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Electronic Warfare: EA-6B Aircraft Modernization and Related Issues for Congress

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Summary

Congress and the Department of Defense (DoD) face difficult and potentially costly choices when considering updating a key facet of the U.S. electronic warfare (EW) force structure. Presently, the Navy's EA-6B Prowler is the only airborne radar jamming system available to protect Navy, Marine Corps, and Air Force aircraft. The Prowler, though still capable, is aging and in short supply. Its retirement is scheduled for 2015.

There has been debate on how much EW is required to protect an aircraft force that increasingly incorporates stealth technology. However, recent operational experience suggests that future U.S. military aviation superiority will be best achieved by a combination of EW and stealth techniques. Indeed, the recent conflict in Kosovo reportedly indicates that the United States needs to augment the EA-6B force immediately to maintain its capability until a long-term replacement is found.

In the past, Congress has been a strong supporter of the EA-6B specifically, and EW in general. Congress has consistently increased the administration's request for EA-6B-related procurement funding over the last five years. The 106th Congress has exhibited continued support for EW by forming a Congressional Working Group and initiating a Joint Service Electronic Attack Analysis of Alternatives Study. In December 2001, this study is due to release its roadmap for replacing the EA-6B fleet specifically, and rejuvenating DoD's electronic attack capabilities in general.

Today and in the near future, Congress will face a variety of decisions about the size and composition of DoD's EW force structure. In the near-term, Congress faces decisions on how to maintain and modernize DoD's current active and passive EW force structure. The options Congress may consider to augment the present EW force include speeding up the planned EA-6B upgrade program, promoting the development and deployment of smart radar decoys, resurrecting some number of retired EF-111 radar jamming aircraft, and retroactively putting EW capabilities on aircraft other than the EA-6B. Congress will also be faced with overseeing DoD's choice of a permanent replacement for the EA-6B. The options include converting the F/A-18E/F Super Hornet, the F-15E Strike Eagle, the Joint Strike Fighter, the F-16CJ Fighting Falcon and the F-22 Raptor, using UAVs, or designing a new EW aircraft. There are a variety of criteria which can be used to measure the pros and cons of each aircraft. These criteria include the platform's unit cost, operations and maintenance considerations, whether or not the platform is "joint", and a variety of operational characteristics that will effect the platform's ability to escort aircraft strike packages in future threat environments.

Finally, Congress is faced with identifying the potentially high pay-off R&D pathways to future EW capabilities in the post 2020 timeframe. Considering the time that many DoD programs require to move from the drawing board to the field, it has been suggested that new EW technologies be investigated as soon as FY2001. Two potential future EW platforms that Congress may wish to investigate include networked, micro-UAVs (un-piloted air vehicles) and satellites.

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Introduction

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Congress and the Department of Defense (DoD) face difficult and potentially costly choices when considering updating a key facet of U.S. electronic warfare (EW) force structure. Presently, the Navy's EA-6B Prowler is the only airborne radar jamming system available to protect Navy, Marine Corps, and Air Force aircraft.[1] The Prowler, though still capable, is aging and in short supply. It is scheduled to leave the active inventory in 2015.

Congress will face a variety of decisions about the size and composition of DoD's EW force structure. In the near-term (to about 2010), Congress faces decisions on how to maintain and modernize DoD's current active and passive EW force structure. Recent experience in Kosovo has drawn attention to the EW mission area and the negative consequences of potential EW shortfalls. The EA-6B Prowler has been credited with effectively protecting allied aircraft during the 1999 air campaign. Yet, DoD found that they didn't have as many Prowlers as they required, nor were those aircraft particularly adept at destroying Serbian radar systems that employed deceptive tactics. Furthermore, there is a consensus in the intelligence community that the types of threats that airborne radar jammers are designed to counter will likely grow in the future.

Some options Congress may consider to improve EW capabilities in the near term include: (1) modernizing the EA-6B Prowler to improve its effectiveness and potentially extend its life; (2) improving EA-6B inventory management; (3) accelerating the development and production of electronic protection technologies, such as decoys; (4) bringing some number of EF-111 radar jamming aircraft out of retirement; (5) giving existing U.S. aircraft, such as the B-52 an EW capability to augment the Prowler fleet; (6) re-starting the EA-6B production line; (7) extending the EA-6B service life beyond its currently planned retirement date; and (8) converting existing A-6 aircraft into EA-6Bs.

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[1]In 1998 the Air Force retired the EF-111 Raven, its only EW jamming aircraft and the Prowler was designated a "joint asset." Also, most if not all U.S. military aircraft have some self-protection electronic countermeasures capability, which can include jamming and chaff dispensing.

In the mid-term (2010-2015) Congress will be faced with the need to replace the EA-6B aircraft. Due to the long development time lines of many DoD acquisition programs, Congress may wish to focus today on deciding which aircraft or platform is best suited to replace the EA-6B in the 2015 era. While many different options could be considered, most of the options now being evaluated would replace the EA-6B with another manned aircraft. DoD appears to be focusing on EW variants of Air Force aircraft such as the F-15, F-16, or F-22, the Navy's F/A-18E/F Super Hornet, the Joint Strike Fighter or some combination of these platforms. Building a new EW aircraft from scratch or developing an EW UAV are also possibilities to be assessed. Each of these aircraft have strengths and weaknesses in the EW realm, and Congress may likely wish to assess these qualitative, and sometimes elusive distinctions when deciding on acquisition programs measured in billions of dollars.

Finally, when considering how to best allocate near term research, development, test and evaluation (RDT&E) money, Congress may wish to examine current investment opportunities in EW that will likely pay dividends in and beyond the 2020 era. The most likely investment areas will be in networked micro-UAVs and space-based jammers. These investment areas offer risks and opportunities that aren't always obvious. Congress might therefore survey these technology areas to identify potentially high payoff pathways for today's EW R&D.

Background

Brief Overview of Electronic Warfare

The Department of Defense defines Electronic Warfare as "Any military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy.... The three major subdivisions within electronic warfare are: electronic attack, electronic protection, and electronic warfare support."[2] This report will focus on the electronic attack facet of electronic warfare – specifically, electronic attack against enemy radars. However, the three EW sub-elements are mutually supporting (as evidenced by the fact that the EA-6B jamming aircraft employs EW self protection systems and is an important consumer of electronic warfare support information) and are intimately linked. References will be made to electronic warfare support and electronic protection throughout this report as needed. Brief descriptions of electronic warfare support, electronic protection, and electronic attack follow.

