a survivable way.

The Navy plans to upgrade the E/A-18G with the NGJ starting in 2021, and the E/A-18G will likely receive a service life extension during the early to mid-2030s.[191] As described above, the Navy should pursue operational concepts that increasingly rely on short-range EMW effects generated within enemy air defense range that could be created by low-observable aircraft using onboard EW systems such as the NGJ and expendable EMW payloads that conduct sensing, jamming, deception, and decoy operations. Expendable payloads could also act as communication relays and sensors in contested areas, reducing the risk to manned or unmanned aircraft.[192]

Dedicated AEA aircraft will likely continue to be necessary for persistent or the responsive jamming and deception of adversary sensors and communications that exceed the endurance of expendable payloads. A low-observable platform such as the proposed unmanned attack aircraft or a future fighter could be made into an AEA platform by incorporating subsystems of the E/A-18G into its mission bay and installing multiple AESA arrays along its wings and fuselage. Compared to the E/A-18G and its pod-based AEA systems, incorporating EW systems into the body of an aircraft could enable more antenna apertures that provide greater sensitivity in passively monitoring threats, dispersion of EW effects in more directions, and the use of narrower jamming beams. As a result, the new AEA aircraft would be able to enter contested airspace and conduct jamming and deception operations with precise beam shapes and power levels that can affect the target sensor without significantly increasing the risk of detection of the AEA aircraft.

Shifting Navy AEA operations to an unmanned aircraft will require a high degree of autonomy or protected communications. Unlike DCA, ISR&T, strike, or SUW operations, AEA operations may directly impact the communication links the aircraft would need to obtain targeting information from command staffs or to report findings and results. To support persistent and responsive AEA operations, an unmanned AEA aircraft will therefore need to use beam shaping and schedule management to deconflict communications and jamming,

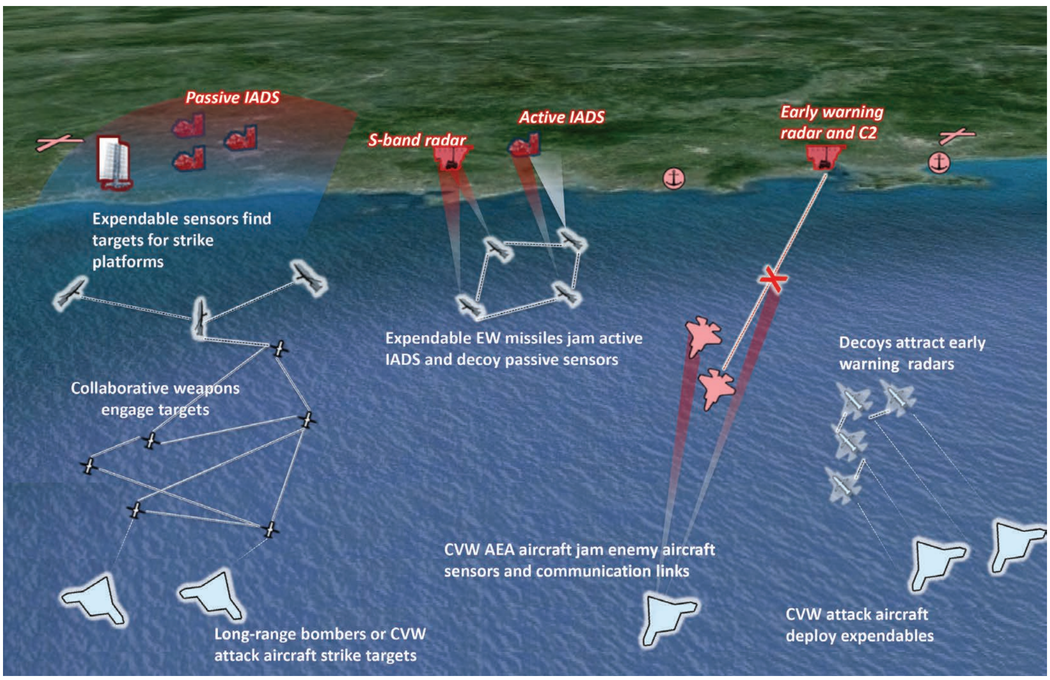
191 Joseph Treveithick, "Here Is Boeing's Master Plan For The F/A-18E/F Super Hornet's Future," *The Drive*, May 23, 2018, available at http://www.thedrive.com/the-war-zone/21045/here-is-boeings-master-plan-for-the-f-a-18e-f-super-hornets-future.

192 John Haystead, "The Future of Airborne Electronic Attack: Building a 'Smarter' Approach," *The Journal of Electronic Defense* 39, no. 12, December 2016, p. 38, available at https://www.baesystems.com/en-us/download-en-us/20170301194258/1434593319062.pdf.

complemented by highly autonomous EW control systems such as DARPA's Adaptive Radar Countermeasures (ARC) or the Office of Naval Research's Reactive Electronic Attack Measures (REAM) programs.[193]

Even with a low signature, future AEA aircraft would likely need to remain outside the range of the enemy's ground-based or airborne point defense missiles. Expendable EMW payloads such as UAVs and missiles could complement AEA aircraft by conducting sensing, jamming, and deception operations within range of enemy point defenses or short-range AAMs, as shown in Figure 45.[194] Sensing could be done much closer to the target by UAVs and missiles using synthetic aperture radar (SAR), EO/IR focal plane arrays, or passive RF sensors. Through their proximity and ability to view the target from different aspects, expendables may be able to circumvent enemy camouflage, decoy, and obscurant efforts. Expendable sensors could also provide battle damage assessment (BDA) to strike forces, enabling faster reengagement of priority targets.

FIGURE 45: FUTURE EMW OPERATIONS



193 Colin Clark, "DARPA Ups Funding For Autonomous Electronic Warfare Work," *Breaking Defense,* November 3, 2016, available at https://breakingdefense.com/2016/11/darpa-ups-funding-for-autonomous-electronic-warfare-work/; and Tom Killion, "Innovative Technology Programs," Office of Naval Research, February 4, 2015, available at https://www.onr.navy.mil/en/Conference-Event-ONR/Future-Force-Expo/~/media/Files/Conferences/EXPO-2015/Proceedings/Killion-Tom.ashx.

194 Concepts and capabilities for using expendable EMW UAVs and missiles to defeat enemy air defenses and sensors are described further in Clark, Gunzinger, and Sloman, *Winning in the Gray Zone*.

Expendable sensors would ideally not need to provide their output to a manned strike platform, which would then launch weapons at identified targets. Instead, using collaborative weapons, expendable sensors could allow weapons salvos to be targeted in flight. This capability could also allow BDA information to be acted upon by later-arriving weapons in the same strike package rather than requiring a new strike operation to be mounted in order to reattack surviving high priority targets.

Expendable jammers and decoys could be used in the target area to improve the survivability of both weapons and attack aircraft. By raising the noise level in the area or attracting air defenses away from the incoming strike, EMW expendables could enable low-observable strike aircraft to approach targets more closely and use smaller, shorter-range weapons. Because they could approach adversary sensors more closely, expendable jammers and decoys could achieve a similar jamming strength as a larger system operating at standoff range.

Expandable EMW payloads could also act as communication relays, forming a mobile ad hoc network (MANET) to convey sensor information to weapons and attack aircraft, as well as enabling expendable jammers to coordinate their operations with the movement of attack platforms and weapons. Although expendables would likely need to specialize in either sensing or jamming operations due to space and power constraints, they could all act as communications relays using high-bandwidth datalinks such as Tactical Targeting Network Technology (TTNT).

Although AEA aircraft may be able to carry some expendable EMW UAVs and missiles, their capacity will be constrained by the need to also carry AEA equipment. Attack aircraft that are designed to carry large payloads over similar distances as the strike packages they are supporting may be the best platforms to deploy expendable UAVs and missiles. Low observable attack aircraft would also be better able to deploy expendables close to the target. Although EMW expendables will have propulsion systems, strike planners may use their endurance to loiter in the target area for sensing and jamming operations, rather than to make a long transit to the target.

Implications for Capabilities

The operational concepts above differ from today's CVW tactics, quite significantly in some cases, and reflect an emerging operational environment marked by great power competition and the proliferation of new sensor and weapons technologies. To implement these concepts, the CVW will need to evolve, as it has several times during the last century. The next chapter describes the new aircraft needed in the CVW and how the CVW's composition should change between now and 2040.

CHAPTER 5

Capabilities Needed in the Future Carrier Air Wing

A renewed focus on great power competition and conflict will require the United States to develop new military postures, operational concepts, and capabilities. Deterrence strategies based on threatening to overturn the results of aggression after the fact, such as those the United States pursued during the quarter century following the end of the Cold War, will not be effective against the militaries of China or Russia, which are now capable of quickly gaining a measure of control over areas on their periphery. Dislodging enemy forces after they have achieved a *fait accompli* would require a significant military intervention that may be more disruptive than the original aggression. Instead, the U.S. military should shift to a strategy of denying, degrading, or delaying aggression as it occurs, rather than after the fact. Naval forces in general, and aircraft carriers specifically, will be key to this approach. Naval forces will continue to provide the persistence, responsiveness, and lethality to resist aggression until the joint force arrives, and carriers will provide the ability to sustain combat operations from a survivable range after surface combatants and submarines have expended their weapons during the first hours of a conflict.

CVWs will need new capabilities for them to be able to contribute to such a strategy. Chapter 4 highlighted some of the attributes needed in aircraft and systems to implement new CVW operational concepts, and this chapter translates those attributes into types of aircraft and configurations required in a proposed 2040 CVW. In general, these concepts will require greater range or endurance and survivability than is available in today's CVW aircraft. Longer range will permit effective carrier and base defense and allow blunt or Maneuver Forces to deny, degrade, or delay aggression more rapidly. Greater survivability will allow CVW aircraft to counter the growing reach of air defense and early warning sensors ashore, at sea, and in the air.[195]

This chapter focuses on new aircraft in the 2040 CVW proposed by this report. The Navy is pursuing versions of some of these aircraft already, including the MQ-25 and F/A-XX Next Generation Air Dominance (NGAD) system. This report proposes new aircraft to augment these programs, such as a multi-mission, highly survivable UCAV. The rest of the proposed 2040 CVW comprises aircraft that are likely to be in service and relevant in 2040 because they are still in production or recently completed production, such as the F-35C, E-2D, and MH-60R/S.[196] The composition of the proposed 2040 CVW is addressed at the end of this chapter and assumes the CVW's size will continue to be limited to what can fit on *Nimitz*- and *Ford*-class carriers. Chapter 6 describes the programmatic evolution necessary to field the proposed CVW by 2040.

The proposed 2040 CVW assumes the Navy will not retire existing aircraft before their end of service life. Fiscal constraints, however, may slow efforts to field new aircraft, which could prompt the Navy to keep some legacy aircraft, including the E/A-18G and Block III F/A-18 E/F, in the CVW past 2040. To address the potential for a slower CVW evolution, this chapter addresses alternative CVWs configuration the Navy could adopt.

The proposed 2040 CVW reflects historical trends described in Chapter 3 for previous CVW configurations. As in the Cold War-era, the proposed CVW includes specialized counterair, refueling, and attack aircraft to provide capabilities needed for the operational concepts of Chapter 4 against great power competitors. Specialization, however, can increase logistics complexity and cost. Today the Navy improves logistics efficiency by using the F/A-18 E/F strike fighter airframe for the E/A-18G AEA aircraft, both of which share some avionics commonality with older F/A-18 A-D strike fighters.[197] The proposed CVW manages logistics complexity and cost by using a common attack aircraft airframe to support ISR&T, strike, SUW, ASW, and AEA missions and shifting specialization from the aircraft itself onto offboard missiles and UAVs. The proposed CVW also assumes a common airframe for strike fighter and fighter missions.

195 Bryan Clark and Mark Gunzinger, "The Next Carrier Air Wing: Stealthy UCAS Needed for Contested Airspace," *Defense News,* February 24, 2014.

196 Although not part of the CVW, this analysis assumes C-2A Greyhound Carrier On-board Delivery (COD) aircraft are replaced by CMV-22 cargo aircraft over the next decade.

197 "F/A-18 E/F Super Hornet," FAS.

New Aircraft of the Proposed 2040 CVW

Long-range, Multi-Mission Survivable UCAV

IAMD, ISR&T, strike, SUW, ASW, and EMW missions are all evolving in a way that makes them best conducted by an aircraft with longer range and endurance, higher survivability, and a similar or larger payload capacity compared to today's CVW strike fighters. In IAMD and ISR&T, for example, the improving range and kinematics of AAMs including the AIM-120D and longer-range AAMs in development make aircraft maneuverability less important than endurance, sensor capability, and weapons capacity.[198] For both air defense and ISR, passive and low probability of intercept/low probability of detection (LPI/LPD) sensor capabilities will be needed to detect and track enemy targets while reducing the likelihood of U.S. aircraft being counter-detected.[199] In general, aircraft passive RF and IR sensors can achieve greater gain and accuracy by using larger or multiple apertures. For air defense, a larger attack aircraft would also be better able to carry more AAMs or the power generation capacity needed for directed energy weapons to defeat enemy missiles.[200]

A low-observable attack aircraft would better address strike, EMW, and SUW missions than today's strike fighters. As small UAVs and missiles are used more frequently to carry decoys, jammers, and other countermeasures, payload capacity and range will become a more important characteristic for EMW aircraft than speed or maneuverability. For persistent or responsive EMW operations, future EMW systems such as the NGJ could be incorporated into an attack aircraft with all-aspect, broadband low observability characteristics to fully exploit their ability to closely approach a target and use hard-to-detect low power and narrow beam width jamming. Payload and stealth will similarly be important for strike and SUW missions to enable aircraft to deliver larger salvos.

Long range and endurance needed

Sustaining DCA, ISR&T, ASW, or ASUW operations 800–1,000 nm from a carrier or defended land target using F/A-18 or F-35C strike fighters would place a significant burden on a CVW. Flying from the carrier to a CAP area will take about 2 hours and require at least one aerial refueling. While conducting CAP operations, strike fighters would need to be refueled about 1.5 hours after arrival on station and every 2 hours thereafter, for a total of four refueling

198 Mizokami, "The Pentagon Is Working on a New Air-to-Air Missile"; and John Stillion, *Trends in Air-to-Air Combat: Implications for Future Air Superiority* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015).

199 China Power Team "Does China's J-20 rival other stealth fighters?" *China Power*, updated December 18, 2017, available at https://chinapower.csis.org/china-chengdu-j-20; Andrew Roth, "New Russian Stealth Fighter Spotted in Syria," *The Guardian,* February 22, 2018, available at https://www.theguardian.com/world/2018/feb/22/new-russian-stealth-fighter-spotted-in-syria; and Lee Fuell, *Broad Trends in Chinese Air Force and Missile Modernization*, Presentation to the U.S.–China Economic And Security Review Commission (Washington, DC: U.S. Air Force, 2014), p. 6., available at http://www.dtic.mil/dtic/tr/fulltext/u2/a593473.pdf.

200 Gideon Grudo, "Lasers Coming to USAF Fighter Jets By 2021," *Air Force Magazine,* November 7, 2017, available at http://www.airforcemag.com/Features/Pages/2017/November%202017/Lasers-Coming-to-USAF-Fighter-Jets-By-2021.aspx.

operations during a 12-hour mission. The return trip to the carrier will take another 2 hours, with one aerial refueling operation in transit.[201]

In contrast, a UCAV with a 3,000-nm range could transit to a CAP station 1,000 nm from its carrier with one refueling in transit and remain on station for about 5 hours before refueling.[202] If the UCAV were not refueled while on station, it would need to return to the carrier after about 3 hours on station. Like the strike fighter, if the UCAV travels 500 kts, it would spend 4 hours total in transit to and from the CAP station. If it also conducted a 12-hour mission, the UCAV would need to refuel twice during its 8 hours on station and would not require refueling on the return trip.[203] Two UCAVs would be required to sustain a continuous CAP station at 1,000 nm if they could be refueled on station. If refueling is not possible, three UCAVs may be required or short gaps accepted in CAP coverage.

The benefits of range also affect the ability to conduct strikes, as described in Chapter 4. A UCAV with a 3,000-nm range could conduct a strike operation from 2,000 nm away, provided it refueled at about the 1,000 nm point on the way to the target from either a carrier-based or land-based tanker aircraft. Although this is farther from the carrier than the 500–800 nm in which the Navy plans for its MQ-25 to operate, the UCAV would only require a third of its fuel to be replaced, rather than half the fuel of a strike fighter. The lower amount of fuel needed from the MQ-25 should enable it to refuel two UCAVs at 1,000 nm and use the remaining fuel for its longer transit to and from the refueling area.

Because it is unmanned, the UCAV could also conduct missions longer than 12 hours, with adequate refueling. Although a manned tactical aircraft would generally be limited to a 12-hour mission due to crew duty limitations,[204] UCAVs such as the jet powered MQ-1C Avenger can conduct missions of 20 hours and do so without air refueling.[205] Using the same mission profile described above, during a 24-hour mission the unmanned attack aircraft could spend 20 hours on station.