Electronic Warfare Support. Several systems contribute to DoD's electronic warfare support efforts – "that division of electronic warfare involving actions tasked by, or under direct control of, an operational commander to search for, intercept, identify, and locate sources of intentional and unintentional radiated electromagnetic energy for the purpose of immediate threat recognition (JCS Pub 1-02)." In other words, electronic warfare support is a passive activity, that intercepts enemy signals, locates them and analyzes them so they can be exploited by other

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[2]JCS Pub. 1-02: DoD Dictionary of Military and Associated Terms. U.S. Department of Defense. [http://www.dtic.mil/doctrine/jel/doddict/]

users. Several DoD systems contribute to this mission area. The EP-3E Aries, for instance, provides indications and warning for the Naval Battle Group commander. The USAF RC-135V/W Rivet Joint surveillance aircraft are also equipped with an extensive array of sophisticated intelligence gathering equipment that monitors the electronic activity of adversaries. Using Rivet Joint data, analysts can precisely locate, record, and analyze much of what is being done in the electromagnetic spectrum.

Electronic Protection. Electronic protection involves actions to protect personnel, facilities, and equipment from any effects of friendly electromagnetic emissions or enemy employment of electronic warfare that degrade, neutralize, or destroy friendly combat capability. Radar homing and warning receivers that are organic to every modern military aircraft are an example of an electronic protection system. Chaff and decoys are other important and ubiquitous electronic protection systems. Chaff is thin, narrow metallic strips of various lengths and frequency responses dispensed from aircraft and used to reflect radar echoes and confuse the enemy. Decoys are more advanced countermeasures. They are small devices that emit signals that emulate a manned aircraft's signal and thus actively draw an enemy missile to it. Decoys can be towed behind aircraft, expended from aircraft to lure a threatening missile, or launched early-on to fly tactical missions in an autonomous mode.

Electronic Attack. Electronic attack is broadly defined as that aspect of electronic warfare involving the use of electromagnetic, directed energy, or anti-radiation weapons to attack personnel, facilities, or equipment to degrade, neutralize, or destroy enemy combat capability. Anti-radiation weapons differ from other air-to-surface weapons primarily in that they employ a passive radar seeker that "listens" for enemy radar transmissions and then follows this energy to its source. To physically attack enemy radars, the Department of Defense relies predominantly on the AGM-88 HARM (High Speed Anti-Radiation Missile). The HARM can be launched from the EA-6B, F/A-18, and F-16 C/D aircraft. The AGM-88 is normally fired against radars whose frequency and wavelength have been preprogrammed into the HARM's database. However, if fired from an EW aircraft such as the EA-6B, the HARM can be re-programmed in flight, based on inputs from the aircraft's radar warning receiver, and thus attack unanticipated threats. The Navy and Marine Corps also use the AGM-122 SideARM, a lighter, shorter-range, and less expensive system than the AGM-88, to attack enemy radars. Based on the AIM-9C Sidewinder air-to-air missile, the SideARM can be fired from AH-1W Super Cobra helicopters and AV-8B and F/A-18 fighter aircraft.

Presently, DoD has only two aircraft dedicated to "jamming" enemy electronic emissions. The EC-130H Compass Call and the EA-6B Prowler. The Compass Call's mission is to jam enemy voice and data communications. The Prowler is optimized to jam enemy radars, and also has the capability to attack communications emissions.

Table 1. Electronic Warfare Tasks and Systems
(Highlighted Cell Indicates Focus of this Report)

Electronic Warfare Attack		Electronic Warfare Protection		Electronic Warfare Support	
Tasks	**Systems**	**Tasks**	**Systems**	**Tasks**	**Systems**
Anti-radiation weapons	-AGM-88 *HARM* -AGM-122 *SideARM*	Radar Warning	-AN-ALR-56 -AN-ALR-69	Intercept, locate and analyze enemy signals	-EP-3E *Aries* -RC-135 *Rivet Joint*
Jamming Noise Deception	**- EC130H *Compass Call*** **- EA6B *Prowler***	Chaff	Aluminum, glass or plastic strips, ½ wavelength of enemy radar		
		Decoys Towed, Expendable Tactical	- ALE-50 - GEN-X - TALD		

The tactical employment of radar jammers may also be divided into two general approaches, stand-off jamming and mission jamming. As the name implies, stand-off jamming positions the airborne jamming platform at a distance from the target. The stand-off jammer creates a "jamming corridor" between the target and the attack aircraft. In mission jamming, the airborne jamming platform flies in close formation with the attacking aircraft in order to mask the attacker throughout its flight in hostile airspace.

Basic Description of the EA-6B

The EA-6B Prowler is a twin turbojet engine, four seat, all-weather, electronic attack aircraft designed to operate from aircraft carriers. It contains a wide assortment of integrated, computer-controlled, active and passive electronic attack equipment.

The Prowler closely resembles, and was developed concurrently with the two seat A-6 Intruder attack aircraft. The basic airframe was elongated and strengthened to accommodate a four-seat cockpit. Another distinguishing characteristic of the Prowler is its pod-shaped fairing at the top of the vertical fin that holds sensitive surveillance receivers, used to detect hostile radar emissions.

The crew of the Prowler consists of the pilot and three electronic countermeasures officers (ECMOs). The two ECMOs in the rear cockpit operate the

Prowler's primary jamming equipment. The ECMO in the right front seat handles navigation, communications, and defensive electronic countermeasures.

The EA-6B was manufactured by the Northrop Grumman Corporation.[3] Development of the aircraft began in the Fall of 1966. The Prowler's first flight was on May 25, 1968 and delivery of the first 12 production aircraft started in January 1971. The Prowler's initial operating capability was established in July 1971. The last of a total of 170 aircraft were delivered on July 29, 1991.

In constant FY2001 dollars, the final EA-6Bs, when procured at a rate of six per year in the early 1980s had unit procurement costs ranging from about $50 million to $90 million. When procured at a rate of 12 per year in the late 1980s, unit procurement costs ranged from $45 to $60 million. Since the A-6/EA-6B production line has since been shut down, additional EA-6Bs procured today would likely have a higher unit procurement cost, at least initially.[4]

One analyst has called the Prowler "...one of the most expensive military aircraft in service,"due to its short production runs and its complex electronics.[5] The operating cost of the EA-6B has been estimated at $5,091.00 per flight hour.[6] The Prowler is the ninth most expensive aircraft to operate per hour of the 27 different fixed-wing U.S. aircraft that were flown in Operation Allied Force. Long-range bombers (e.g., B-1, B-2, B-52) cost more than the EA-6B to operate, as do advanced reconnaissance and surveillance aircraft (e.g. AWACS, JSTARS, E-2C Hawkeye) and some fighters (e.g., F-15, F-14). However, many fighters/attack planes (e.g. F/A-18, F-16, F-117, A-10), and all other support aircraft (e.g. tankers, cargo, ASW, surveillance) cost less to operate per hour than the Prowler.

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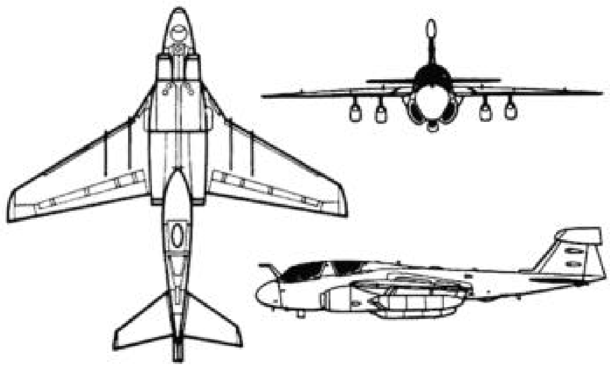
[3] Original sub contractors included: Aeronca: speed brakes; Fleet Industries: flaps and honeycomb panels; Kaman Aerospace: control surfaces, flaps and slats for composite wings; Litton: radar warning receivers, tactical jamming receivers; Lockheed Martin: honeycomb panels; Lockheed Martin Sanders: various deception and communications jammers; Magnavox: radar warning receivers; PPG Industries: windshields; Lavelle Aircraft: tailpipes; Gull Airborne Instruments: fuel gauge system; Lear Siegler: servos; Parker Hannifin: fuel valves; Plessey Airborne: trim actuators; Rockwell Collins: HF radio transceivers; TRACOR: chaff/flare dispensers; Uniroyal Plastics: fuel cells; Western Gear: wing folding actuators, win slat drives. Sources: *Jane's All the World's Aircraft* and *World Military and Civil Aircraft Briefing*, Teal Group Inc.

[4]Analysis of DoD P-1 documents from the 1980s.

[5]Luttwak, Edward and Stuart L. Koehl. *The Dictionary of Modern War* (New York: Harper Collins, 1999,:470)

[6]Letter on Operation Allied Force from LtGen C.W. Fulford, USMC, to Daniel P. Mulhollan, Director, Congressional Research Service 19 October 1999.

Figure 1: EA-6B Prowler



Propulsion: two Pratt & Whitney J52-P408 engines
Length: 59 feet 10 inches
Wingspan: 53 feet
Height: 16 feet 8 inches
Max Weight: 61,500 lbs
Speed: Over 500 knots
Range: Over 1,000 nm
Ceiling: 37,600 feet
Crew: Four
Armament: AGM-88 HARM

The core of the Prowler is the AN/ALQ-99 Tactical Jamming System, a sophisticated collection of electronic gear that forms the major portion of the U.S. Navy EA-6B ECM aircraft's operational payload. (The Prowler can carry external fuel tanks, chaff and flare dispensers, and HARM anti-radiation missiles.) The AN/ALQ-99 is comprised of five external pods, each capable of housing two very high-powered jamming transmitters, a tracking receiver, and antennas. The pods can be detached from the aircraft and can hold various combinations of transmitters to cover any desired frequency bands.

Another key system is the AN/USQ-113 communications jammer. By attacking both VHF and UHF communications, the AN/USQ-113 enables the EA-6B to "attack the archer rather than the arrows." While a single surface-to-air missile (SAM) system may be troublesome, an integrated air defense system (IADS), composed of numerous SAMs and their associated radars is a significant threat to U.S. aircraft. By jamming communications between the individual SAMs and their command and control (C^2) nodes, the EA-6B can degrade or totally disrupt the IADS and thus force the SAMs to operate individually. The individual SAM can then be more easily avoided or attacked.

EA-6B Upgrades. The original EA-6B operated with the initial AN/ALQ-99 EW system and was limited to the four jamming frequency bands used by early Soviet-made early warning and fire control radars. Since then, the system has undergone a series of upgrades. To keep pace with the expanding threat, the number of frequency bands covered have doubled, and other improvements in operational use and reliability have been made.

The Prowler's first upgrade was the EXCAP (EXpanded CAPability) program, first delivered in 1973, which upgraded the AN/ALQ-99's capability from four to six frequency bands. The upgrade also improved the system's computer, enabling new operating modes.

The ICAP (Increased CAPability) upgrade followed EXCAP in mid-1976. The ICAP upgrade replaced the EA-6B's ALQ-100 deception jammer with the improved ALQ-126. It also reduced the AN/ALQ-99's processing times, provided new Cathode Ray Tube (CRT) displays and improved communication, navigation, and IFF equipment.

In 1982, the first ICAP-2 Prowlers were delivered, representing the next improvement in the program. ICAP-2 upgraded the receivers, displays, and software to cover a wider range of known surveillance and surface-to-air missile radars. ICAP-2 jammers were also able to attack two different frequency bands simultaneously. Perhaps most importantly, the main computer was upgraded to enable the AN/ALQ-99 to act in concert with equipment on other Prowlers so that three aircraft could together mount coordinated countermeasure missions. There were three different ICAP 2 configurations, designated Block-82, Block-86 and Block-89 for the years in which they were introduced. These block configurations provided the following highlighted capabilities: Block -82 provided a software-driven rapidly re-programmable Universal Exciter (which generates the system's radar energy), Block -86 provided receiver and communications upgrades, and Block -89 upgraded safety. The Navy is currently upgrading all 124 Prowlers to a common standard, known as ICAP 2 Block 89A, which improves navigation and communication capabilities.

The next planned upgrade for the AN/ALQ-99 was the Advanced Capability (ADVCAP) program that began even as ICAP-2 was being delivered late in 1982. ADVCAP upgraded the processing equipment (new central computer), jammers (replacement of AN/ALQ-92 jammer by the AN/ALQ-149), receivers (better passive detection) and displays (new heads-up display). Out of 130 EA-6Bs, 105 were to be re-manufactured with the ADVCAP, to extend the service life of the aircraft to 2020. The first engineering model ADVCAP version for the EA-6B was delivered in early 1988. Further improvements to the ALQ-99 transmitters were made just prior to Operation Desert Storm in 1991, but the ADVCAP program was cancelled in late 1994.

The most recent EA-6B upgrade program began in March 1998 when the Navy awarded Northrop Grumman a contract to develop the ICAP III. The intent of ICAP III is to keep the joint Prowler force going until 2015. ICAP III will upgrade and replace the 1960's era receivers, improve connectivity, and provide low-range jamming. Northrop Grumman is expected to have the first batch of ICAP III Prowlers finished in late FY01, with a full-rate production decision made in June 2003. The first EA-6B ICAP III prototype completed its initial test flight on November 16, 2001.[7] ICAP III's key feature is the introduction of 'selective-reactive' jamming. Instead of jamming all the frequencies on which enemy radars might be emitting, ICAP III is designed to automatically identify, prioritize, and jam only those frequencies actually in use. Many modern enemy radars are capable of employing very fast "frequency hopping" techniques to deceive radar warning receivers and radar jammers. If threat radars use frequency-hopping techniques, the selective-reactive system will instantly shift its transmissions to match the adversary's actions.[8]