201 Aerial refueling occurs at about 1,000–1,500 lb/minute. An F/A-18 E/F carries 18,840 lb of internal fuel and has a range of more than 1,200 nm; refueling at 50 percent of fuel/range would take about 10 minutes each time, plus about 5 minutes to set up and 5 minutes to disengage. In the best case, refueling occurs on the same course the aircraft must transit to the CAP station, which would add no time to the transit. see Christopher Bolkcom, *Air Force Aerial Refueling Methods: Flying Boom versus Hose-and-Drogue* (Washington, DC: Congressional Research Service, 2006), available at https://fas.org/sgp/crs/weapons/RL32910.pdf; and "F/A-18 E/F Super Hornet," Naval Air Systems Command, available at http://www.navair.navy.mil/index.cfm?fuseaction=home.displayPlatform&key=C42247D4-36AF-4038-AD33-B559F68AA774.

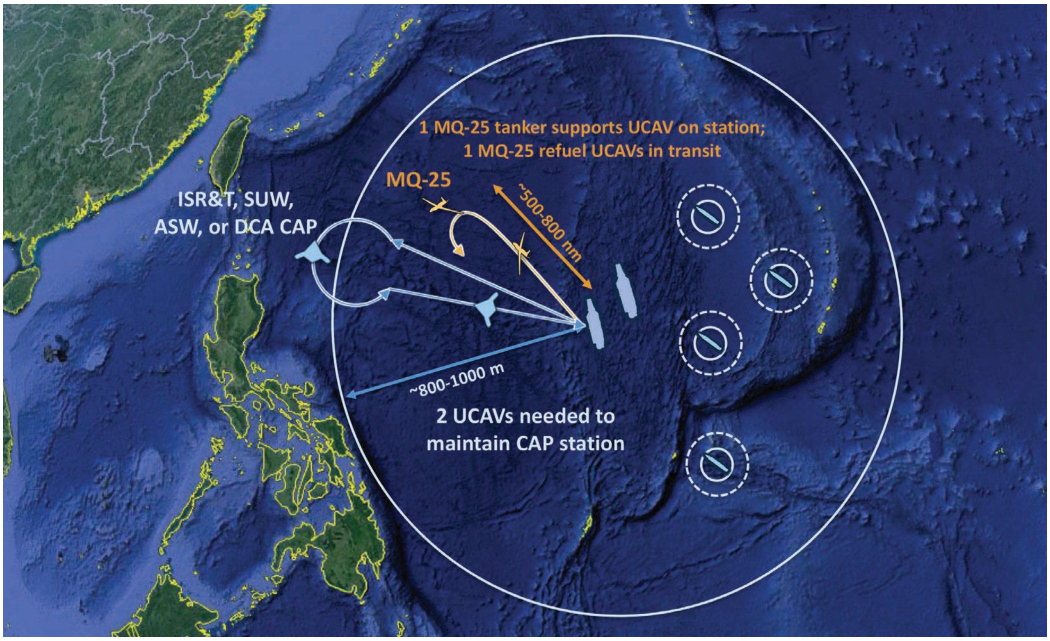
202 The X-47B's reported range was more than 2,100 nm. See "X-47B Unmanned Combat Air System (UCAS)," data sheet, Northrop Grumman Systems Corporation, August 2015, available at http://www.northropgrumman.com/Capabilities/X47BUCAS/Documents/UCAS-D_Data_Sheet.pdf.

203 The UCAV mission profile would be the same as that of the strike fighter, except the UCAV has a range of 3,000 nm. The UCAV is assumed to carry the same amount of fuel, use the same amount of fuel (4,000 lb) to take off, and refuel at the same fuel remaining (4,000 lb, or about 500–600 nm range) as a strike fighter. Because of its longer range, the UCAV can fly for 4–4.5 hours between refueling events while on the CAP station.

204 Secretary of the Air Force, "General Flight Rules," Air Force Instruction 11-202V3.

205 "Predator C Avenger RPA," fact sheet, General Atomics Aeronautical, 2015, available at http://www.ga-asi.com/Websites/gaasi/images/products/aircraft_systems/pdf/Predator_C021915.pdf.

FIGURE 46: REFUELING TO SUPPORT LONG-ENDURANCE UCAV ON CAP STATION



Another significant benefit of long-endurance aircraft is the number of refueling aircraft needed. Overall, each refueling of a strike fighter or UCAV when they have about 4,000 lb of fuel remaining will require about 14,000 lb of fuel. This would take nearly all of the transferable fuel on the Navy's proposed MQ-25 refueling UAV.[206] However, because the proposed future carrier UCAV could have about twice the range of manned strike fighters, it will require about half the MQ-25 sorties and aircraft to support it.

Balancing range, speed, survivability, and payload

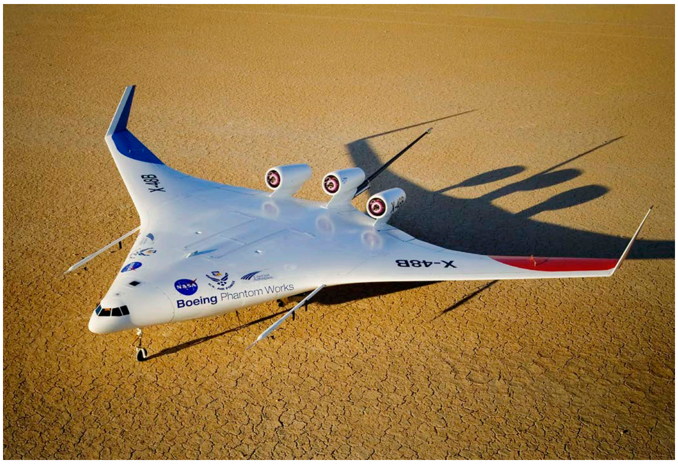
A carrier-based UCAV design will need to balance its speed, survivability characteristics, and useful payload to achieve a high fuel efficiency that supports a 3,000-nm unrefueled range. The most central is survivability, because it can influence other design characteristics. A UCAV can achieve greater survivability through a combination of stealth features such as radar-absorbing coatings and fewer radar reflecting surfaces; sensor countermeasures such as onboard jammers and offboard decoys; a design that diffuses or "hides" heat emissions from its engine or engines; and self-defense weapons such as lasers or AAMs. The balance between these approaches will need to consider the aircraft's planform and how it may impact payload and fuel efficiency.

For example, blended-wing-body (BWB) planforms, such as in Figure 47, could achieve up to 25 percent greater fuel efficiency than a traditional tube-and-wing (TAW) planform for the

206 Sam LaGrone, "Navy Releases Final MQ-25 Stingray RFP; General Atomics Bid Revealed," *USNI News,* October 10, 2017, available at https://news.usni.org/2017/10/10/navy-releases-final-mq-25-stingray-rfp-general-atomics-bid-revealed.

same overall payload weight. This is the result of the greater lift a BWB design can achieve with its larger surface area and the lighter weight of its internal structure.[207] Although the most efficient speeds for BWB planform designs are generally slower than for TAW designs, recent analyses show BWB designs can fly up to Mach 0.9, the cruising speed of most strike fighters, without incurring significant efficiency penalties.[208]

FIGURE 47: X-48B BWB AIRCRAFT PLANFORM DESIGN



NASA photo courtesy of Boeing by Robert Ferguson.

A BWB planform could also improve UCAV survivability. It has fewer radar-reflecting edges and surfaces than a TAW planform, and it would be able to carry more of its payload internally, further reducing its radar cross section. Alternatively, a TAW design aircraft could compensate for a higher signature by using EW systems and self-defense weapons to achieve higher levels of survivability. The BWB radar cross section, heat signature, and drag could be further reduced by removing the tail and moving the engines inside the outer mold line of the aircraft to create a flying wing planform, as with the X-47B and Lockheed Martin's proposed MQ-25 aircraft.[209] This design may offer the most advantageous combination of characteristics in the future UCAV.

207 Egbert Torenbeek, "Blended Wing Body Aircraft: A Historical Perspective," *Encyclopedia of Aerospace Engineering* May 15, 2016.

208 Dino Roman, Richard Gilmore, and Sean Wakayama, "Aerodynamics of High-Subsonic Blended-Wing-Body Configurations," 41st Aerospace Sciences Meeting and Exhibit, Reno, NV, January 6–9, 2003, available at http://aircraftdesign.nuaa.edu.cn/mdo/ref/application/bwb/aerodynamics%20of%20high-subsonic%20blended-wing-body%20configurations.pdf.

209 S. M. Vaitheeswaran et al., "Monostatic Radar Cross Section of Flying Wing Delta Planforms," *Engineering Science and Technology, an International Journal*, 2017, available at https://www.researchgate.net/publication/313736093_monostatic_radar_cross_section_of_flying_wing_delta_planforms.

FIGURE 48: X-47B FLYING WING AIRCRAFT PLANFORM DESIGN

U.S. Navy photo.

FIGURE 49: PROPOSED LOCKHEED MARTIN MQ-25 FLYING WING AIRCRAFT PLANFORM DESIGN

Image courtesy of Lockheed Martin.

The UCAV would need a payload capacity equivalent to or larger than today's strike fighters. This would enable the UCAV to take advantage of its endurance for DCA, SUW, or ASW CAP missions, as it would not need to return to the carrier frequently to reload weapons. For long-range strike, SUW, and EMW missions, a larger payload would better enable the UCAV to overcome enemy defenses through larger salvos of offensive weapons and more sensor coverage and jamming from EMW expendables. The UCAV's payload capacity could also be used to host directed energy weapons which have a magazine limited only by the UCAV's ability to generate electrical power.

In the past, one consideration in choosing TAW instead of BWB or flying wing planforms was flight control; stability was sometimes difficult to maintain with early BWB and flying wing aircraft.[210] These problems have been addressed in computer-aided control systems for modern BWB planform designs such as the National Aeronautics and Space Administration's (NASA) X-48B and flying wing designs such as the Navy's X-47B.[211]

Autonomy and manned-unmanned teaming

A carrier-based UCAV will need to conduct missions with varying levels of autonomy, dependent on its ability to communicate with controllers and the speed and complexity of the operation. When conducting DCA, SUW, ASW, and strike, operations should be at a slow enough pace for human controllers in AEW&C aircraft such as the E-2D or on a surface combatant in LOS contact to review targeting information from ISR&T UCAVs or external sources and decide when to engage targets. C2 would be assisted by computer-based decision aids that could help find, classify, and identify targets and determine the weapons and platforms best able to conduct an engagement. Examples of these include the Aegis Combat System, which uses a contact's motion, radar signature, and electronic emissions to classify and identify the target, and then determines which weapons should engage it.[212] Emerging decision support systems such as Project Maven, developed by DoD's Algorithmic Warfare Cross Functional Team (AWCFT), use artificial intelligence (AI) approaches to conduct target classification and identification.[213]

Enabling human-in-the loop C2 for UCAV operations will require the ability to communicate with UCAVs at extended ranges in contested environments. Enemy jamming will likely make sending large amounts of raw sensor data in these conditions impossible or induce unacceptable latency in the data received by UCAVs. Communications could be maintained with UCAVs using LOS datalinks that employ low-power and signal processing to avoid detection and defeat jamming, although this would reduce the available communication bandwidth.[214] UCAVs will therefore require onboard sensor processing and autonomous target recognition (ATR) to enable them to send only small files with targeting information and necessary sensor data to support operator decision-making. Today's ATR technology is sufficient to support this level of human-in-the-loop operation.[215]

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210 Rodrigo Martínez-Val and Erik Schoep, "Flying Wing Versus Conventional Transport Airplane: The 300 Seat Case," International Civil Aviation Symposium 2000, Madrid, available at http://www.icas.org/icas_archive/icas2000/papers/ica0113.pdf.

211 Xiaoping Xu and Zhou, "Study on Longitudinal Stability Improvement of Flying Wing Aircraft Based on Synthetic Jet Flow Control," *Aerospace Science and Technology* 46, October 1, 2015.

212 "Aegis Weapons System," *Fact File*, U.S. Navy, updated January 26, 2017, available at http://www.navy.mil/navydata/fact_print.asp?cid=2100&tid=200&ct=2&page=1.

213 Adin Dobkin, "DOD Maven AI Project Develops First Algorithms, Starts Testing," *Defense Systems*, November 3, 2017, available at https://defensesystems.com/articles/2017/11/03/maven-dod.aspx.

214 Joseph Evans, "Communications Under Extreme RF Spectrum Conditions (CommEx)," DARPA, available at https://www.darpa.mil/program/communications-under-extreme-rf-spectrum-conditions.

215 U.S. Air Force Scientific Advisory Board, *Automatic Target Recognition* (Washington, DC: U.S. Air Force, July 2005), p. 7, available at http://www.dtic.mil/dtic/tr/fulltext/u2/a633787.pdf.

Some missions—such as ASCM CAPs, EMW, and strike—may require UCAVs to act faster than human-in-the-loop C2 could support or do so in environments where communications are likely to be denied. The UCAV will need to rely on its organic sensor processing and ATR capability to support these engagements. When operating as part of ASCM CAPs, CVWs should be able to minimize the risk of using ATR for ASCM engagements by only allowing UCAVs to autonomously engage ASCM-sized targets in certain altitudes and areas. In some cases, such as during EMW operations in support of long-range strike by land-based bombers, the UCAV could be controlled by operators on the manned bomber or escort fighters using LPI/LPD datalinks. Moreover, in strike and EMW operations the weapon, UAV, or missile will often be autonomous and only receive initial direction from a UCAV before launch.

Multi-mission Unmanned Refueling Aircraft

Today, carrier aircraft fly up to 700 nm to conduct strikes and provide CAS for troops in Syria or Afghanistan, supported by a combination of F/A-18 E/F Super Hornets with aerial refueling "buddy tanks" and land-based tankers such as the KC-135.[216] This approach reduces the CVW's offensive capacity and may not be feasible during future confrontations when land-based refueling aircraft are threatened by enemy fighters or unable to operate from airfields in the region because they are under attack. Moreover, future CVW operations will often need to occur at ranges of up to 1,000 nm, putting more demands on a land-based refueling fleet that is already under stress.

FIGURE 50: F/A-18 E/F WITH BUDDY TANKS

U.S. Navy photo.

216 Douglas Jehl, "A Nation Challenged: Air Operation; Afghanistan's Distance From Carriers Limits U.S. Pilots' Flights," *The New York Times*, October 11, 2001, available at https://www.nytimes.com/2001/10/11/world/nation-challenged-air-operation-afghanistan-s-distance-carriers-limits-us-pilots.html.

FIGURE 51: KC-135 TANKER

U.S. Navy photo.

A dedicated carrier-based aerial refueling tanker could enable CVW aircraft to conduct long-range attacks to promptly respond to aggression or keep the carrier far enough away from threat areas to reduce the density of air and missile threats to within the capacity of the CSG's defenses. The U.S. Navy is pursuing the MQ-25 carrier-based tanker UAV for this reason. The Navy intends the MQ-25 to be focused on the refueling mission, rather than being a multi-mission aircraft like other UAVs such as the MQ-9 Reaper.[217] This approach was designed in part to reduce technical and programmatic risk for the MQ-25. The focus on a single mission was also intended to preclude further delays that could be incurred by continuation of the Navy's decade-long debate over the aircraft's roles and resulting requirements.[218]

The full MQ-25 specifications are classified, but the unclassified official RFP requires that the MQ-25 be able to supply at least 15,000 lb of fuel to F-35C or F/A-18 aircraft 500 nm from their carrier.[219] Assuming a strike fighter fuel capacity of about 18,000 lb, the minimum MQ-25 fuel capacity would enable complete refueling of two strike fighters at about 500 nm from the carrier. They could then travel another 1,270–1,500 nm, depending on the aircraft, or conduct a combat mission 800–1,000 nm from the carrier. For comparison, assuming the proposed UCAV has a fuel capacity of 18,000 lb and a range of 3,000 nm, an MQ-25 could refuel four to five UCAVs 500 nm from the carrier, enabling them to conduct a 1.5- to 2-hour orbit at about 1,000 nm or travel 3,500 nm total.

217 "MQ-9 Reaper," Fact Sheets, U.S. Air Force, September 23, 2015, available at https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104470/mq-9-reaper/.

218 Megan Eckstein and Sam LaGrone, "Navy Picks Boeing to Build MQ-25A Stingray Carrier-Based Drone," *USNI News*, August 30, 2018, available at https://news.usni.org/2018/08/30/navy-picks-boeing-build-mq-25a-stingray-carrier-based-drone.

219 Sam LaGrone, "Navy Releases Final MQ-25 Stingray RFP; General Atomics Bid Revealed," *USNI News,* October 10, 2017, available at https://news.usni.org/2017/10/10/navy-releases-final-mq-25-stingray-rfp-general-atomics-bid-revealed,

The Navy recently awarded the MQ-25 program to Boeing, which already has a prototype aircraft, shown in Figure 52. The Boeing prototype is a variation on a BWB design, which will afford it relatively high fuel efficiency and payload capacity. Compared to a flying wing, however, the BWB design will have a higher radar signature. This may reduce its ability to conduct new missions, such as ISR, in highly contested environments.

The MQ-25 design reflects the Navy's focus on it being a tanker first, with other missions being only potential future applications. This approach will likely fail to take advantage of the MQ-25's full potential and could precludes designs that would enable more commonality between the MQ-25 and a future UCAV. Specifically, by focusing the MQ-25 on the refueling mission, its requirements did not include characteristics that would enable it to be a potential UCAV, such as having a low all-aspect radar and IR signature across multiple frequencies or being able to incorporate a mission bay to carry weapons or expendables. If these characteristics had been considered in the MQ-25, the Navy may have been able to create a modified version that could be the UCAV. In its planned form, the MQ-25 would likely need to rely on external carriage for most weapons or expendables, which would increase its radar cross section, and a combination of mission planning and EW systems to help reduce its vulnerability against threat radars and EO/IR sensors.

FIGURE 52: MQ-25 STINGRAY

Image courtesy of Boeing

It is unlikely Navy leaders will want to modify or truncate the MQ-25 program to start a new one focused on a multi-mission UAV. Therefore, this report proposes the following approach that leverages ongoing development of the MQ-25 to address the urgency of developing a tanker aircraft while also promoting greater commonality and flexibility in the future CVW.

To better exploit the potential of the MQ-25, the Navy should re-designate it as a multi-mission UAV. The initial version of the MQ-25 would remain focused on the aerial refueling mission to avoid delays in program development. While fielding and testing MQ-25 EDMs between 2018 and 2023, however, the Navy could develop modifications that would enable it to also conduct ISR, attack, and EW missions in appropriate operational environments. These modifications could be incorporated into production MQ-25s starting in 2025. Operationally, MQ-25s would be able to complement UCAVs when the risk is acceptable, providing the future CVW a potentially less expensive option for surveillance, EW, or attack missions in less stressing environments.

Because the MQ-25 will not fully meet the Navy's needs in coming years, the Navy should also develop the UCAV described above between 2020 and 2025, followed by a tanker variant that repurposes mission payload capacity and fuel to cargo fuel. The UCAV tanker should be able to provide the same fuel delivery as the Navy required for the MQ-25. The refueling version would enter production after enough UCAVs are fielded to provide the capacity needed in future CVWs for DCA, SUW, ASW, strike, and EMW operations at long range and in highly contested environments, which may not happen until the mid-2030s. As a result, the Navy would build most of its planned 72 MQ-25s, and then transition the refueling mission to tanker variants of the UCAV.

This approach will result in the future CVW including two different fixed-wing UAVs, a reflection of the growing importance of unmanned systems in naval aviation. This will increase logistics and maintenance complexity compared to the Navy's current plan of only including the MQ-25 in the future CVW. Diversity of airframes, however, can improve the resilience of the CVW, as evidenced by recent groundings of entire aircraft models such as Air Force T-6 Texans due to onboard oxygen generation system failures.[220] As described in Chapter 3, the diversity of CVWs also often increased when naval forces faced improved adversary capabilities and the Navy fielded more specialized aircraft.

Long-range Fighter (FA-XX)

Future CVW DCA, counter-ASCM, and OCA operations will require carrier-based aircraft with the ability to intercept enemy aircraft or cruise missiles and engage them with either AAMs or directed energy weapons. UCAVs are particularly well suited for DCA CAPs, where speed and maneuverability are less important than sensor capability, payload, survivability, and endurance. Strike fighters like the Block III F/A-18 E/F or a variant of the MQ-25 would be well suited for ASCM CAPs, particularly if they were upgraded with a high-energy laser or HPM weapon pod.

Escort and OCA operations, however, will likely require a family of systems. U.S. weapons salvos will need a combination of survivability, complexity, and size to overcome Chinese and Russian air defense systems. To increase the complexity and survivability of strikes, CVW UCAVs could complement land or carrier-based attack aircraft or bombers by launching

220 Stephen Losey, "Lawmaker Blasts Air Force General Over Unsolved Hypoxia Problem," *Air Force Times*, February 6, 2018, available at https://www.airforcetimes.com/news/your-air-force/2018/02/06/lawmaker-blasts-air-force-general-over-unsolved-hypoxia-problem/.

expendable sensors, jammers, and decoys from outside the range of enemy ground-based air defense systems.[221]

To achieve larger salvos, attack aircraft will need to approach targets more closely where they can use smaller, shorter-range weapons. As a result, they are likely to encounter enemy DCA CAPs. Unlike the CVW DCA CAPs proposed in this report, Chinese and Russian DCA CAPs could operate within range of shore-based sensors and air defense systems. This would create a dense array of overlapping radars and passive sensors that would challenge the low observability features incorporated into today's strike fighters and bombers. Because of the dual threat from enemy DCA CAP aircraft and ground-based air defense systems, OCA operations will likely require a survivable aircraft able to intercept enemy fighters while avoiding SAMs.

OCA operations could be conducted by a UCAV, as in the CVW DCA CAPs against enemy bombers concept described in Chapter 4. The UCAV, however, may lack the speed and maneuverability needed to engage enemy fighters in a dense SAM environment. Further analysis and experimentation would be needed to evaluate this concept.

If speed and maneuverability are needed for OCA operations, the Navy is pursuing a longer-range fighter to replace the F/A-18 E/F in the 2030s that could provide these requirements. The new fighter, now called the FA-XX, would emphasize range and speed with low observability being a secondary concern.[222] Navy leaders intend FA-XX to be survivable in highly contested environments, which it might achieve through a combination of sensor countermeasures and self-defense weapons rather than aircraft shape and coatings alone.

FIGURE 53: FA-XX CONCEPT FROM BOEING

Image courtesy of Boeing.

221 "Disrupting Enemy Air Defense Systems," *Raytheon Missile Systems*, Raytheon, available at https://www.raytheon.com/capabilities/products/mald.

222 Valerie Insinna, "Speed and Range Could be Key for Navy's Next Fighter Jet," *Defense News*, July 21, 2017, available at https://www.defensenews.com/air/2017/07/21/speed-and-range-could-be-key-for-navys-next-fighter-jet/.

FIGURE 54: FA-XX CONCEPT FROM LOCKHEED MARTIN

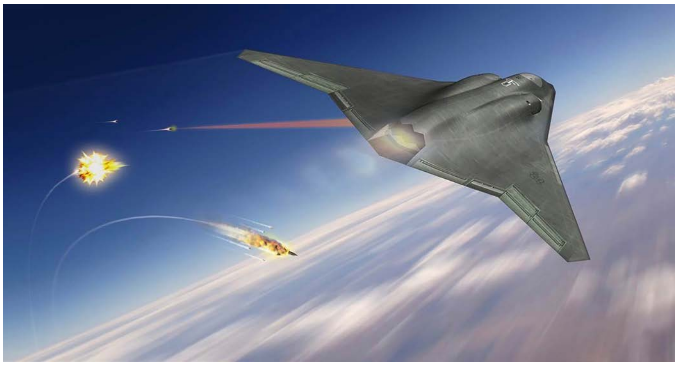


Image courtesy of Lockheed Martin.

The Navy's emphasis on range is consistent with the needs of future CVW operational concepts envisioned in this report. A challenge today for land-based bombers is the possibility that U.S. or allied fighter bases located within 2,000 nm of Chinese or Russian territory could be unavailable due to enemy attacks, host nation concerns, or the geography of the region, especially in the Pacific. CVW aircraft could provide OCA support for these strikes from carriers that are located 1,000–1,200 nm away from the bulk of enemy missile launchers, enabling the CSG's defenses to manage the remaining attack salvos. To enable OCA operations over these ranges with one refueling from an MQ-25, the FA-XX would need a combat radius of more than 800 nm or an overall range of more than 1,600 nm.[223]

One way the Navy intends to increase the FA-XX's endurance is by making it optionally manned.[224] Although this will not reduce the weight of the aircraft, it could enable the aircraft to fly unmanned missions longer than 12 hours when required. More importantly, optional manning could allow human operators to focus their attention on command and control of sensors and offboard systems rather than physically flying the aircraft. This could reduce the impacts of pilot fatigue on longer missions.

The Navy's emphasis on the FA-XX's speed is less compelling than its other attributes, considering the significant speed overmatch modern Chinese and Russian SAMs enjoy today and are likely to maintain in future threat environments.[225] Instead of emphasizing speed, the FA-XX program should prioritize sensor capability and weapons capacity. Sensors, especially passive sensors, could enable CVW fighters to detect enemy fighters or SAMs before being detected themselves, allowing the U.S. fighter to evade or attack first. The emerging generation of long-range IRST sensors in the long- and medium-wave IR frequency ranges, passive RF receivers, and EO cameras could provide these capabilities, but they will require more and larger

223 For comparison, the maximum range of the F-35C is about 1,275 nm.

224 Optionally manned aircraft are designed to be flown without an onboard aircrew.

225 Carlo Kopp, "Almaz-Antey 40R6/S-400 Triumf Self Propelled Air Defence System/SA-21," *Air Power Australia*, May 2009, available at http://www.ausairpower.net/APA-S-400-Triumf.html#mozTocId843249.

apertures on the FA-XX airframe or to be carried in pods, which may impact speed. FA-XX weapons capacity will also be more important than speed. Given the long ranges needed to conduct OCA operations, the CVW will not be able to quickly send fighters to replace those that have expended their weapons.

Except for range, the sensor capability and weapons capacity described above for the FA-XX or future long-range fighter could be provided by a version of a current production fighter or strike fighter, such as the Block III F/A-18 E/F or F-35C. A modified aircraft could avoid the potentially unsustainable cost of a new fighter development program, with some of the saved funding being reallocated to the UCAV development effort.[226]

FIGURE 55: F-35C OR F/A-18 E/F COULD BE ADAPTED TO BE LONG-RANGE FIGHTER

U.S. Navy and Air Force photos.

Proposed 2040 CVW Composition

The Navy's planned CVW of 2040 would only modestly improve the CVW's range and survivability. It continues to rely on strike fighters for offensive operations, as the Navy plans for F-35Cs to replace older F/A-18 E/Fs, and FA-XXs to replace newer F/A-18 E/Fs.[227] The Navy is now buying Block III F/A-18 E/Fs and conducting service life modernization for in-service F/A-18 E/Fs that will extend all F/A-18 E/Fs to 9,000 flight hours, which equates to 20–30 years of service life, depending on the amount and severity of their use.[228] These changes could result in F/A-18 E/Fs remaining in service into the 2040s, delaying introduction of the FA-XX.

226 Sydney J. Freedberg Jr., "Navy May Buy More F-35s, Not Fewer, Under F/A-XX Initiative," *Breaking Defense,* July 13, 2012, available at https://breakingdefense.com/2012/07/navy-may-buy-more-f-35s-not-fewer-under-f-a-xx-initiative/.

227 U.S. Navy, *Naval Aviation Vision: 2016-2025* (Washington, DC: U.S. Navy, 2016), p. 59, available at https://www.navy.mil/strategic/Naval_Aviation_Vision.pdf.

228 Valerie Insinna, "Boeing Super Hornet Program Gets Second Life Through Future Sales and Upgrades," *Defense News*, April 4, 2018, available at https://www.defensenews.com/digital-show-dailies/navy-league/2018/04/04/boeing-super-hornet-program-gets-second-life-through-future-sales-and-upgrades/.

The Navy's planned CVW will also add four MQ-25s to extend the range of strike fighters,[229] maintain the current complement of five E-2Ds and eleven helicopters, and up to six or more E/A-18G AEA aircraft, assuming their service lives are extended.[230]

This report's proposed 2040 CVW improves on the Navy's planned CVW using a combination of new and legacy aircraft to support the operational concepts described in Chapter 4. This proposed CVW composition represents the future ideal case. Some aircraft types may be substituted with legacy aircraft as the CVW evolves from its current and planned structure to the proposed configuration.

The number of each aircraft in the proposed 2040 CVW and accompanying rationale are described below. For new aircraft, the following discussion also addresses requirements for overall aircraft inventory, assuming ten CVWs to support twelve CSGs, and the potential cost of new aircraft.

Strike Fighters

The proposed 2040 CVW includes ten strike fighters, which will be used for smaller strike operations, as they are today, and to support ASCM CAPs. This is far fewer than the 44 strike fighters in the Navy's planned CVW and would consist of the first half of F-35C production, which completes in 2025.[231] Using today's strike fighter inventory as a guide, sustaining ten F-35C strike fighters in each of the Navy's ten CVWs will require about 250 total aircraft.[232]

Due to fiscal constraints and life extension of legacy aircraft, the actual 2040 CVW may include more than ten strike fighters, consisting of a mix of F-35Cs in the middle and Block III F/A-18 E/Fs in the latter part of their service lives. In this case, strike fighters could be used in place of UCAVs to conduct the operational concepts described in Chapter 4, albeit less efficiently and with greater risk.

Multi-Mission UCAVs

Based on the operational concepts for IAMD, ISR&T, strike, SUW, ASW, and EMW described in Chapter 4, the proposed 2040 CVW could need to support up to three DCA CAPs requiring two UCAVs each, up to eight ISR&T CAPs requiring two UCAVs each, and up to four SUW or ASW CAPs requiring two aircraft each. This would result in a requirement for up to 30

229 Rich Smith, "Boeing Unveils Its MQ-25 Stingray Prototype," *The Motley Fool*, January 14, 2018, available at https://www.fool.com/investing/2018/01/14/boeing-unveils-its-mq-25-stingray-prototype.aspx.

230 Valerie Insinna and David Larter, "US Navy Selects Builder for New MQ-25 Stingray Aerial Refueling Drone," *Defense News*, August 30, 2018, available at https://www.defensenews.com/naval/2018/08/30/us-navy-selects-builder-for-new-mq-25-stingray-aerial-refueling-drone/.

231 Roy Kelley, "F-35C Integration into the Fleet," *NavyLive*, August 3, 2017, available at http://navylive.dodlive.mil/2017/08/03/f-35c-integration-into-the-fleet/; and U.S. Navy, *Naval Aviation Vision: 2016–2025*, p. 59.

232 This total accounts for aircraft needed for training and test squadrons, to enable some aircraft to be in depot maintenance, and to make up for attrition due to mishaps.

UCAVs; the requirement could be higher if CAPs cannot be refueled on station or the threat environment worsened.

Due to space and likely fiscal constraints, the proposed CVW will include 18 UCAVs. With a notional average aircraft operational availability of 0.8, 15 operational UCAVs could sustain three DCA CAPs, two ISR&T CAPs, and two SUW, strike, or ASW CAPs. Alternatively, 15 UCAVs could conduct one or more strikes of 120 SDB-size weapons total without carrying external weapons that would increase their signature and vulnerability.

The UCAV complement in the proposed CVW would not provide complete DCA and ISR&T coverage around the CSG, but it would provide IAMD coverage for the most important threat sectors. If two CSGs are operating simultaneously in the Maneuver Force, additional aircraft would be available. CSGs or the Maneuver Force could also employ non-organic sensors on MQ-4 Triton UAVs or space capabilities to augment or replace some ISR&T CAP orbits, or to free up UCAVs for SUW, strike, or ASW operations.

As described above, a tanker variant of the UCAV will be developed later in the production run to take over the refueling mission from the MQ-25. Because combat missions are the priority for UCAV employment, production of tanker UCAVs will likely start in the mid to late-2030s.

The Navy will need about 96 UCAVs to sustain 18 aircraft in six CVWs. Although there will be ten CVWs total, only three are likely to be deployed at one time; one CVW would be recently returned from deployment, and another one to two CVWs would be preparing to deploy. The other CVWs would be conducting refresher training and maintenance. Because UCAV operators can be trained and qualified using simulators, the four CVWs not preparing to deploy or on deployment do not need UCAVs. To account for depot-level maintenance and attrition, the Navy will likely need to achieve a total inventory of about 150 UCAVs to support the 2040 CVW.

For this study, the UCAV's cost is assumed to be approximately that of the F-35C in the same timeframe. Although they are different aircraft, the UCAV and F-35C will be of a similar size, level of sophistication, and signature.

EMW UCAVs

To conduct future EMW missions, the proposed CVW includes six EMW-configured UCAVs. Because incorporating systems of the E/A-18G, such as the NGJ, into a UCAV will likely reduce its payload and availability for other missions, these aircraft will be focused on the AEA mission and deploying EMW expendables against enemy aircraft and air defenses. Similar to the multi-mission UCAV, about 36 EMW UCAVs will be needed to support six operating CVWs. To account for depot maintenance and attrition, a total inventory of about 50 EMW UCAVs will be needed to support the 2040 CVW. These aircraft will be procured as F/A-18 E/Fs leave the fleet at the end of their service lives in the 2030s.

FA-XX Fighters

Long-range fighters will be needed for OCA missions and to support DCA, ASCM, or ISR&T CAPs when UCAVs are not available. The proposed 2040 CVW includes ten FA-XX fighters. Assuming a notional 0.8 operational availability, these fighters would enable two to three OCA operations or sustain two to three ASCM CAPs. Again, using today's strike fighter inventory as a guide, sustaining ten fighters in each of the Navy's ten CVWs will require about 250 total inventory aircraft. Although any current aircraft could form the basis for the FA-XX, this study assumes the cost of the FA-XX to be that of the F-35C, plus 10 percent to account for improvements to increase its range.

Multi-Mission Refueling Aircraft

The proposed 2040 CVW includes twelve refueling aircraft, consisting of a combination of MQ-25 and UCAV tankers. Because the UCAV tanker will not be introduced until enough UCAVs are fielded for combat missions, in 2040 the CVW tanker complement will mostly consist of MQ-25s. Assuming they have an average operational availability of 0.8, ten tankers could support three DCA CAPs; three ISR&T CAPs; and four SUW, strike, or ASW CAPs. Moreover, twelve tankers would provide enough fuel to enable the CVW's full complement of 24 UCAVs to conduct a strike mission up to 2,000 nm from the carrier.