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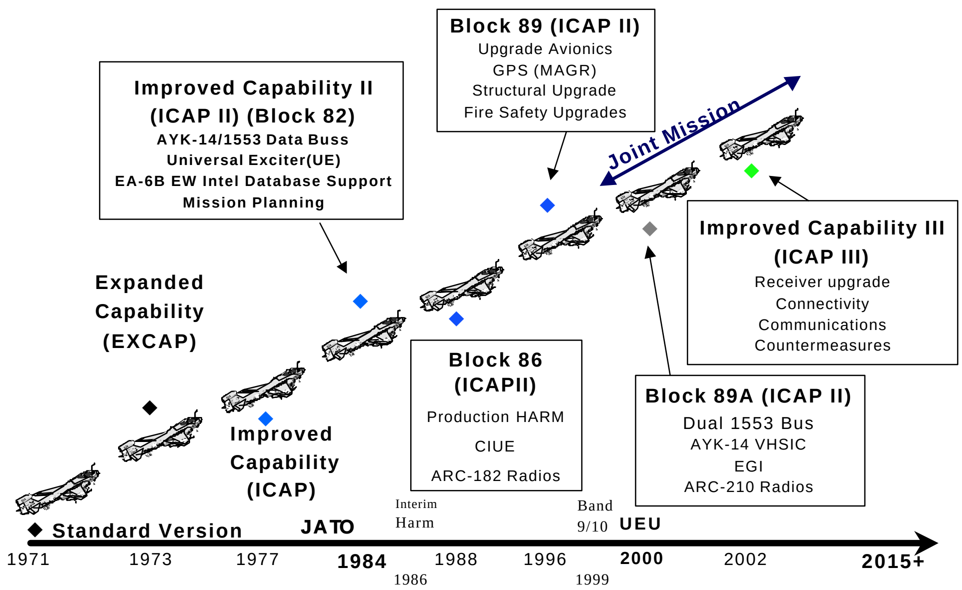
[7]Northrop Grumman Completes First Flight of ICAP III EA-6B. *Defense Daily*. November 20, 2001.

[8]E-mail communication with Naval Air Systems Command, EA-6B Program Integration.

Figure 2: Evolution of the EA-6B



Source: Naval Aviation Systems Command (NAVAIR)

Current Status. As of April 2000, there were 124 EA-6B Prowler airframes in the Navy and Marine Corps inventory.[9] These 124 aircraft are organized into 19 squadrons. Eleven of these squadrons are carrier-based (including one Naval Reserve squadron that does not usually deploy), four squadrons are expeditionary (land-based) Navy squadrons devoted to supporting the USAF Aerospace Expeditionary Force wings, and four squadrons belong to the Marine Corps.[10] The Navy is in the process of establishing another expeditionary squadron of four aircraft. It is using funds from the FY1999 Supplemental Appropriations (Kosovo) and is requesting additional money in the FY2001 Budget Request. The new Prowler squadron has a target operational date of 2003.[11]

Current Navy plans call for Prowlers to remain in the active force until at least 2015. However, the EA-6B is a classic "low density/high demand" (LD/HD) asset: there are few of them and they are used frequently.[12] The EA-6B Prowler is included in every aircraft carrier deployment and is an integral part of the fleet's first line of

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[9]On November 22, 2001. It was reported in the *Washington Post* that a Marine Corps EA-6B crashed into the ocean 26 miles off the North Carolina coast. The extent of the loss is currently unclear.

[10]Thompson, Loren B. Shaping the Battlespace: The Future of Airborne Electronic Warfare. *Sea Power,* March 2000: 40.

[11] Hebert, Adam J. Navy Asks Congress for FY-01 Money to Stand Up New EA-6B Squadron. *Inside The Air Force,*February 18, 2000: 3.

[12] In his Annual Report to the President and the Congress (U.S. Department of Defense, 2000: 35) Defense Secretary William S. Cohen defined LD/HD units as "force elements consisting of major platforms, weapons systems, units and/or personnel that possess unique mission capabilities and are in continual high demand to support worldwide joint military operations."

defense. As a result of restructuring DoD assets in 1995, the U.S. Air Force's dedicated airborne radar jamming aircraft, the EF-111 Raven was retired, and the EA-6B was left as the only airborne radar jammer in DoD. Supporting USAF Aerospace Expeditionary Force wings has contributed to the Prowler's already high operational tempo (OPTEMPO). In fact, EA-6B utilization rates are at an all time high. Due to this high wear and tear, the Prowler may actually be retired as early as 2010.

One strong indication that the Prowler fleet is under stress is the grounding of eight EA-6Bs on November 28, 2001 due to structural fatigue cracks in the center wing section. A memo from the Commander of NAVAIR to the Chief of Naval Operations and Commandant of the Marine Corps describes the basis for this action. In May 2001 NAVAIR analysis predicted as many as 51 EA-6Bs had extensive center wing section cracks. The Prowler fleet was restricted to flying 3-G or less maneuvers to mitigate the risk posed by this fatigue. Subsequent analysis found that the eight grounded aircraft had "accrued the highest level of fatigue damage and the potential for catastrophic failure of the wing."[13] Fatigue assessment of the remaining EA-6Bs is ongoing.

Table 2. Custody, Configuration and Basing of EA-6Bs[14]
(as of April 13, 2000)

Custody	# Aircraft	Configuration			Based
		Block 82	Block 89	Block 89A	
USMC	20	20	-	-	MCAS Cherry Point, NC
USN	90	26	61	3	NAS Whidbey Island, WA
Test	5	1	1	3	NAS Patuxent River, MD (3) NAS China Lake, CA (2)
Fleet Support	9	6	2	1	Northrup Grumman, St Augustine, FL NADEP, Jacksonville, FL

EW and Stealth

Electronic warfare has been a significant part of military operations since military forces began using radios and radar. EW techniques were used extensively in World War II, for instance during the Battle of Britain, the invasion of Normandy, and the allied strategic bombing campaign against Germany.

[13] "Redstripe Message" PMA-234/217. Memorandum from Commander, Naval Air Systems. 28 November 2001.

[14] Source: Naval Aviation Systems Command (NAVAIR).

The importance of exploiting and controlling the electromagnetic spectrum has grown as the revolution in information technology, which has so profoundly affected global business, economics, and society in general, has been paralleled in military affairs. One military analyst has written,

> "...the most important single outcome of technological progress during the decades since World War II has been that, on the modern battlefield, a blizzard of electromagnetic blips is increasingly being superimposed on, and to some extent substituted for, the storm of steel in which war used to take place."[15]

Many future U.S. warfighting capabilities are premised on a revolution in military affairs. This revolution will be one in which U.S. military forces will achieve "dominant battlespace awareness" over the enemy. U.S. forces will make decisions and coordinate operations by building a "common operational picture" and by exploiting a vast and intricate array of computer and communications networks. Among other techniques, this force of the future will generally exploit various information technologies in ways that will allow it to mass weapons effects against an adversary over great distances and from widely dispersed locations. Therefore, one analyst believes that EW will increase significantly in importance for future warfighters as the ability to monitor, suppress, manipulate, and exploit enemy electronic transmissions will become essential to assure military superiority.[16]

Within DoD, EW is generally recognized as an important part of doing business. The Joint Staff considers EW "... a military capability that must be integrated into a given joint operation as it supports all phases and aspects of a campaign."[17] While the importance of militarily dominating the electromagnetic spectrum is established, the best mix of resources and most effective methods for achieving this dominance, today and in future scenarios, is currently being debated.