Similar to the UCAV, the total inventory of refueling aircraft would need to support six CVWs: three CVWs would be deployed, one would be recently returned, and one or two would be preparing for deployment. Operators of the remaining four UCAV squadrons could stay proficient using simulators. As a result, about 72 total refueling aircraft would be needed.

E-2D AEW&C Aircraft

E-2Ds are still in production and expected to operate past 2040. Adversaries, however, will increasingly consider it a high-value target for their counterair operations.[233] Since the E-2D's signature and high-power radar could make it easy for enemy sensors to detect, it may therefore be too vulnerable to operate in contested areas by 2040. The E-2D, however, will still be a valuable C2 platform for DCA operations and could provide ISR&T for ASCM CAPs that are located closer to a carrier. To support these missions, the proposed 2040 CVW includes six E-2Ds, which will support up to two orbits.

MH-60 Helicopters

The proposed 2040 CVW includes eleven helicopters that operate from the carrier, similar to the 2018 CVW: six MH-60Rs and five MH-60Ss. An additional six MH-60R ASW helicopters and two MH-60S cargo and CSAR helicopters are also technically part of the CVW, but usually

233 T.J. May and Mike Pietrucha, "We Already Have An Arsenal Plane: It's Called The B-52," *War on the Rocks*, June 22, 2016, available at https://warontherocks.com/2016/06/we-already-have-an-arsenal-plane-its-called-the-b-52/.

operate from the CSG's surface combatants. Although the proposed CVW will use UCAVs for long-range ASW pouncer operations, ASW attacks may be executed by MH-60Rs flying from surface combatants operating 100–800 nm from the carrier. Both MH-60 variants could be used to deploy unmanned ASW sensors, and the MH-60S would support logistics and force protection operations.

Rotary-wing UAVs

The Marine Corps is pursuing a MALE UAV called the MUX primarily to provide AEW&C capabilities for the ACE when operating independently from a CVW. The Navy is also fielding VTUAVs, such as the MQ-8C Fire Scout, with helicopter squadrons.[234] The proposed 2040 CVW includes two MALE VTUAVs such as DARPA's TERN to support ASW pouncer operations at longer ranges and with greater persistence than MH-60Rs. The TERN or MQ-8C takes about half the space as a MH-60R, enabling Navy HSMs to add two VTUAVs without significantly impacting space constraints on surface combatants or carriers.[235]

CMV-22B Rotary Wing Cargo Aircraft

Fixed-wing C-2A aircraft are used today to carry personnel and conduct expedited logistics with carriers. The Navy is replacing the C-2As by the mid-2020s with the CMV-22B cargo variant of the Marine Corps rotary-wing MV-22 Osprey.[236] The proposed 2040 CVW assumes this transition continues, although CMV-22Bs will operate in detachments from shore squadrons and are not formally based on the carrier itself.

Proposed 2040 CVW Configuration

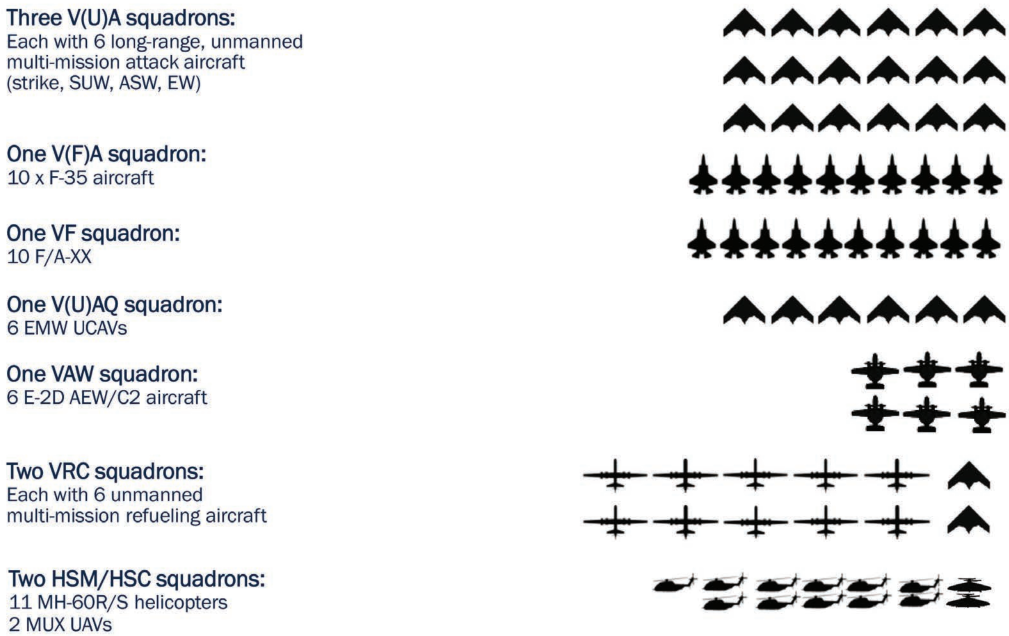
The proposed 2040 CVW is illustrated in Figure 56. Although it includes about the same number of aircraft as today's CVW, it would require a smaller number of spot factors because new aircraft such as the UCAV would take up less space than legacy F/A-18 E/Fs.

234 Commander, Naval Air Forces Public Affairs, "Magicians Reborn as Navy's First Squadron to Operate Manned and Unmanned Aircraft," *Navy News Service,* May 3, 2013, available at http://www.navy.mil/submit/display.asp?story_id=73876.

235 Graham Drozeski, "Tactically Exploited Reconnaissance Node (TERN)," DARPA, available at https://www.darpa.mil/program/tern.

236 U.S. Navy, *Naval Aviation Vision: 2016–2025*, p. 72; and Office of Budget, *Highlights of the Department of the Navy FY 2019 Budget* (Washington, DC: U.S. Navy, 2018), p. 4-6. available at http://www.secnav.navy.mil/fmc/fmb/Documents/19pres/Highlights_book.pdf.

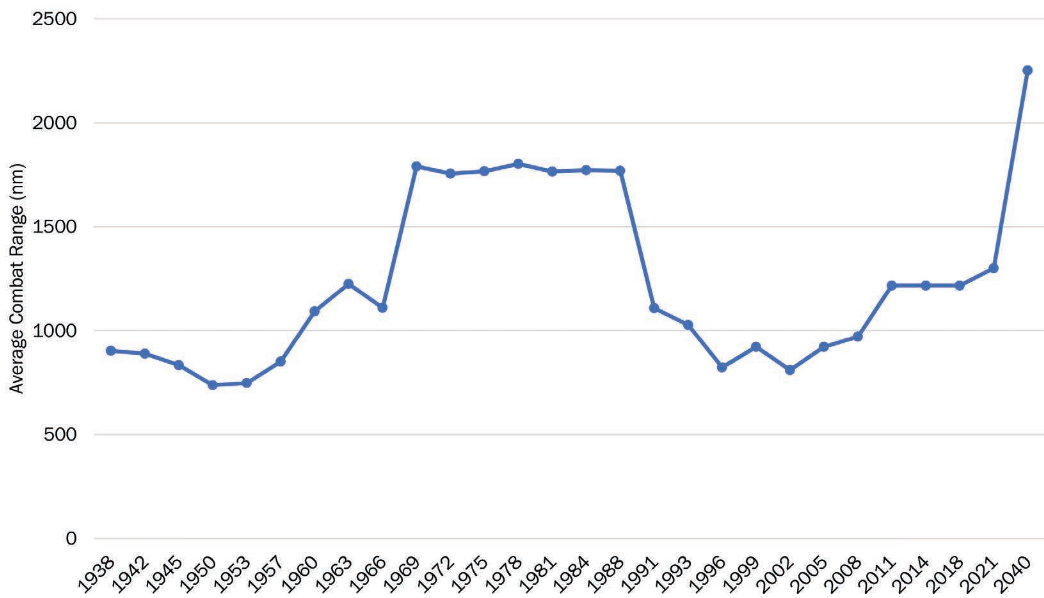
FIGURE 56: PROPOSED 2040 CVW



Analysis of the Proposed 2040 CVW

The proposed 2040 CVW reflects the stressing mission requirements of great power competition. Most importantly, the addition of long-range UCAVs and FA-XX fighters would increase the average range of combat aircraft in the CVW, as shown in Figure 57.

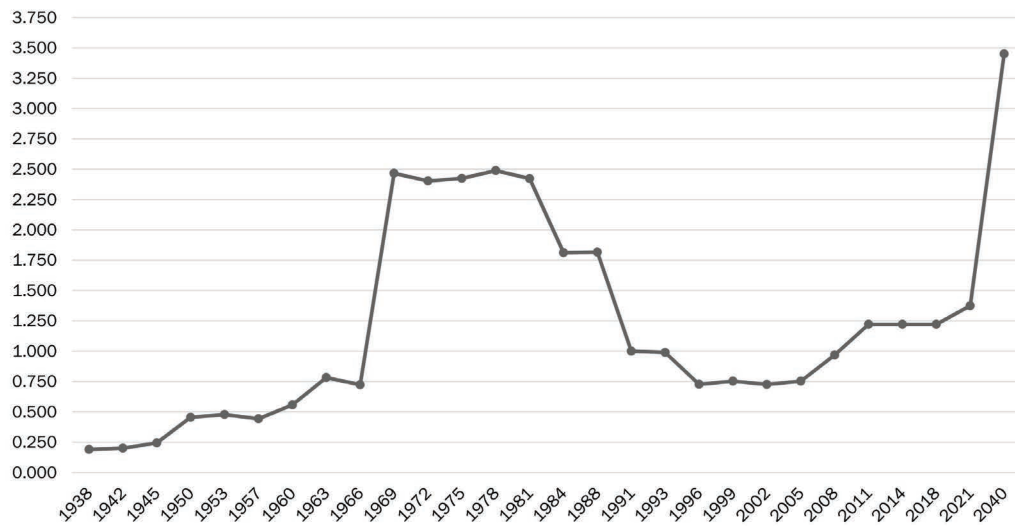
FIGURE 57: AVERAGE RANGE OF CVW COMBAT AIRCRAFT



The combination of longer-range, consistent payload, and more compact aircraft would also improve the payload efficiency of the proposed 2040 CVW compared to today's fleet. The proposed UCAV, for example, takes up about three-fourths of the space of an F/A-18C Hornet (which is equal to a spot factor of 1.0). Although the proposed 2040 CVW includes a few more aircraft than today's CVW, it would only take up 60 F/A-18C-sized spots compared to the 70 spots in today's CVW. The maximum number of spots available in a *Nimitz*-class CVN is about 98 to 104, enabling the future CVW to incorporate additional aircraft to address emergent mission requirements.[237]

Because payload capacity can be used for fuel or weapons, one way to compare combat aircraft is the combination of their combat range on internal fuel and their total internal and external weapons payload. Because aircraft could simply be made larger to enable them to carry more fuel or weapons, different aircraft should also be compared based on their size. Figure 58 shows the comparison of the product of range and payload divided by spot factor for Navy CVWs over time, including the proposed 2040 CVW. As the graph shows, the proposed CVW not only has a significantly longer range than its predecessors but also is able to deliver payloads more efficiently.

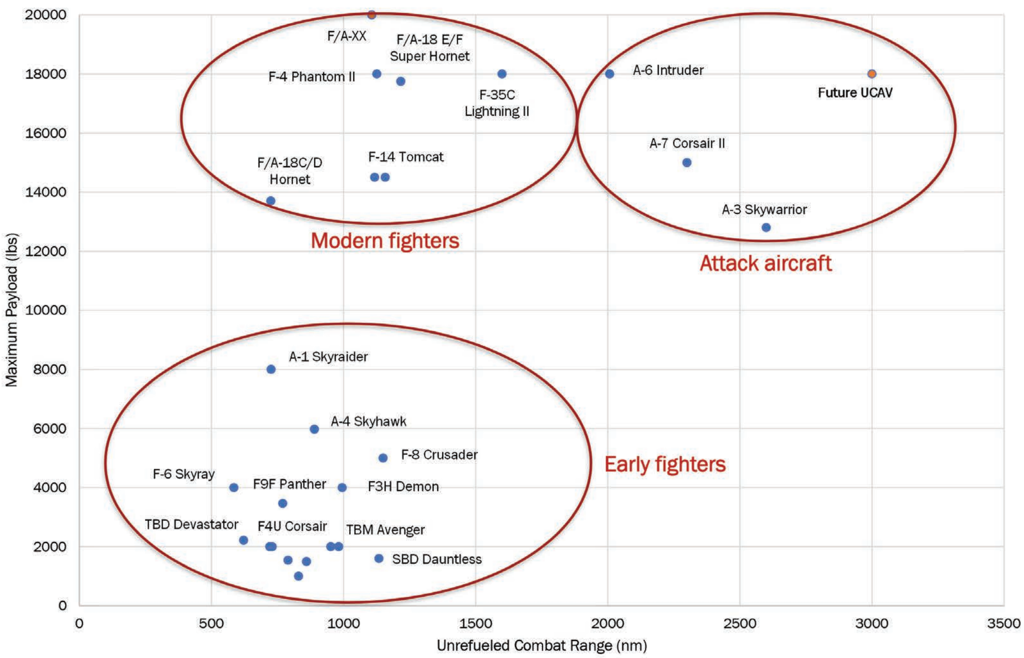
FIGURE 58: PAYLOAD EFFICIENCY OF THE CVW



237 The max *Nimitz*-class carrier capacity is 130 spots. 75–78 percent of max density (98 to 101 spots) is the "optimum number," and anything over 80 percent (104 spots) must be coordinated with headquarters. See U.S. General Accounting Office (GAO), *Navy Aircraft Carriers: Cost Effectiveness of Conventionally and Nuclear-Powered Carriers*, Report to Congressional Requesters (Washington, DC: GAO, August 1998), available at https://www.gao.gov/archive/1998/ns98001.pdf.

The constraints imposed by carrier size tend to drive aircraft into groups based on their primary purpose, as shown in Figure 59. Because they do not require the same speed and maneuverability as fighter aircraft, attack aircraft can be designed to be more fuel-efficient and achieve greater ranges. Jet engines and increases in aircraft size enabled fighter aircraft to carry larger payloads, but their ranges have not dramatically improved since the early Cold War.

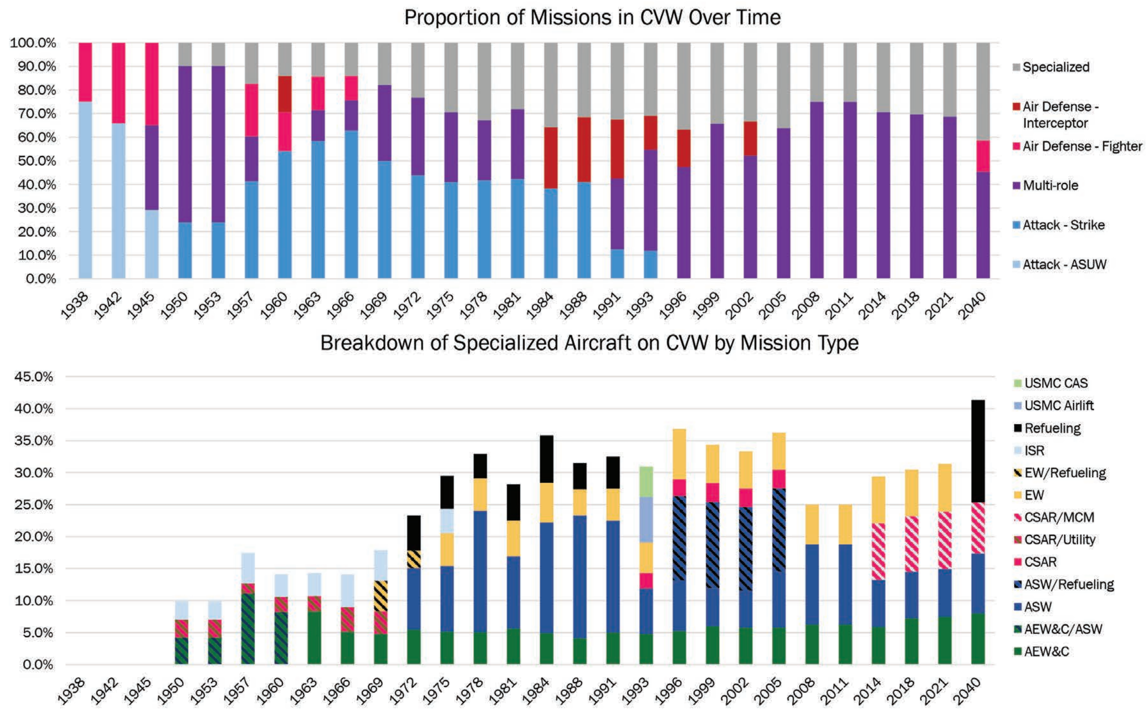
FIGURE 59: CVW AIRCRAFT RANGE VS. PAYLOAD



The composition of the proposed 2040 CVW improves the CVW's lethality by retaining the same payload per aircraft as today, increasing aircraft range, and adding specialized aircraft. As discussed in Chapter 3, when threats abated, the Navy usually shifted the composition of CVWs to include more multi-role aircraft that were not optimized for any single mission, which improved the CVW's logistics efficiency. When threats returned, more specialized aircraft were fielded. Figure 60 shows the percentage of aircraft other than attack, air defense, and multi-role—or specialized aircraft—in the CVW over time on the top chart; the bottom chart shows the composition of those specialized aircraft by mission area.