Among the military services, for instance, differences of opinion on the "how" and "how much" aspects of EW can be observed. The Air Force has procured two dedicated manned stealth platforms and has generally been more aggressive in applying stealth technology to existing platforms. It has also de-emphasized the use of active EW relative to the Navy, as evidenced by the EF-111's retirement and the Navy's continued use of the EA-6B.

When considering EA-6B follow-on options, it is useful to recognize that there are two over-arching schools of thought regarding the importance and application of EW in modern warfare and how these schools of thought have influenced operations and force structure to date. The first perspective contends that stealth technology is a substitute for EW, and can be called "Stealth *vs* EW." The counter-perspective

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[15] Van Creveld, Martin L. *Technology and War: From 2000 BC to the Present.* The Free Press, New York, 1991: 28.

[16] Thompson, Loren B. Shaping the Battlespace: The Future of Airborne Electronic Warfare. *Sea Power,* March 2000: 40.

[17] *Joint Doctrine for Electronic Warfare*. Joint Publication 3-51. U.S. Department of Defense, Washington, DC: vii.

holds that stealth technology and EW are complementary, and can be characterized as "Stealth *and* EW."

Stealth as a Substitute for EW. The first perspective on the use of EW in modern warfare contends that in many applications, active EW works at cross purposes with low-observable or stealth technology. The more stealthy a platform or force structure is, the less need there is for EW. If an enemy radar can't detect a stealthy platform, there is little need to jam or attack the radar. Furthermore, active radar transmissions, such as those emanating from an EW platform are easily detected by adversaries. Thus, active EW is not only unnecessary to protect stealthy planes, but it contradicts stealth's basic function by loudly broadcasting the jamming aircraft's location in the theater of operations. Stealthy aircraft are often able to achieve tactical surprise by avoiding detection right up until they drop their bombs or shoot their missiles. This stealthiness not only enhances aircraft survivability, but it also increases mission effectiveness. The enemy has no time to make defensive preparations. Adherents to a Stealth *vs* EW perspective would argue that active EW platforms make tactical surprise impossible.

One of the many arguments put forth to support the Air Force's decision to retire the EF-111 Raven was that stealthy aircraft would require much less dedicated jamming than conventional aircraft. Air Force Chief of Staff, General Ron Fogleman stated that the Air Force's increasing use of low-observable platforms such as the F-22 fighter and the JAST (which became the JSF) leads to "a lot less need for a standoff jammer."[18]

The increased use of standoff weapons was another, related argument for the reduced need for the Raven. Then-BrigGen David McCloud argued that "Standoff munitions mean that I expose myself to the high-threat environment less than I had to before, and if I have cruise missiles that launch from 100 or 200 or 300 miles out, then that dramatically changes the picture....That changes the need for standoff or penetrating jamming."[19]

The 1991 Persian Gulf War (Operation Desert Storm) marked the first concerted use of stealthy aircraft in combat.[20] The Gulf War also witnessed a large and sophisticated EW campaign. Following the conflict there was little if any criticism regarding either the effectiveness of the Stealth Fighter or the jamming aircraft and the suppression of enemy air defenses (SEAD) campaign. Senior Pentagon officials said that "Stealth technology represented another electronic combat success. Although they accounted for only 2.5% of the Air Force's combat assets, the F-117s

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[18] USAF Plans to Keep 12 EF-111s Through FY'98. *Aerospace Daily,* September 22, 1995: 453.

[19] USAF Requirements Chief Defends Airborne Electronic Warfare Program. *Aerospace Daily*, July 20, 1995: 91.

[20] The US Air Force employed the F-117 in Panama during Operation Just Cause (1989). The Panamanian air defense system was not a serious threat, however, and the six aircraft were used because of their precision bombing and night flight capabilities rather than because they were stealthy.

covered 31% of the targets in the first 24 hours and were the only allied aircraft to strike targets in Baghdad." Also, "We have no reports that any SAM locked-up an attacking aircraft while being escorted by an EA-6B..."[21] Furthermore, a major NATO Conference after Desert Storm assessed the contribution of SEAD to the Gulf War: "the Joint SEAD campaign and SEAD support of the Gulf War will long be remembered as an outstanding success."[22]

What was debatable, however, was whether, and to what degree the F-117 Stealth Fighter operated with support from jamming aircraft. Those who believed that stealthy aircraft reduced the need for dedicated radar jamming argued strenuously that the F-117 was not supported either by the EF-111 or the EA-6B and that Operation Desert Storm proved their perspective on the diminishing need for active EW.

Adherents to the "Stealth *versus* EW" perspective claimed that the F-117 operated quite autonomously during Operation Desert Storm. The stealth fighter evaded enemy radars and required only minimal coordination with support aircraft. Official information on how effectively the F-117 evaded detection by the Iraqi's air defense radars is still classified. However, trade press articles from that time period report that "Iraqi radar apparently never tracked the F-117, which was referred to in intercepted Iraqi communications as 'the ghost.'"[23]

Because they were not tracked by the Iraqi radars, supporters argue, the stealthy F-117 did not require either the dedicated EW support nor the fighter escort that traditional non-stealthy attack aircraft required to survive in a hostile air defense environment. Thus, during Operation Desert Storm, the F-117 was a true force multiplier. Eight F-117s supported by two tankers could do the same job as 32 traditional attack aircraft supported by 43 other aircraft (12 of which were SEAD aircraft). Figure 3 (found on page 13 of this report) was used by the Air Force to make this point during Testimony to the House Appropriations Subcommittee on Defense.

Proponents of the Stealth *vs* EW perspective concede that the United States did plan to support the F-117 with EF-111 jammers during the very first air attacks against Baghdad, when Iraq's air defenses were strongest. However, due to an operational mix up, the EF-111s never arrived, and "...the F-117s that attacked the first targets in the capital, including the AT&T Building and the Telecommunications Center, flew into, over and through the heart of the fully operating air defenses of Baghdad with no support from electronic countermeasures."[24]

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[21]Nordwall, Bruce D. Electronic Warfare Played Greater Role In Desert Storm Than Any Conflict. *Aviation Week & Space Technology,* April 22, 1991.