Today's multi-role-focused CVW lacks the range and survivability to defeat great power competitors. Because missions such as strike and OCA emphasize different characteristics, and missions such as ISR&T and EW require different mission systems, improving the CVW's capabilities in these missions will likely require greater specialization of aircraft designs. Similar to previous periods when the CVW faced emerging threats, today the CVW needs to again incorporate more specialized aircraft.

FIGURE 60: CVW COMPOSITION



Comparison of Alternative 2040 CVWs

The proposed 2040 CVW is obviously not the only composition the Navy could pursue by 2040. Although there are a large variety of CVW configurations that could result by 2040, this report will compare the proposed CVW with CVWs that represent the two main categories of alternatives. In one, the Navy continues to develop its planned CVW, which relies on new or life-extended strike fighters and E/A-18Gs for almost all missions and adds MQ-25 tankers to extend strike fighter range. In the other, the Navy pursues a balanced CVW that adds UCAVs to replace retiring F/A-18 E/Fs, but continues the planned F-35C and FA-XX programs and extends the lives of E/A-18Gs. These two alternatives are shown in Figures 61 and 62.

FIGURE 61: ALTERNATIVE 2040 CVW—STRIKE FIGHTER FOCUSED

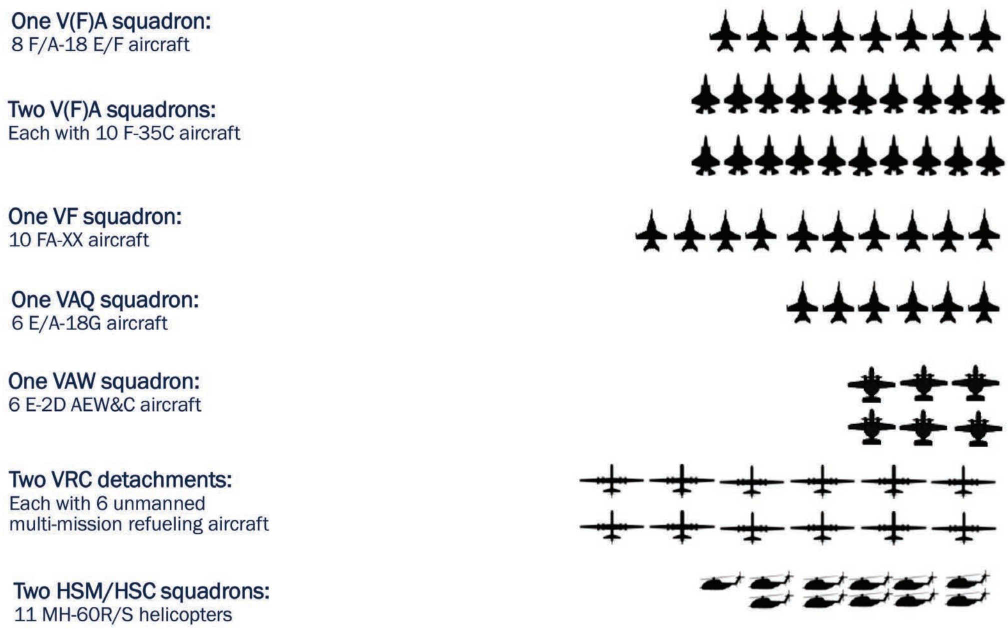
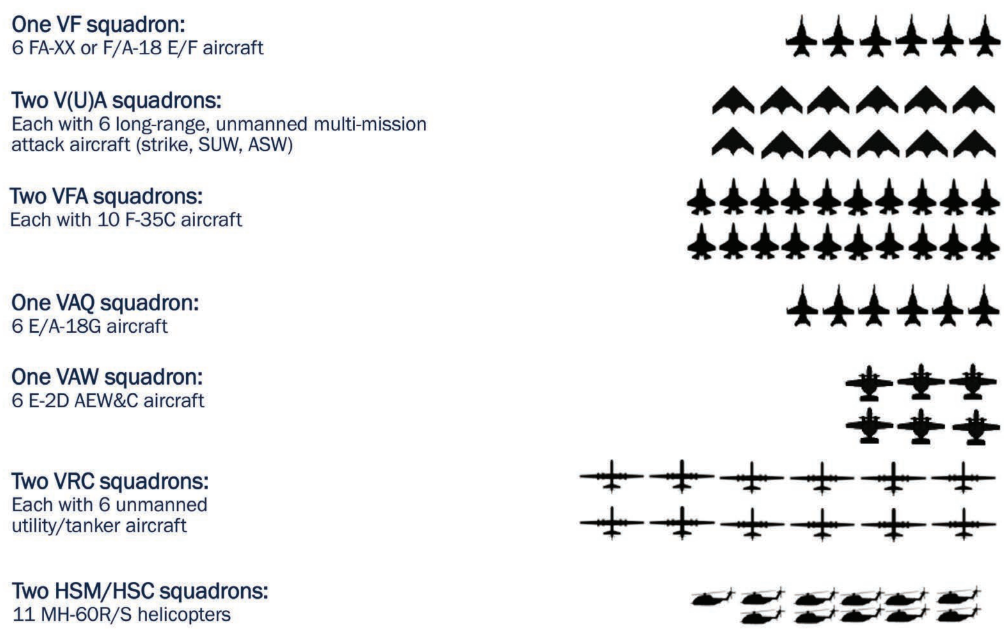


FIGURE 62: ALTERNATIVE 2040 CVW—BALANCED



Like the proposed 2040 CVW, both alternatives include six E-2Ds for AEW&C, twelve multi-mission tankers similar to the MQ-25 or UCAV-derived tankers, and eleven MH-60 R/S helicopters for ASW, CSAR, and logistics. To ensure each CVW uses about the same amount of carrier deck and hangar space, the strike fighter-focused CVW only includes eight F/A-18E/Fs, and the balanced CVW includes only six F/A-18 E/Fs.[238] F/A-18 E/Fs were chosen as the adjustable element of these CVWs because F/A-18 E/Fs would be reaching their end of service life around 2040, which may result in a smaller number being available for deployment. The most significant impact of fewer F/A-18 E/Fs is a reduction in CVW refueling capacity. The following mission analysis mitigates this impact by assuming FA-XX fighters can also conduct refueling operations.[239]

Two scenarios are used to compare these alternative CVWs and the proposed 2040 CVW. Aircraft in both scenarios rely on organic CVW tanking to maximize the number of aircraft that can reach the launch point, but the maximum capacity possible using land-based tankers is also identified for each CVW.

- SUW or strike: The UCAVs, strike fighters, and fighters in a CVW attack an enemy SAG or C2 facility 1,000 nm from the carrier using standoff missiles such as the JASSM-Extended Range (JASSM-ER) from 300 nm standoff range.[240] Four escort fighters support the strike by engaging enemy DCA CAPS; two AEA aircraft jam enemy aircraft and air defense radars. UCAVs also deploy EMW payloads to degrade point defenses and refine targeting.
- OCA or destruction of enemy air defenses (DEAD): The UCAVs, strike fighters, and fighters in a CVW attack an enemy air defense site or enemy fighter group 1,000 nm from the carrier using weapons similar to Advanced Anti-Radiation Guided Missiles (AARGM) or medium-range AAMs from 100 nm away from the target.[241] The short range of the attack and the threat environment allows for internal weapons carriage only.

SUW and Strike Mission Comparison

Figure 63 shows the number of weapons each CVW is able to deliver at 700 nm for the first scenario, assuming the target is 300 nm away from the launch point. Each CVW is able to deliver more than 200 munitions, largely because the use of standoff missiles allows external carriage of weapons. This enables F/A-18 E/Fs to contribute to attacks as well as refueling. Standoff weapons also reduce the distance aircraft travel from the carrier to the combat radius limit of strike fighters, reducing the advantage resulting from the long-range UCAV.

238 The three alternative CVWs take 73 spots, using the Navy's standard of one spot equaling the space needed for a F/A-18 A-D Hornet.

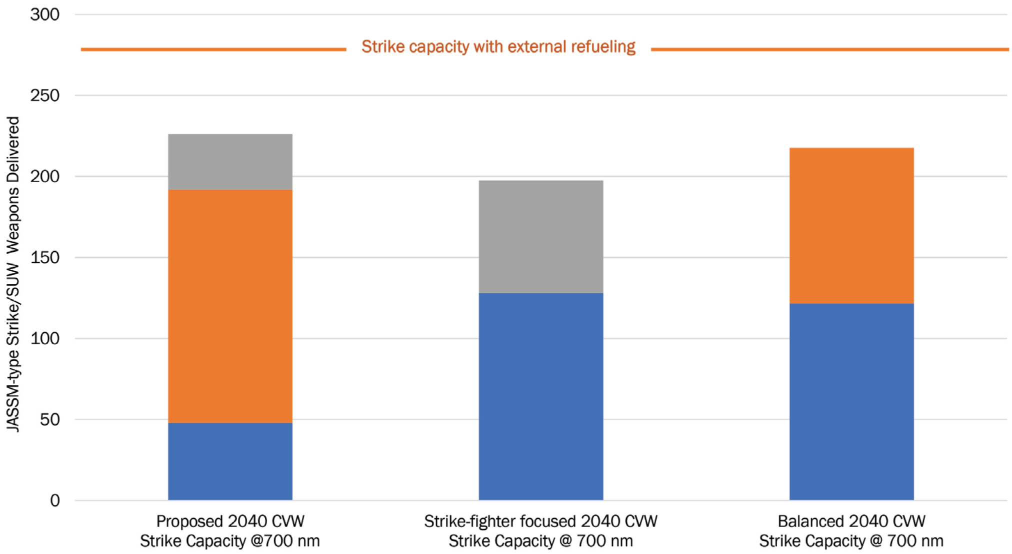
239 To reduce the impact of F/A-18 E/Fs on long-range CVW capacity, the following mission analysis assumes that F/A-18 E/Fs and the future FA-XX fighter are both able to conduct refueling operations using buddy tanks and that F-35Cs are used for OCA and escort operations in support of strikes when FA-XXs are needed as tankers. This approach was chosen because of the potential for the FA-XX to be an F/A-18 E/F derivative, whereas the F-35C does not have this capability today and is not envisioned as having it in the future.

240 Each UCAV, fighter, and strike fighter can carry eight JASSM-like weapons internally and externally for a total payload of 16,000 lb.

241 Each UCAV, fighter, and strike fighter can carry four AARGM or AAM weapons internally.

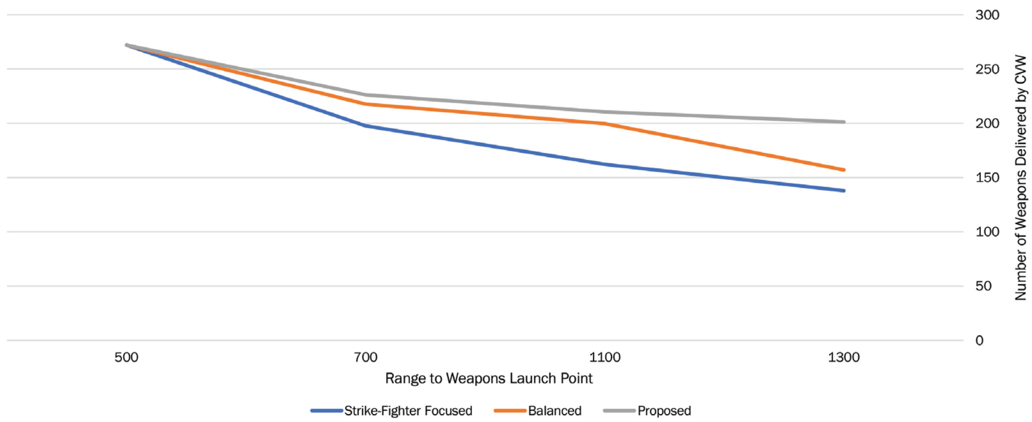
To maximize the number of strike aircraft reaching the 700 nm launch point, all the CVWs needed F/A-18 E/Fs with refueling tanks to augment MQ-25X or UCAV-based tankers, which reduced their total strike capacity. If external refueling were used instead of F/A-18 E/Fs, all the CVWs would have been able to deliver 272 weapons, as shown by the line on Figure 63.

FIGURE 63: NUMBER OF JASSM-TYPE WEAPONS DELIVERED BY PROPOSED AND ALTERNATIVE CVWS AT 700 NM FOR SUW OR STRIKE



The strike capacity of the three CVWs is relatively similar at 700 nm, but diverges significantly as range increases. Figure 64 depicts the number of weapons that can be delivered by each CVW in the above scenario at various ranges, again assuming only organic CVW tankers are used for refueling operations. Beyond 700 nm, the approximate combat radius of CVW strike fighters, refueling requirements rapidly reduce the strike capacity of the balanced and strike fighter-focused CVWs. This effect is driven by the repurposing of additional F/A-18 E/Fs from strike to refueling missions. When all the available MQ-25s and F/A-18 E/Fs are in use for refueling, they begin conducting multiple refueling operations, dramatically reducing their efficiency. As a result, insufficient tanking for F-35Cs prevents the balanced CVW from exploiting its greater low observable strike capacity at longer ranges.

FIGURE 64: NUMBER OF JASSM-TYPE WEAPONS DELIVERED BY PROPOSED AND ALTERNATIVE CVWS FOR SUW OR STRIKE AT VARIOUS RANGES



These findings suggest that if long-range operations are anticipated, the Navy should reconfigure CVWs to include more multi-mission refueling aircraft or F/A-18 E/Fs and fewer F-35Cs.[242] Although the F-35C is a more capable C4ISR platform with greater stealth than the F/A-18 E/F, without sufficient tankers not all F-35Cs can reach relevant ranges and employ their capabilities.

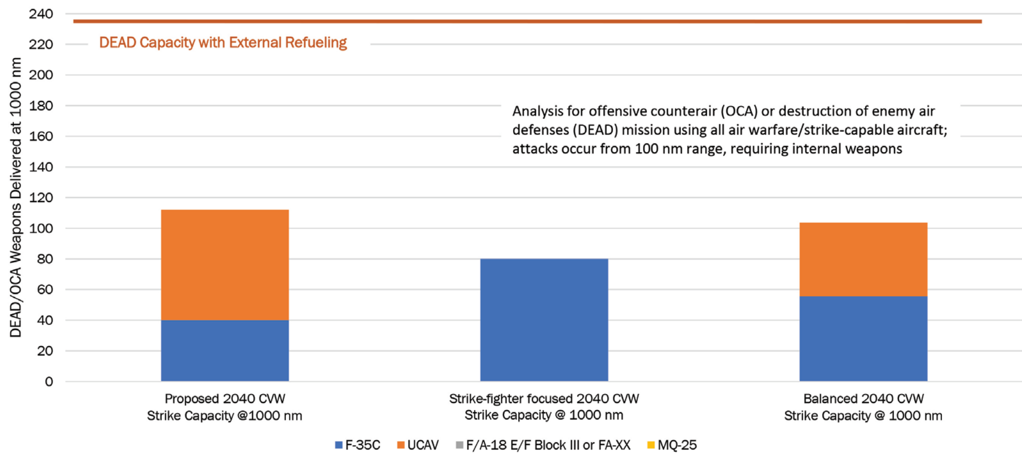
OCA and DEAD Mission Comparison

The longer range of the OCA/DEAD scenario also results in divergence of attack capacity between the three CVWs, shown in Figure 65. Although it may seem counterintuitive, OCA/DEAD capacity is not affected by the potential inability of F/A-18 E/Fs to closely approach targets because of their external weapons and consequently higher signature. As in the strike/SUW example above, longer range requires all F/A-18 E/Fs to be used for refueling. Even if they were equipped with a weapons pod that could reduce the aircraft's signature and enable close-in DEAD engagements, F/A-18 E/Fs were more effectively employed to increase the overall DEAD capacity of the CVW.[243] If external refueling were available and all strike fighters in the CVWs were able to carry internal weapons, the DEAD capacity of all the CVWs would be 228 weapons, as shown by the line on Figure 65.

242 Refueling platforms would include FA-XX in this analysis, because they are assumed to be capable of buddy tanking like today's F/A-18 E/Fs.

243 Boeing has developed an Advanced Super Hornet version of the Block III F/A-18 E/F that includes an enclosed weapons pod. See Valerie Insinna, "How Stealthy is Boeing's New Super Hornet?" *Defense News*, April 8, 2018, available at https://www.defensenews.com/digital-show-dailies/navy-league/2018/04/09/how-stealthy-is-boeings-new-super-hornet/.