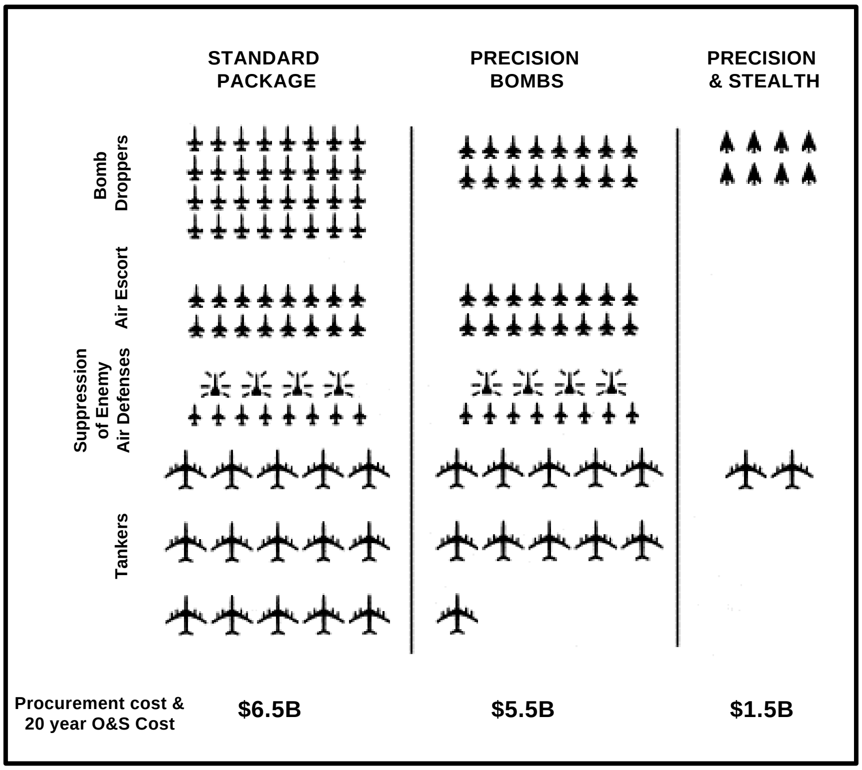
[22] AAFCETLP Gulf War Conference Report, 1730.13.7/AFOOAT/S-078/92, 20 Feb 1992 NATO. As reported by Williamson Murray.

[23]Nordwall, Bruce D. Electronic Warfare Played Greater Role In Desert Storm Than Any Conflict. *Aviation Week & Space Technology,* April 22, 1991.

[24]Williamson Murray. *Air War in the Persian Gulf*. The Nautical & Aviation Publishing Company of America. Baltimore. 1995: 106-109.

It can be argued that for much of the 1980s and 1990s the Stealth *vs* EW perspective was the dominant mind-set among many in the defense establishment, and has been a powerful factor shaping force structure and operations. The Air Force, for instance, with its stealthy F-117 and B-2 bombers, and its lack of dedicated radar jamming aircraft can be characterized as having chosen the "stealth route." The Navy, on the other hand, has lacked true stealth aircraft and has assumed the joint responsibility for jamming with its EA-6B aircraft. The Navy can be characterized as having pursued the "EW route".

Figure 3: "The Value of Stealth"



Source: Secretary of the Air Force, SAF/OSX, 1991.

Stealth and EW are Complementary. A number of factors have given rise to a contradictory school of thought regarding stealth and EW. This perspective contends that low-observable aircraft and EW jammers are not contradictory but are in fact complementary, and should be procured and used collaboratively. Those who subscribe to this philosophy would argue that EW and stealth are both designed to increase aircraft survivability and that it is impractical, if not dangerous, to put all of one's eggs in one basket.

Proponents of the Stealth *and* EW perspective maintain that stealth aircraft are not totally invisible to enemy radars nor invulnerable to SAMs. There are a variety of radar techniques and technologies that have been and will increasingly be employed to detect stealth aircraft. If a stealthy aircraft is detected, it is vulnerable to attack unless EW aircraft are nearby to protect it. While the United States continues to reduce the detectability of its aircraft, it is prudent to also improve and use EW to protect those aircraft, according to this view. Furthermore, while EW emissions do clearly broadcast the position of the emitting aircraft, there are operational techniques that can be employed to protect a stealth aircraft with EW without giving away the stealthy plane's exact position. A powerful stand-off jammer, for instance, could protect a stealthy aircraft as it traverses a target area without giving away its exact location as an escort jammer might.

Also, the evolution of technology will make the use of radar in general less susceptible to enemy interception. A new generation of radars is being developed called AESA or Active Electronically Scanned Arrays that are planned to be deployed on JSFs and F-22s and potentially retrofitted onto other aircraft such as the F/A-18EF and even legacy aircraft. The AESA is made up of thousands of very small transmit/receive (T/R) modules located on the face of the radar antenna, high speed computer processors and sophisticated computer algorithms. Each AESA T/R module can send out its own pencil thin beam of radar energy that is very difficult to detect. The aircraft's stealth profile is further protected by the fact that the AESA quickly alters the pencil beam's "wave form" to make it look as though it came from a different radar, and broadcasts it at a different and variable frequency. Thus, even if the enemy intercepts the AESA radar beams, the signals appear to be from a variety of sources, and the aircraft's location is safely "lost in the noise." Finally, even if an enemy was finally able to detect and recognize the AESA radar signals, it would find it difficult to lock onto and target the aircraft because the AESA has a limited, built in jamming capability that could also be employed. This jamming capability has been described as "very discriminating, jamming only long enough to break the ground-based guidance radar's or missile radar's lock."[25]

Those who believe that a synergy exists between stealth and EW also find evidence in recent military operations to support their perspective. This perspective would argue that the portrayal of the F-117 as "lone wolf" during Operation Desert Storm is a false one. First, while support aircraft might not have flown wing-to-wing with the Stealth Fighter, jammers and air superiority escorts did fly the same missions. The Desert Storm Lessons Learned Report of the 37th Tactical Fighter Wing, for instance describes unambiguously how their jamming aircraft were incorporated into F-117 operations. Furthermore, F-15 air superiority fighters always flew CAP (Combat Air Patrol) within striking distance of the F-117, which carries limited air-to-air weapons.[26]

Not only did jamming aircraft support the Stealth Fighter, it is argued, but they employed innovative techniques to improve the F-117's survivability. For instance, "F-117 pilots report the jammers were used to indicate false target locations to the Iraqis."[27] The Iraqis then attacked these false targets, leaving the F-117's unmolested. Another clever technique was "to turn the jamming on at, for example, 7 minutes before the time on target. The AAA fire would start, but would stop in about 5 minutes as the gun barrels began to overheat. Two minutes later the F-117As would

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[25]Fulghum, David A. "F-22, JSF Designed for Distinct Roles." *Aviation Week & Space Technology*. February 7, 2000. P. 53 and Cook, Nick. Survival of the Smartest. *Jane's Defense Weekly*. March 1, 2000: 26.

[26]General Accounting Office. *Operation Desert Storm: Evaluation of the Air Campaign.* (GAO/NSIAD-97-134) Washington, DC June 12, 1997: 92

[27]Nordwall, Bruce D. Electronic Warfare Played Greater Role In Desert Storm Than Any Conflict. *Aviation Week & Space Technology*, April 22, 1991.

attack while the defenses were recuperating."[28] Also, EW was used after an F-117 attacked a target, to protect the fleeing stealth fighter from any enemy air defenses that might have survived the attack.

Perhaps even more innovative than the jamming techniques described above, U.S. forces attacking Baghdad successfully employed un-piloted EW systems (i.e. the Air Force BQM-74 drone and the Navy Tactical Air Launched Decoy) to draw attention away from F-117 operations and to incite enemy radars into exposing their positions so that HARM-firing aircraft could destroy them. In one mission, the United States created a massive EW feint. The Air Force launched approximately 75 BQM drones toward the Iraqi air defenses, which converged with 25 Navy decoys also flying toward Iraq. Totally deceived by what appeared to be a huge attack, the Iraqis lit up the sky with their radars. Meanwhile, the real air strike commenced more or less unopposed. [29]

There was much evidence from Operation Desert Storm that EW capabilities played an important role in the victory and that EW aircraft and stealth aircraft were not oil and water. Even so, the time period following Desert Storm has been described as a "period of neglect of the electronic warfare mission..."[30] For instance, it has been argued that during this era, the EA-6B was not upgraded with numerous technologies (such as night vision devices and key communications links) required to keep the Prowler current with threats and advanced operational concepts. Furthermore, it was during this time period that the Air Force decided to retire the EF-111 and allow the Navy to assume the EW mission for all services.

Kosovo: The EW Experience

Operation Allied Force, the 1999 NATO operation in Kosovo, appears to be an important watershed in the debate over current and future U.S. airborne EW needs. The military leader of the operation, General Wesley Clark, described how critical a role EW played in the allies' success. He testified that "We couldn't have fought this war successfully without the EA-6B contribution. We really need the electronic warfare capacity that we have there."[31] Yet, following the air campaign, concerns have been raised over the number of jamming aircraft in the U.S. inventory, whether these aircraft can be incorporated into stealth aircraft operations, and the ability of the force in general to respond to and defeat an enemy who employs deceptive radar tactics. Each of these issues is discussed below.[32]

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[28]Dornheim, Michael A. F-117A Pilots Conduct Precision Bombing in High Threat Environment. *Aviation Week & Space Technology.* April 22, 1991

[29]Williamson Murray. *Air War in the Persian Gulf.* The Nautical & Aviation Publishing Company of America. Baltimore. 1995: 113-117.

[30]Thompson, Loren B. Shaping the Battlespace: The Future of Airborne Electronic Warfare. *Sea Power,* March 2000: 41.

[31]General Wesley Clark, SACEUR, Testimony to Senate Armed Services Committee. Washington, DC. July 1, 1999.

[32] The EW challenges experienced in Kosovo were foreshadowed by the 1995 conflict in (continued...)

EW Operations in Brief. During Operation Allied Force, the Marine Corps deployed two EA-6B squadrons, totaling an average of eight aircraft (the peak USMC deployment was 11 Prowlers). The Marine Corps Tactical Electronic Warfare Squadron Two (VMAQ-2) provided the first land-based EA-6B electronic warfare capability present at the start of the operation, entering combat within 24 hours of their arrival at Aviano Air Base in Northern Italy, and supported the full 78-day air campaign with five aircraft.[33] The U.S. Navy deployed the preponderance of Prowlers to Operation Allied Force, committing 18 EA-6Bs to the Kosovo theater.[34] At the peak of the Kosovo conflict 10.5 of the 19 active and reserve Navy and Marine Corps EA-6B squadrons were forward deployed.[35]

The United States flew 60 percent of all NATO combat sorties during Operation Allied Force. However, a full 86 percent of NATO SEAD strikes against Serbian forces were flown by U.S. planes.[36] This very large role played by U.S. EW aircraft strongly attests to both the criticality of suppressing enemy radars and SAMs in general, and to how central U.S. EW aircraft were to the whole operation.

According to various sources, the EA-6Bs were fully integrated into the air tasking orders to support Air Force, Navy, and Marine Corps aircraft during their strike missions against Yugoslav targets. During the course of the conflict, the EA-6B Prowlers had a 100% mission completion rate, and flew 464 sorties adding up to over 2,121 combat flight hours.[37] No EA-6Bs were destroyed or seriously damaged during

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[32](...continued)
Bosnia (Operation Deliberate Force). The Bosnian Serbs in this conflict operated their early warning and SAM radars much more cleverly than the Iraqis during Desert Storm. By turning on their radars infrequently, the Bosnian Serbs defied NATO efforts to jam or suppress them. Also, the topography of this region was much more challenging than in Iraq for those prosecuting the EW mission. The Bosnian hills and forests provided numerous hiding spots for the radars, SAMs and command and control (C^2) assets that the Serbs moved frequently. Collateral damage had very high political visibility in this conflict, and minimizing it put real constraints on air operations. Finally, the June 2, 1995 shoot-down of Captain Scott O'Grady's F-16 by a 30 year old SA-6 SAM highlighted the need for capable jamming aircraft. EW and SEAD escort of strike packages became the norm after it was determined that O'Grady did not have such support when shot down. Sources: Hitchens, Theresa, and Robert Holzer. U.S. Extends Life of Radar-Jamming EF-111. *Defense News*. June 19-25, 1995: 3. And Grant. Rebecca. Airpower Made it Work. *Air Force Magazine*. November 1999: 34.

[33]Hebert, Adam J. Prowler Community was Well Equipped for Kosovo, Participants Say." *Inside the Air Force*. August 6, 1999.

[34]Telephone conversation with CDR Jeff Cathey, USN. Office of Legislative Affairs, U.S. Navy.

[35]Polmar, Norman. On the Prowl(er). *Proceedings*. October 1999: 85.

[36] Percentages derived from information from Letter from LtGen C.W. Fulford, USMC, Director, Joint Staff to Daniel P. Mulhollan, Director, Congressional Research Service. October 19, 1999: on Operational Allied Force.

[37]B.Gen. Robert M. Flanagan, Deputy Commander II Marine Expeditionary Force, Testimony
(continued...)

the conflict, and only two allied aircraft were shot down during the entire operation. This very low loss rate can be credited in part to successful EA-6B radar jamming. Prowlers performed both standoff jamming missions for strikes and attacks of their own against radar installations using HARMs, sometimes on the same sortie. Marine Corps Prowlers alone launched 57 HARMs at Serbian radars.[38] Despite the very positive outcome of the Operation Allied Force EW campaign, serious issues have been raised within academic, DoD, and congressional circles.

Scarcity of EW Aircraft. Perhaps the most prominent issue raised by the Kosovo conflict was the perception that there just weren't enough EA-6Bs to optimally execute the air war. This caused problems both in the execution of Operation Allied Force and in the satisfaction of military commitments elsewhere.