FIGURE 65: NUMBER OF AARGM-TYPE WEAPONS DELIVERED BY PROPOSED AND ALTERNATIVE CVWS AT 1,000 NM FOR CLOSE-IN DEAD ATTACK (INTERNAL WEAPONS ONLY)



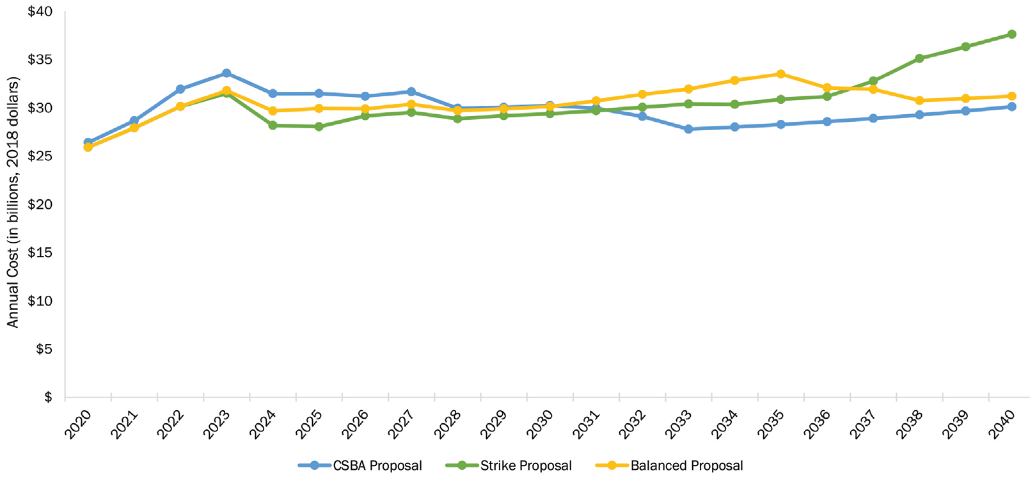
Cost Comparison

The costs of the alternative CVWs, shown in Figure 66, show that the proposed CVW is the least expensive long-term option. The proposed CVW costs a total of $626.1 billion from FY 2020 to FY 2040, compared to $642.0 billion for the strike fighter-focused CVW and $642.5 billion for the balanced CVW.[244] In part, the lower cost of the proposed CVW results from recapitalizing older aircraft as they reach their end of service life, rather than extending their service lives, funding higher maintenance costs for the aging aircraft, and recapitalizing them later. Because of this recapitalization, the proposed CVW has the highest total cost of the three CVWs during the first half of the 2020–2040 period, reflecting the procurement and standup of new V(U)A UCAV and VRC refueling squadrons. This higher cost is mitigated by the lower operations and sustainment costs for new aircraft relative to aging and life-extended strike fighters in the balanced and strike fighter-focused CVWs.

The other reason the proposed CVW is less expensive than the alternatives is its greater percentage of unmanned aircraft. As noted above, fewer unmanned aircraft are needed overall compared to manned aircraft because simulators can be used for most operator training and qualification. Furthermore, CVWs only require unmanned aircraft during the later phases of pre-deployment preparations. As a result, the proposed CVW has lower overall procurement costs than the other CVWs.

244 All costs are in FY 2018 dollars.

FIGURE 66: TOTAL COST FOR THE THREE ALTERNATIVE CVWS, INCLUDING PROCUREMENT, OPERATIONS AND MAINTENANCE, AND PERSONNEL



Conclusion

The proposed 2040 CVW would improve the ability of carriers and CVWs to conduct operations needed to support America's emerging national and operational strategies. Without significant changes to the reach and survivability of CVW aircraft, the joint force will be unable to promptly deny, degrade, or delay great power aggression; sustain peripheral operations against great powers; or counter opportunistic aggression by regional powers during a great power confrontation.

The aircraft in the proposed CVW all exist, are in development, or are derived from existing aircraft. As a result, the proposed future CVW could be in place by 2040. If that objective is not achievable, the operational concepts of Chapter 4 remain valid, and the Navy's planned CVW aircraft could execute them with ISR&T and refueling support from the joint force.

CHAPTER 6

Conclusion and Recommendations

The sustainability, persistence, and firepower of naval forces make them integral to future U.S. military posture and strategy as described in the 2018 NDS. Denying, degrading, or delaying great power aggression, however, will require that the U.S. fleet be able to counter the large number of capable precision weapons Russian or Chinese forces could launch at U.S. ships. Overcoming this central operational challenge will require future naval operations to occur from greater standoff ranges where the threat density is lower; increasing the air defense capacity of naval groups such as SAGs and CSGs; engaging enemy weapons platforms before they can launch ASCMs or ASBMs; and retaining sufficient capacity for offensive operations against a great power aggressor.

Current and planned Navy CVWs do not have the capability or capacity to support joint force efforts to counter aggression. They lack the reach to operate at sufficient ranges from operational areas; the stealth to fight in contested environments; and the specialized capabilities in ISR&T, EMW, and ASW needed to defeat adversary platforms and systems. The changes to CVW posture, missions, operational concepts, and capabilities proposed in this report would allow CVWs to complement ship- and shore-based air defenses and conduct offensive operations to defeat enemy forces. The research and development, procurement, and organizational actions needed to implement these changes, described below, will likely require significant funding and take two decades to fully field. Without them, carrier aviation will not be able to contribute to the joint force's most pressing operational needs, and Navy leaders should reconsider whether to continue investing in carriers and carrier aviation.

The following programmatic recommendations assume the Navy reactivates a tenth CVW to support a fleet of twelve CVNs. Although the fleet will not always have twelve CVNs, the additional CVW will be needed to support the periods when a twelfth carrier is operational, and it will afford additional flexibility in apportioning aircraft to deployed CVWs.

Building the Proposed 2040 CVW

Transforming today's CVW into the proposed CVW by 2040 will require significant changes to the Navy's aviation programs, especially in terms of its strike fighter procurement. Today, the Navy is experiencing an increasing shortage of strike fighters due, in part, to delays in fielding the F-35C, which was originally intended to replace F/A-18 C/Ds by 2026.[245] The overuse of F/A-18 C/Ds in operations over the Middle East for the last two decades led to some being retired early, and the rest are now expected to leave the fleet between 2017 and 2020.[246] The F-35C, however, will not be ready for CVW deployments until FY 2019, mostly due to delays in the development of the Block 3F software needed to launch relevant Navy weapons.[247] The Navy is also using F/A-18 E/Fs more than expected to support aerial refueling operations, resulting in some older F/A-18 E/Fs entering a service life extension program that further reduces strike fighter inventories.[248]

The Navy plans to buy 110 F/A-18 E/Fs beyond its original inventory objective between FY 2019 and FY 2023 to restore strike fighter inventories; this is in addition to 97 F-35Cs.[249] The new F/A-18 E/Fs and the Navy's existing inventory of F/A-18 E/Fs will also be upgraded to the new Block III configuration, which provides 100 nm to 150 nm greater range and a lower radar signature compared to today's Block II F/A-18 E/Fs.[250] The Navy plans for CVWs to eventually include 24 F/A-18 E/Fs and 20 F-35Cs, but shortly after it reaches this configuration in the early 2030s, the oldest F/A-18 E/Fs will begin to retire and be replaced by the FA-XX.[251]

The Navy is finishing a long-term recapitalization of other aircraft types, reducing options to modify production and harvest the savings for new aviation programs. Procurement of MH-60s ended in FY 2017, and P-8As and E-2Ds will reach their inventory objectives in FY 2019 and FY 2023, respectively. Although not formally part of the CVW, the Navy is buying CMV-22B aircraft to replace C-2As as they retire during the 2020s.[252]

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245 U.S. Navy, *Naval Aviation Vision: 2016–2025*, p. 59.

246 David Larter, "US Navy to Scrap Scores of Fighter Jets from Its Inventory," *Defense News*, March 6, 2018, available at https://www.defensenews.com/naval/2018/03/06/navy-to-scrap-scores-of-fighter-jets-from-its-inventory/.

247 F-35 Lightening II Program Office, *F-35 Lightning II Joint Strike Fighter (JSF) Program (F-35)*, SAR (Arlington, VA: DoD, December, 2016), p. 15, available at https://fas.org/man/eprint/F-35-SAR-2018.pdf.

248 Sam LaGrone, "First Super Hornet Inducted Into Service Life Extension Program," *USNI News*, April 6, 2018, available at https://news.usni.org/2018/04/06/first-super-hornet-inducted-service-life-extension-program.

249 Travis Tritten, "Navy, Marines Fighter Jet Shortfall May Top 100 Aircraft," *Washington Examiner*, March 28, 2017, available at https://www.washingtonexaminer.com/navy-marines-fighter-jet-shortfall-may-top-100-aircraft; Office of Budget, *Highlights of the Department of the Navy FY 2019 Budget*, p. 4-5; and Dave Majumdar, "This Is What Congress is Going to Do to Halt the Navy's Strike Fighter Shortfall," *The Buzz* blog, The National Interest, June 27, 2017, available at http://nationalinterest.org/blog/the-buzz/what-congress-going-do-halt-the-navys-strike-fighter-21351.

250 Sydney J. Freedberg Jr., "Navy, Boeing Tout Block III Super Hornet as Partner for F-35," *Breaking Defense,* May 23, 2018, available at https://breakingdefense.com/2018/05/navy-boeing-tout-block-iii-super-hornet-as-partner-for-f-35/.

251 Insinna, "Speed and Range Could be Key."

252 Office of Budget, *Highlights of the Department of the Navy FY 2019 Budget*, p. 4-5.

To reach the proposed CVW by 2040, this study recommends the following actions, starting with the President's Budget for FY 2020:

- Sustain procurement of F/A-18 E/Fs as planned through 2023. Although the future CVW requires half the strike fighters of the Navy's planned CVW, these aircraft will fill near- to mid-term capacity gaps. F/A-18 E/Fs still in service by 2040 can be used in place of UCAVs or F-35Cs if those aircraft are not yet fully fielded. Another reason to sustain procurement of F/A-18 E/Fs is to address the increasing cost of maintaining older aircraft. The planned service life of a new or modernized Block III F/A-18 E/F is 9,000 flight hours, and CVW strike fighters fly an average of 400 hours a year, resulting in a 20-year replacement cycle. Beyond 20 years, the cost to maintain older aircraft for another 5–10 years may exceed the cost of replacing them with new aircraft that have 20 years of more reliable service life.[253]

- Sustain F-35C procurement as planned through the first half of production, ending in 2024, to support the proposed 2040 CVW's squadron of ten F-35Cs.

- Develop the FA-XX fighter during the 2020–2024 timeframe as a derivative of an existing aircraft, with production starting in 2025. Block III F/A-18 E/Fs and F-35Cs will be in production during the FY 2020–2024 FYDP, and either they or another in-production fighter or strike fighter could be modified into an FA-XX. Although this approach will require some additional funding for non-recurring engineering between about 2020 and 2024, it will save billions of dollars in the Navy's planned funding to develop a new fighter aircraft from scratch.

- Develop a low observable UCAV attack aircraft as described in Chapter 5 during the 2020–2024 timeframe, with production starting in 2025. Although the UCAV could be based on an existing design such as the X-47B, 1–2 years of development may be needed to create a missionized version. If this development effort starts in 2020, low-rate production should be able to start by 2025. Although fiscal and industrial base constraints may prevent reaching 200 UCAVs by 2040, the CVW of the mid-2030s will have a significant number of UCAVs. The rest of the attack aircraft can consist of F/A-18 E/F strike fighters still in service.

- Continue development of the MQ-25 and increase the overall procurement of refueling aircraft to support twelve per CVW. The Navy should also develop a refueling variant of the UCAV attack aircraft described above for production in the mid to late-2030s once sufficient attack UCAVs are fielded.

- Retire E/A-18Gs as they reach their end of service life during the 2030s, replacing their capability with EMW UAV and missile expendables and NGJ-equipped UCAVs.

253 LaGrone, "First Super Hornet Inducted"; and FAA, *Aircraft Capacity and Utilization Factors*, p. 3-21.

- In concert with the U.S. Marine Corps, field a MALE rotary-wing UAV such as TERN, which can augment CVW helicopter squadrons and could take over some of their ASW operations by the mid-2030s. Because the MALE UAV would be an augmentation to existing ARG and CSG capabilities, the number of aircraft procured would be flexible, although two to three per operational CVW (or 12–18 total) may be sufficient initially.

Cost and Schedule

Fully implementing these changes will likely take two decades or more. Figure 67 shows how Navy carrier aircraft inventory would evolve to implement the proposed CVW by 2040. Procurement of new aircraft starts in 2025, after the Navy plans to finish procurement of F/A-18 E/Fs and the first half of F-35Cs. The build plan reflected by Figure 67 accounts for likely industrial base constraints and assumes development of the new UCAV and FA-XX could occur between 2020 and 2024. The only other aircraft being developed during this timeframe is the MQ-25, which should permit funding and design capacity to be available for the FA-XX and UCAV.

The overall inventory of CVW aircraft would decrease between 2020 and 2040 as unmanned aircraft replace today's manned strike fighters and AEA aircraft. Operators and maintainers of unmanned aircraft can practice using simulators that will be as realistic as actual UAVs, eliminating the need for unmanned aircraft in training squadrons or in fleet squadrons that are not deployed or preparing to deploy. The smaller number of aircraft and squadrons results in a cost savings for unmanned aircraft compared to manned aircraft.

FIGURE 67: INVENTORY OF NAVY FIXED-WING CVW AIRCRAFT TO IMPLEMENT PROPOSED 2040 CVW

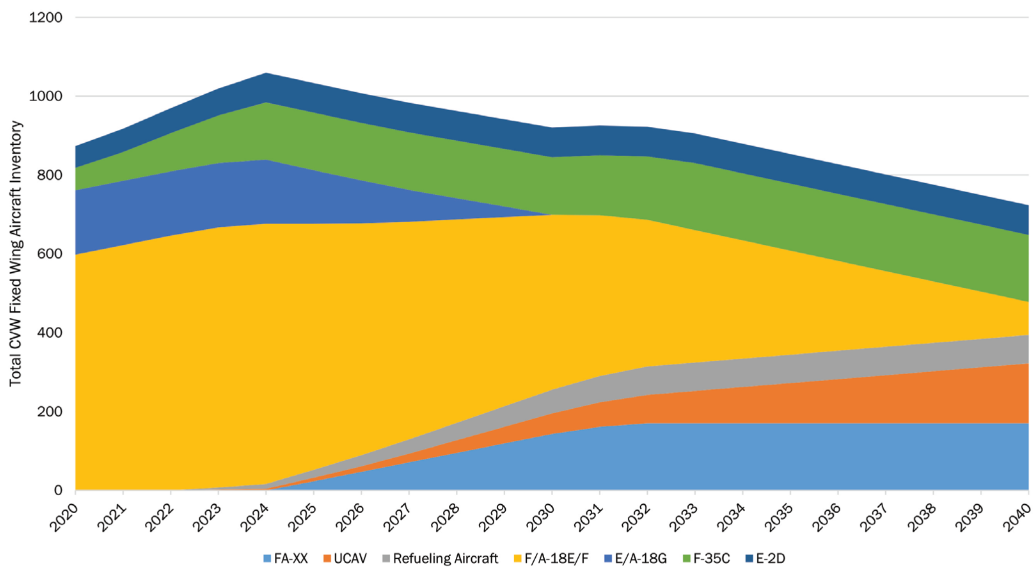


Figure 68 depicts the cost of the proposed 2040 CVW by appropriation category, including RDT&E, procurement, O&M, and personnel. RDT&E costs reflect the cost of developing the UCAV and FA-XX, which is less expensive and takes less time than the Navy's current plan for developing FA-XX alone. Procurement is weighted toward the first half of the 2020–2040 period as new aircraft are brought into service, and then decreases because these aircraft will not need to be recapitalized until the late 2040s. O&M and personnel costs increase as aircraft become older and more types of aircraft join the CVW. The increase, however, is tempered by the retirement of existing CVW aircraft such as the F/A-18 C/D, F/A-18 E/F, and E/A-18G.

Figure 69 shows the same costs as Figure 68, but broken down by aircraft type. The costs for new programs such as the UCAV and MQ-25 increase as more aircraft and squadrons are fielded. Because it essentially replaces the second half of F-35C production, the FA-XX program is combined with the F-35C program, and the personnel and O&M associated with the second half of F-35Cs shifts to FA-XX. The costs for E-2D and MH-60 R/S aircraft programs are assumed to grow with inflation.

FIGURE 68: COST OF NAVY CARRIER AVIATION BY APPROPRIATION CATEGORY

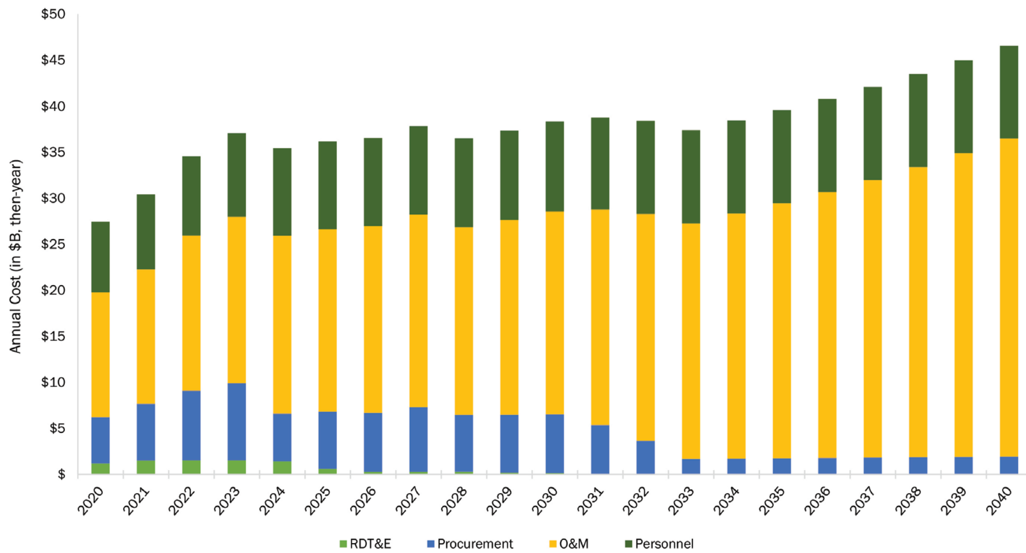
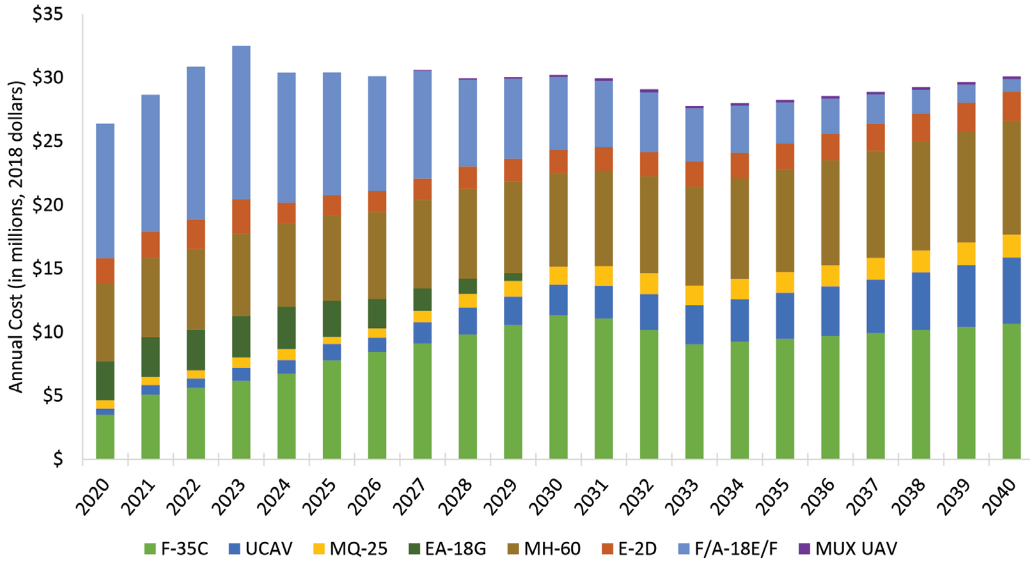


FIGURE 69: TOTAL COST OF NAVY CARRIER AVIATION BY AIRCRAFT TYPE/MODEL/SERIES



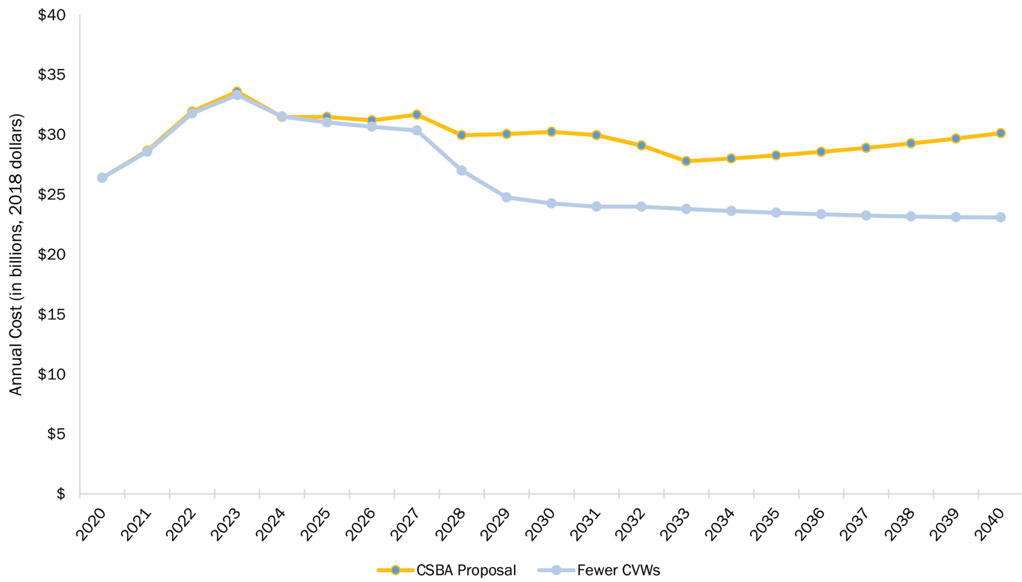
Cost Savings from Reducing the Carrier Fleet

The Navy is facing budget constraints in the near term due to growing budget deficits and spending caps imposed by the Budget Control Act of 2011.[254] These challenges, however, should not prevent Navy leaders from pursuing improvements to CVWs that make them relevant to future warfare. Opting to save money by sustaining today's strike fighter-focused CVWs, rather than developing needed new aircraft, will prevent CVWs from contributing to a growing range of operations during an era of great power competition.

To free up funding to evolve its CVWs, the Navy could reduce the number of carriers and CVWs. Figure 70 shows the cost to implement the proposed CVW as ten CVWs for twelve carriers, as compared to eight CVWs for ten carriers. As the figure indicates, cost savings from eliminating two CVWs are almost entirely realized in the second half of the 2020–2040 period because reductions in aircraft procurement are taken from the end of the program. Alternatively, procurement could be slowed to save costs in the near term. The resulting savings, however, would likely be modest. Development costs will be unchanged, and the procurement cost per aircraft will likely rise because manufacturers will gain less proficiency in construction and be less able to buy parts and materials in economic quantities.

254 Mehta, "Trump Appears to Call for Defense Spending Cuts."

FIGURE 70: COMPARISON OF COSTS TO IMPLEMENT PROPOSED 2040 CVW IN EIGHT CVWS VS. TEN CVWS



Reducing the number of carriers and CVWs would generate other savings that could help enable the remaining CVWs to evolve to better address great power competition. Operations, maintenance, and personnel for a *Nimitz*-class carrier cost about $726 million per year.[255] As shown in Figure 68, O&M and personnel for each CVW is about $1.8 billion per year. Although not all these costs would be harvested by eliminating 2 CVWs, enough savings would be realized in the near term to offset the RDT&E and procurement associated with new aircraft in the proposed CVW.

Conclusion

The proposed 2040 CVW will cost more than Navy's planned CVW, but the Navy may have no choice but to incur these additional costs or decide to relegate carrier aviation to a niche capability dedicated to permissive operations against less stressing threats. The challenges posed by great power competitors and increasingly by regional powers such as Iran and North Korea preclude relying on legacy capabilities to protect American allies and interests overseas. Naval forces are needed for these operations as described in the new U.S. national and defense strategies, and carriers and their air wings provide the ability to sustain naval combat operations beyond the first few days, once standoff missile inventories are depleted. Without a clear plan to improve the Navy's CVWs, the United States may not be able to implement its strategies and would need to reduce its commitments and engagements overseas.

255 PEO, Aircraft Carriers, *Gerald Force Class Carrier*, p.73.

APPENDIX A

CVW Database Sources and Methodology

Methodology

Which Carriers at What Time: Since most carrier air wings are not deployed at any given time, and carrier air wings that are not deployed may not be at full strength, accurately measuring changes in CVWs since before World War II required CSBA to follow one deployed aircraft carrier at a time and its compliment at any particular point in the year approximately every three years. In the event a carrier was occasionally not deployed in a particular year, retiring, or going down for multi-year maintenance, an analogous carrier (similar class or composition) was chosen as a substitute. In the event no substitute or no deployments existed for that year, an adjacent year was used.

Data on Squadron Size: In 1942 and from 1957–1988, data on the types of aircraft in a CVW and the sizes of their squadrons are known exactly. In 1938, 1945, 1950, and 1953, and from 1991 to the present, the numbers of aircraft in each squadron are either notional, based on historical writings, cruise book mentions, or inferences based on practices in prior years (i.e., E-2 squadron size was almost aways four until the ongoing introduction of the E-2D increased it to five); the squadrons and the airframes flown by CVWs are known. Data on the 2021 CVW composition on USS *Carl Vinson* (CVN-70)—the first CVW to receive a deployed squadron of F-35Cs—are inferences based on current Navy plans. The proposed 2040 CVW is a suggested air wing composition by CSBA. The strike fighter-focused 2040 CVW is an extrapolation of current Navy plans, while the balanced 2040 CVW is an extrapolation of Navy plans with more unmanned aircraft. The aircraft characteristics of the notional future aircraft in these three 2040 CVWs are based on the F-22, the GA-ASI Sea Avenger, and the X-47B.

Carrier Onboard Delivery (COD): COD aircraft like the C-1 Trader, C-2 Greyhound, and the CMV-22B are not included in the CVW database because they are not permanently aboard the carrier during its deployment. Aircraft with both a COD and another mission that are permanently based on the carrier are included.

HSM and HSC Squadron Sizes: Since many of the MH-60Rs in Helicopter Maritime Strike (HSM) and MH-60Ss in Helicopter Sea Combat (HSC) squadrons in the CVW are spread throughout the CSG rather than on the carrier, CSBA only counted those based onboard the carrier. For the current and future HSMs and HSCs, CSBA estimates that five of eleven MH-60Rs and six of the eight MH-60Ss are housed on the carrier, with the rest in the CSG.

Spot Factor: The exact spot factors of various carrier aircraft are not publicly available; CSBA approximated carrier aircraft spot factors by comparing the area created by multiplying the aircraft's length by its wingspan to that of an F/A-18 A-D Hornet. If the aircraft's wings fold, then its folded wingspan was used. If the aircraft was a helicopter, then its rotor length was used as its width.

Fuel Weight: When exact weight of fuel in lbs was unknown but capacity of fuel in gallons was known, the number of gallons of fuel were multiplied by 6.78 to approximate fuel weight in lbs.

Combat Range: Listed combat ranges are the highest ranges attainable using internal fuel only for any combat loadout with a meaningful payload (500 lbs or above) in that aircraft's Selected Aircraft Characteristics (SAC). If that aircraft did not have a SAC, then the number was attained through other sources.

Year-by-Year CVW Composition Sources

(1) "Allowances and Locations," Naval History and Heritage Command: https://www.history.navy.mil/research/histories/naval-aviation-history/allowances-and-location.html.

(2) "Carrier Air Wing Deployments and Composition, 1991–2005," Naval History and Heritage Command, August 7, 2017: https://www.history.navy.mil/research/histories/naval-aviation-history/carrier-air-wing-deployments.html.

(3) Mark L. Evans and Roy A. Grossnick, *United States Naval Aviation 1910–2010*, volume II, *Part V: Deployments* (Washington, DC: Naval History and Heritage Command, 2015): https://www.history.navy.mil/content/dam/nhhc/research/publications/1910/Part5.pdf.

(4) "US Navy Cruise Books," Unofficial US Navy Website: https://www.navysite.de/cruisebooks/.

(5) Norman Friedman, *U.S. Aircraft Carriers: An Illustrated Design History* (Annapolis, MD: U.S. Naval Institute, 1983).

(6) Bradley Martin and Michael E. McMahon, *Future Aircraft Carrier Options* (Santa Monica, CA: RAND Corporation, 2017): https://www.rand.org/content/dam/rand/pubs/research_reports/RR2000/RR2006/RAND_RR2006.pdf.

1938, USS *Saratoga* (CV-3): (5), p. 13.

1942, USS *Yorktown* (CV-5): John B. Lundstrom, *The First Team: Pacific Naval Air Combat from Pearl Harbor to Midway* (Annapolis, MD: U.S. Naval Institute, 1984), p. 301.

1945, USS *Lexington* (CV-16): (5), p. 16; and Thomas P. Ehrhard and Robert O. Work, *Range, Persistence, Stealth, and Networking: The Case for a Carrier-Based Unmanned Combat Air System* (Washington, DC: Center for Strategic and Budgetary Assessments, 2008).

1950, 1953, USS *Princeton* (CV-37): (5), p. 21; and (3).

1957, USS *Saratoga* (CV-60), substituting for USS *Forrestal*: (1).

1960–1981 (except for 1969), USS *Forrestal* (CV-59): (1).

1969, USS *Enterprise* (CVN-65), substituting for USS *Forrestal*: (1).

1984, USS *Dwight D. Eisenhower* (CVN-69): (1); and "USS *Dwight D. Eisenhower* (CVN-69), Mediterranean Cruise, 1984-1985," from (4).

1988, USS *Dwight D. Eisenhower* (CVN-69): (1).

1991, USS *Dwight D. Eisenhower* (CVN-69): (1); and "USS *Dwight D. Eisenhower* (CVN-69), Mediterranean Cruise, 1990," from (4).

1993–2008, USS *Theodore Roosevelt* (CVN-71): (3); (2); and "USS *Theodore Roosevelt* (CVN-71), Mediterranean and Arabian Sea Cruise, 2008," from (4).

2011, 2014, USS *George Washington* (CVN-73): "USS *George Washington* (CVN-73), WestPac Cruise, 2011," and "USS *George Washington* (CVN-73), WestPac Cruise, 2014," from (4). Data on the MH-60R and MH-60S come from (6).

2018, USS *Ronald Reagan* (CVN-76): "CVW-5 (NF)/USS *Ronald Reagan* (CVN 76) (Aug. 2015–Present)," *GoNavy.jp*, updated December 12, 2018: http://www.gonavy.jp/CVW-NF6f.html. Data on the MH-60R and MH-60S come from (6). Increased regular E-2 squadron size confirmed by Sydney J. Freedberg Jr., "E-2D Hits IOC; Navy Hawkeye Gets Larger, Lethal Role," *Breaking Defense*, October 17, 2014: https://breakingdefense.com/2014/10/e-2d-hits-ioc-navy-hawkeyes-larger-more-lethal-role/.

2021, USS *Carl Vinson* (CVN-70) Squadrons and their aircraft assumed to be the same as the 2018 CVW, but with the last squadron of F/A-18Cs on USS *Carl Vinson* replaced by one squadron of ten F-35Cs. Ben Werner, "Schedule at Risk for Navy F-35C Fighters to be Combat Ready by the End of Year," *USNI News*, March 29, 2018: https://news.usni.org/2018/03/29/current-schedule-risk-navy-f-35c-fighters-combat-ready-end-year.

Aircraft Specifications Sources:

"Performance Data"; "Airplane Characteristics & Performance"; "Standard Aircraft Characteristics"; etc. from the Bureau of Aeronautics, Navy Department and Naval Air Systems Command, various dates: www.alternatewars.com.

> SBD Dauntless; F4F Wildcat; F6F Hellcat; TBM Avenger; SB2C Helldiver; F4U Corsair; A-1 Skyraider; AD-4 Skyraider; Navy Model A-1E Aircraft F9F Panther; UH-25/HUP Retriever; F2H Banshee; F3H Demon; FJ-3 Fury; A-3 Skywarrior; A-4 Skyhawk; F-6 Skyray; F-8 Crusader; UH-2 Seasprite; A-7 Corsair II; A-6 Intruder; F-4 Phantom II; RA-5C Vigilante; E-2 Hawkeye; F-14A/B Tomcat; EA-6B Prowler; S-3A Viking; SH-3 Sea King; S-3B Viking; F-14D Tomcat; CH-53D Sea Stallion; UH-1N Huey

Maximum payload and external stores data from National Naval Aviation Museum website: http://www.navalaviationmuseum.org.

FJ-4 Fury; F4D Skyray; F-8 Crusader

TBD Devastator: "TBD Devastator, U.S. Carrier Torpedo Bomber," The Pacific War Online Encyclopedia: http://pwencycl.kgbudge.com/T/b/TBD_Devastator.htm.

H-5/HO3S-1: "S-48/R-5 Helicopter," Sikorsky Product History, Igor I. Sikorsky Historical Archives, September 7, 2012, http://www.sikorskyarchives.com/S-48(R-5).php.

F-4 Phantom II: Jerry Hendrix, *Retreat From Range: The Rise and Fall of Carrier Aviation* (Washington, DC: Center for a New American Security, October, 2015): https://www.files.ethz.ch/isn/194448/CNASReport-CarrierAirWing-151016.pdf.

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F/A-18A-D Hornet: "Boeing (McDonnell Douglas) F/A-18 Hornet," *Jane's Aircraft Upgrades*, July 18, 2018; and Eric Wertheim, *The Naval Institute Guide to Combat Fleets of the World*, 16th Edition (Annapolis, MD: U.S. Naval Institute, August 15, 2013)

SH-60 Seahawk; HH-60 Seahawk; MH-60S Seahawk; and MH-60R Seahawk: "Sikorsky SH-60/MH-60/S-70B Seahawk and Aegean Hawk/S-70C(M) Thunderhawk," *IHS Janes' Weapons: Naval*, April 30, 2008.

F/A-18E/F Super Hornet: "Standard Aircraft Characteristics: F/A-18E Super Hornet," Naval Air Systems Command, March, 2001; and "F/A-18 Hornet Strike Fighter," U.S. Navy Fact File, May 26, 2009.

F-35C Lightning II: "Lockheed Martin F-35 Lightning II," *Jane's All the World's Aircraft*, January 23, 2018; and "Selected Acquisition Report (SAR): F-35 Lightning II Joint Strike Fighter (JSF) Program (F-35)," Defense Acquisition Management Information Retrieval (DAMIR), December 2016.

EA-18G Growler: Wertheim, *The Naval Institute Guide to Combat Fleets of the World*.

FA-XX Fighter: Notional next-generation carrier air superiority fighter based off of "F-22 Specifications," Lockheed Martin Website, 2018: https://www.lockheedmartin.com/en-us/products/f-22/f-22-specifications.html.

UCAV: Notional next-generation long-range strike unmanned aerial vehicle based off of "X-47B UCAS: Unmanned Combat Air System," Northrop Grumman, 2015: http://www.northropgrumman.com/Capabilities/X47BUCAS/Documents/UCAS-D_Data_Sheet.pdf.

MQ-25 (GA-ASI): Notional specifications for MQ-25 based off of "GA-ASI Introduces Sea Avenger UAS for UCLASS Carrier Operations: Carrier-based Predator C Derivative Offers

Navy Low-risk Strike & Surveillance Solution," General Atomics Aeronautical Systems, Inc., *Press Release*, May 3, 2010: https://web.archive.org/web/20110711062821/http://www.ga-asi.com/news_events/index.php?read=1&id=285.

MALE UAV: Notional combat radius, combat range, and payload for MALE UAV based on Marine Corps' MUX Technical Requirements Brief. Notional spot factor based on the claim that it will have a similar footprint on deck to the UH-1Y Venom. William Collier, "MUX Technical Requirements Brief," United States Marine Corps, June 6, 2018: https://govtribe.com/project/request-for-information-marine-air-ground-task-force-magtf-unmanned-aircraft-system-uas-expeditionary-mux; and "Standard Aircraft Characteristics: Navy Model UH-1N Aircraft," Naval Air Systems Command, August, 1974.

APPENDIX B

Aircraft Numbers and Location

Aircraft	1938	'42	'45	'50	'53	'57	'60	'63	'66	'69	'72	'75	'78	'81	'84	'88	'91	'93	'96	'99	'02	'05	'08	'11	'14	'18	'21	2040
SBD Dauntless	36	36																										
TBD Devastator	18	16																										
F4F Wildcat	18	27																										
F6F Hellcat			36																									
TBM Avenger			15																									
SB2C Helldiver			15																									
F4U Corsair			37	30	14																							
F4U Corsair ISR variant				2																								
F4U-5N Corsair night fighter				3	3																							
A-1 Skyraider				15	15	14	12	13																				
A-1 Skyraider night attack (AD-4N)				2	2																							
Skyraider AEW/ASW variant (AD-4W)				3	3																							
Skyraider AEW/ASW variant (AD-5W)						7	7																					
F9F Panther				14	30																							
F9F Panther ISR variant					2																							
H-5/HO3S-1				2	2																							
UH-25/HUP Retriever						1	2	2																				
F2H Banshee						12																						
F2H Banshee ISR variant						3																						
F3H Demon						14																						
FJ-3 Fury																												
A-3 Skywarrior							10	12	6																			
EKA-3B Skywarrior ELINT/refueling variant										4	2																	
EA-3B Skywarrior ELINT variant															1													
A-4 (A4D) Skyhawk						12	24	24	43																			
F-6 (F4D) Skyray							13																					
F8U Crusader							14	12	8																			
F8U Crusader ISR variant							3	3	4																			
E-1 Tracer								7	4																			
UH-2 Seasprite									3	3																		
A-7 Corsair II										30	24	24	23	21	22	20												
A-6 Intruder										12	8	8	10	9	9	10	10	10										
KA-6 Intruder refueling variant											4	4	3	4	6	3	4											

Aircraft	1938	'42	'45	'50	'53	'57	'60	'63	'66	'69	'72	'75	'78	'81	'84	'88	'91	'93	'96	'99	'02	'05	'08	'11	'14	'18	'21	2040
F-4 Phantom II								11	10	27	24	23	20	21														
A-5 Vigilante ISR variant										4		3																
E-2 Hawkeye										4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	5	5	6
F-14A/B Tomcat															21	20	20	12	12		10							
EA-6B Prowler												4	4	4	4	3	4	4	4	4	4	4	4	4				
S-3A Viking													10	8	8	7	7											
SH-3 Sea King											7	8	5		6	7	7											
ES-3A Viking ELINT variant																			2									
S-3B Viking (Refueling, ASW/ASUW)																			10	9	9	9						
SH-60 Seahawk																		6	6	4	4	6	8	8				
HH-60 Seahawk																		2	2	2	2	2						
F-14D Tomcat																				20		20						
F/A-18C Hornet																	24	36	36	24	36	24	24					
CH-53D Sea Stallion (USMC Det.)																		6										
UH-1N Huey (USMC Det.)																		4										
F/A-18 E/F Super Hornet																							24	48	48	48	36	
MH-60S Seahawk																									6	6	6	6
MH-60R Seahawk																									5	5	5	5
FA-XX Fighter																												10
MQ-25 (GA-ASI)																												12
UCAV																												24
F-35C Lightning II																											10	10
EA-18G Growler																									5	5	5	
MALE UAV (MUX)																												2

APPENDIX C

Aircraft Specifications

Aircraft	Spot Factor (Factors of F/A-18C Hornets)	Combat Range (nm)	Combat Radius (nm)	Payload/ External Stores (lbs.)	Max Fuel (lbs.)	Internal Fuel (lbs.)	Specialized Status	Combat/Specialized Comparison	Mission Type
SBD Dauntless	0.87	1134	225	1600	2101.8	2101.8	Combat	Attack - ASUW	Attack - ASUW
TBD Devastator	0.54	622	175	2216	1220.4	1220.4	Combat	Attack - ASUW	Attack - ASUW
F4F Wildcat	0.27	721	325	2000	1762.8	976.32	Combat	Air Defense - Fighter	Air Defense - Fighter
F6F Hellcat	0.35	830	365	1000	3051	1695	Combat	Air Defense - Fighter	Air Defense - Fighter
TBM Avenger	0.50	952	435	2000	3627.3	2271.3	Combat	Attack - ASUW	Attack - ASUW
SB2C Helldiver	0.54	982	425	2000	3837.48	2169.6	Combat	Attack - ASUW	Attack - ASUW
F4U Corsair	0.37	730	285	2000	2841.6	1586.52	Combat	Multi-role	Multi-role
F4U Corsair ISR variant	0.37				2841.6	1586.52	Specialized	Specialized	ISR
F4U-5N Corsair night fighter	0.37	730	285	2000	2841.6	1586.52	Combat	Multi-role	Multi-role
A-1 Skyraider	0.62	726	510	8000	5880	2280	Combat	Attack - Strike	Attack - Strike
A-1 Skyraider night attack (AD-4N)	0.62	726	510	8000	5880	2280	Combat	Attack - Strike	Attack - Strike
Skyraider AEW/ASW variant (AD-4W)	0.62				5880	2280	Specialized	Specialized	AEW&C/ASW
Skyraider AEW/ASW variant (AD-5W)	0.62				5880	2280	Specialized	Specialized	AEW&C/ASW
F9F Panther	0.47	770	420	3465	6018	4578	Combat	Multi-role	Multi-role
F9F Panther ISR variant	0.47				6018	4578	Specialized	Specialized	ISR
H-5/HO3S-1	0.30				1254.3	1254.3	Specialized	Specialized	CSAR/Utility
UH-25/HUP Retriever	0.17				1017	1017	Specialized	Specialized	CSAR/Utility
F2H Banshee	0.43	790	540	1540	6662	5262	Combat	Multi-role	Multi-role
F2H Banshee ISR variant	0.43				6662	5262	Specialized	Specialized	ISR
F3H Demon	0.97	995	442	4000	9789	9789	Combat	Air Defense - Fighter	Air Defense - Fighter
FJ-3 Fury	0.55	860	560	1494	6521	3801	Combat	Specialized	Multi-role
A-3 Skywarrior	2.38	2600	1195	12800	29818	29818	Combat	Attack - Strike	Attack - Strike
EKA-3B Skywarrior ELINT/refueling variant	2.38				29818	29818	Specialized	Specialized	EW/Refueling
EA-3B Skywarrior ELINT variant	2.38				29818	29818	Specialized	Specialized	EW
A-4 (A4D) Skyhawk	0.70	890	590	5975	7480	5440	Combat	Attack - Strike	Attack - Strike
F-6 (F4D) Skyray	0.77	585	306	4000	6110	4160	Combat	Air Defense - Interceptor	Air Defense - Interceptor
F8U Crusader	0.79	1150	345	5000	8275	8275	Combat	Air Defense - Fighter	Air Defense - Fighter
F8U Crusader ISR variant	0.79				8275	8275	Specialized	Specialized	ISR
E-1 Tracer	0.88				4518	4518	Specialized	Specialized	AEW&C
UH-2 Seasprite	0.28				2684.88	1871.28	Specialized	Specialized	CSAR/Utility
A-7 Corsair II	0.71	2300	1435	15000	16320	10200	Combat	Attack - Strike	Attack - Strike
A-6 Intruder	0.90	2008	1380	18000	25984	15939	Combat	Attack - Strike	Attack - Strike
KA-6 Intruder refueling variant	0.90				25984	15939	Specialized	Specialized	Refueling

Aircraft	Spot Factor (Factors of F/A-18C Hornets)	Combat Range (nm)	Combat Radius (nm)	Payload/ External Stores (lbs.)	Max Fuel (lbs.)	Internal Fuel (lbs.)	Specialized Status	Combat/Specialized Comparison	Mission Type
F-4 Phantom II	1.04	1126	756	18000	22617	13505	Combat	Multi-role	Multi-role
A-5 Vigilante ISR variant	2.10				35360	24880	Specialized	Specialized	ISR
E-2 Hawkeye	1.07				12400	12400	Specialized	Specialized	AEW&C
F-14A/B Tomcat	1.54	1118	739	14500	20000	16200	Combat	Air Defense - Interceptor	Air Defense - Interceptor
EA-6B Prowler	0.96				25458	15423	Specialized	Specialized	EW
S-3A Viking	0.95						Specialized	Specialized	ASW
SH-3 Sea King	0.48						Specialized	Specialized	ASW
ES-3A Viking ELINT variant	0.95						Specialized	Specialized	EW
S-3B Viking (Refueling, ASW/ASUW)	0.95						Specialized	Specialized	ASW/Refueling
SH-60 Seahawk	0.28						Specialized	Specialized	ASW
HH-60 Seahawk	0.28						Specialized	Specialized	CSAR
F-14D Tomcat	1.54	1158	597	14500	20000	16200	Combat	Multi-role	Multi-role
F/A-18C Hornet	1.00	725	325	13,700	17,572	10,860	Combat	Multi-role	Multi-role
CH-53D Sea Stallion (USMC Det.)	0.32						Specialized	Specialized	USMC Airlift
UH-1N Huey (USMC Det.)	0.28						Specialized	Specialized	USMC CAS
F/A-18 E/F Super Hornet	1.28	1217	570	17,747	24595	14850	Combat	Multi-role	Multi-role
MH-60S Seahawk	0.28						Specialized	Specialized	CSAR/MCM
MH-60R Seahawk	0.28						Specialized	Specialized	ASW
FA-XX Fighter	0.99	1107	700	20,000	26000	18000	Combat	Air Defense - Fighter	Air Defense - Fighter
MQ-25 (GA-ASI)	0.94			15,000	27000	12000	Specialized	Specialized	Refueling
UCAV	0.77	3000	840	18,000	26000	18000	Combat	Multi-role	Multi-role
F-35C Lightning II	0.99	1600	640	18,000	19750	19750	Combat	Multi-role	Multi-role
EA-18G Growler	1.19	1217	665				Specialized	Specialized	EW
MALE UAV (MUX)	0.28	1300	525	9,000			Specialized	Specialized	ASW

LIST OF ACRONYMS

AAM	air-to-air missile
AARGM	Advanced Anti-Radiation Guided Missile
AAV	Amphibious Assault Vehicles
ACE	Air Combat Element
AEA	airborne electronic attack
AESA	active electronically scanned array
AEW	airborne early warning
AEW&C	airborne early warning and control
AI	artificial intelligence
AMD	air and missile defense
ARC	Adaptive Radar Countermeasures
ARG	Amphibious Ready Group
ASBM	anti-ship ballistic missile
ASCM	anti-ship cruise missile
ASW	anti-submarine warfare
ATR	autonomous target recognition
AWCFT	Algorithmic Warfare Cross Functional Team
BACN	Battlefield Adaptive Communications Network
BDA	battle damage assessment
BMD	ballistic missile defense
BWB	blended-wing-body
C2	command and control
C3	command, control, and communications
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CAP	combat air patrol
CAS	close air support
CEC	Cooperative Engagement Capability
COD	carrier onboard delivery
CRAW	Compact Rapid Attack Weapons
CSAR	combat search and rescue
CSBA	Center for Strategic and Budgetary Assessments
CSG	carrier strike group
CV	aircraft carrier
CVBG	carrier battle group
CVE	escort carrier
CVN	nuclear-powered aircraft carrier
CVS	anti-submarine carrier
CVW	carrier air wing

DARPA	Defense Advanced Research Projects Agency
DARWIN	Distributed Airborne Reliable Wide-Area Interoperable Network
DCA	defensive counterair
DE	destroyer escort
DEAD	destruction of enemy air defenses
DoD	Department of Defense
DPRK	Democratic People's Republic of Korea
EDM	Engineering Demonstration Models
EEZ	Exclusive Economic Zone
EMCO	electronic countermeasures officer
EMS	electromagnetic spectrum
EMW	electromagnetic warfare
EO	electro-optical
ESSM	Evolved Sea Sparrow Missile
EW	electronic warfare
FYDP	Future Year's Defense Plan
GEO	geosynchronous orbit
G-I-UK	Greenland-Iceland-United Kingdom
GLCM	ground-launched cruise missile
HALE	high-altitude long-endurance
HPM	high-powered microwave
HSC	Sea Combat Squadron
HSM	Maritime Strike Squadron
HVP	hypervelocity projectile
IADS	integrated air defense system
IAMD	integrated air and missile defense
IJN	Imperial Japanese Navy
IOC	initial operational capability
IR	infrared
IRBM	intermediate-range ballistic missile
IRST	infrared search and track
ISR	intelligence, surveillance, and reconnaissance
ISR&T	intelligence, surveillance, reconnaissance, and targeting
JASSM	Joint Air-to-Surface Strike Missile
JASSM-ER	Joint Air-to-Surface Strike Missile - Extended Range
JSOW	Joint Standoff Weapons
LACM	land-attack cruise missile
LCAC	Landing Craft Air Cushion
LCS	Littoral Combat Ship

LEO	low-earth orbit
LFA	low-frequency active
LHA/D	amphibious assault ship
LOS	line-of-sight
LPD	amphibious transport dock
LPI/LPD	low probability of intercept/low probability of detection
LRASM	Long-Range Anti-Ship Missile
LSD	amphibious landing dock
MAC	Multistatic Acoustic Coherent
MAGTF	Marine Air-Ground Task Force
MALD	Miniature Air-Launched Decoy
MALE	medium-altitude long-endurance
MANET	mobile ad hoc network
MCM	mine countermeasures
MEU	Marine Expeditionary Unit
MFTA	multifunction towed array
MPA	maritime patrol aircraft
MRBM	medium-range ballistic missile
MST	Maritime Strike Tomahawk
MUX	MAGTF UAS Expeditionary
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NDS	National Defense Strategy
NGAD	Next Generation Air Dominance
NGJ	Next Generation Jammer
NSS	National Security Strategy
O&M	Operations and Maintenance
OCA	Offensive Counterair
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
PB	President’s Budget
PLA	People’s Liberation Army
PLAAF	People’s Liberation Army Air Force
PLAN	People’s Liberation Army Navy
RAM	Rolling Airframe Missile
RDT&E	research, development, testing, and evaluation
REAM	Research’s Reactive Electronic Attack Measures
RF	radiofrequency
RFP	Request for Proposals

RoK	Republic of Korea
RWR	radar warning receiver
SAG	surface action group
SAM	surface-to-air missile
SAR	synthetic aperture radar
SBD	scout dive bomber
SDB	Small Diameter Bomb
SEAD	suppression of enemy air defenses
SEWIP	Surface EW Improvement Program
SHARC	Sensor Hosting Autonomous Remote Craft
SHiELD	Self-protect High Energy Laser Demonstrator
SHORAD	short-range air defense
SLBM	submarine-launched ballistic missile
SLOC	sea lines of communication
SOSUS	U.S. Sound Surveillance System
SSBN	nuclear ballistic missile submarine
SSGN	nuclear guided missile submarine
SSN	nuclear attack submarine
SSPK	single-shot probability of kill
SURTASS	Surveillance Towed Array Sensor System
SUW	surface warfare
TAW	tube-and-wing
TBD	torpedo bomber
TERN	Tactically Exploited Reconnaissance Node
TRAPS	Transformational Reliable Acoustic Path System
TTNT	Tactical Targeting Network Technology
UAV	unmanned aerial system
UAV	unmanned aerial vehicle
UCAS	Unmanned Combat Air System
UCAV	unmanned combat air vehicle
USV	unmanned surface vessel
UUV	unmanned undersea vehicle
VLA	vertical-launch anti-submarine rocket
VLS	vertical launch system
VPM	Virginia Payload Module
VTUAV	vertical takeoff unmanned aerial vehicle

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