In Kosovo the 27 Prowlers were used to protect hundreds of NATO aircraft flying 37,225[39] combat sorties over 78 days. Since on average, a combat strike package is composed of four aircraft, those 37,225 sorties could translate into 9,306 strike packages; each, in principle requiring protection by EW aircraft. If those 9,306 hypothetical air strikes were spaced out evenly over 78 days, and each strike package required just one EA-6B for protection (in reality they frequently required several Prowlers), then each Prowler would have to fly over four sorties per day, for 78 straight days. Generating this sort of sortie rate is an operational impossibility for both crew and aircraft at the current Prowler force level. During the 78-day air campaign, each Marine Corps EA-6B averaged 95 hours per month. One aircraft flew 123 hours in one month. These numbers are significant if one considers that planned aircraft utilization rates during sustained operations are 36 hours per month.[40]

U.S. military planners took extraordinary steps to protect all combat sorties with EW jammers. Keeping air crews healthy and at appropriate readiness levels became a challenge. Normally, limits are placed on the number of hours crew can fly in a given period of time for both health and safety reasons. With the Prowlers flying missions daily in Kosovo, airplane crews were in constant demand, were forced to rotate, and got only every sixth day off on average. The high number of sorties required an exemption from normal limits on flying hours.[41] The Navy's Deputy Chief of Naval

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[37](...continued)
before the House Armed Services Committee, Subcommittee on Military Readiness, on Problems Encountered, Lessons Learned and Reconstitution following Operation Allied Force. October 26, 1999.

[38]Hebert, Adam J. Prowler Community was Well Equipped for Kosovo, Participants Say." *Inside the Air Force*. August 6, 1999.

[39]William S. Cohen, Secretary of Defense. Prepared Statement to Senate Armed Services Committee, July 20, 1999: 4.

[40]BGen Robert M. Flanagan, Deputy Commander II Marine Expeditionary Force, Testimony before the House Armed Services Committee, Subcommittee on Military Readiness, on Problems Encountered, Lessons Learned and Reconstitution following Operation Allied Force. October 26, 1999.

[41]Hebert, Adam J. Prowler Community was Well Equipped for Kosovo, Participants Say.
(continued...)

Operations for Resources and Requirements recognized the negatives of such deployments on both men and machines. "Ten of the 19 Navy and Marine Corps squadrons were deployed to Allied Force," he said. "That is not the normal rotation that we like to see with a deployed cycle. It degrades PERSTEMPO and it causes deferred maintenance."[42]

To shoulder the increased maintenance burden caused by such high OPTEMPO, the Navy deployed hundreds of extra enlisted maintenance personnel to the theater.[43] Despite this extra manpower, aircraft maintenance was stressed and these crews were forced to resort to "severe" parts swapping between Prowlers to keep them flying.[44]

To achieve the maintenance success that was evidenced by the high number of sorties that the Prowlers were able to fly, DoD was forced to draw down the overall parts supply system to critically low levels. Prowler squadrons outside of Kosovo were brought to a virtual standstill. The lack of spare parts dramatically reduced their ability to train and maintain aircrew proficiency.[45]

Concentrating such a large percentage of the overall Prowler force and its personnel and maintenance resources in one theater had a global ripple effect on U.S. EW assets, straining the ability of the Navy and Marine Corps to meet other global commitments. At one point, for instance an expeditionary squadron based in Incirlik, Turkey, was shifted to the Balkans, forcing a suspension in enforcement of the no-fly zone in Iraq.[46] According to the former commander of the Combined Task Force for Northern Watch, Brig. Gen. David Deptula, "when your tankers are gone, or your EA-6Bs are gone or your F-15C are gone, you just don't operate..."[47]

The Marine Corps Prowler squadron at Iwakuni, Japan – supposedly a permanent presence – was transferred to Kosovo, forcing an alert of CONUS-based

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[41](...continued)
Inside the Air Force. August 6, 1999.

[42]VADM Conrad C. Lautenbacher, Deputy Chief of Naval Operations (Resources, Warfare Requirements & Assessments), Testimony before the House Armed Services Committee, Subcommittee on Military Procurement, Hearing on the Lessons Learned in the Kosovo Conflict, October 19, 1999.

[43]Hebert, Adam J. Prowler Community was Well Equipped for Kosovo, Participants Say. *Inside the Air Force*. August 6, 1999.

[44]Hebert, Adam J. Marine Corps not a Good Place for Air Force to Find OPTEMPO Relief. *Inside the Air Force.* September 10, 1999.

[45]BGen Robert M. Flanagan, Deputy Commander II Marine Expeditionary Force, Testimony before the House Armed Services Committee, Subcommittee on Military Readiness, on Problems Encountered, Lessons Learned and Reconstitution following Operation Allied Force. October 26, 1999.

[46]Thompson, Loren B. Shaping the Battlespace: The Future of Airborne Electronic Warfare. *Sea Power,* March 2000: 41.

[47] Wolfe, Frank. Kosovo Requirements Temporarily Halted Northern Watch. *Defense Daily*. November 17, 1999: 4.

EA-6Bs to cover any problems in northeast Asia. Even instructors from NAS Whidbey Island, WA, were deployed overseas to fill the gaps in EW coverage. [48] "We gapped the CINCPAC requirement at Iwakuni for a year," said the Commanding General of the Marine Corps Combat Development Command. "We will not recover on EA-6Bs until September of '00 following that requirement."[49] Even months after the conflict, the supply system lacked both the aviation parts and manpower to support full time contingency operations and simultaneously support CONUS based units at normal rates.

Despite these efforts and the negative consequences of deploying so many Prowlers to Kosovo, the Navy and Marine Corps Prowlers could not keep up with the pace of combat sorties in Operation Allied Force. The scarcity of EA-6Bs slowed the allied operational tempo. The Prowlers have been described as a "crucial pacing element" for the air campaign. Sorties were geared around the availability of EA-6Bs. If Prowlers weren't available, operational planners either had to wait until Prowlers became available, or risk flying without them. However, on the basis of Assistant Secretary of the Navy Lee Buchanan's testimony to the Senate Armed Services Air-Land Subcommittee on March 22, 2000, in which he said that "the EA-6B accompanied all U.S. strikes in Kosovo and also some coalition strikes," it would appear that operational planners generally chose to wait for the Prowlers.

In addition to the general scarcity of Prowlers, the EA-6B's lack of night vision devices (NVDs) has been identified as a limiting factor in target prosecution for night missions. The lack of NVDs rendered the aircrew incapable of performing precise aircraft positioning through visual means at night and in some cases reduced their effectiveness. Since most of the air campaign was fought at night, this shortcoming might have been a factor in slowing operations.[50]

Integration with Stealth Aircraft Operations. It is difficult to openly discuss stealth aircraft operations due to their high degree of sensitivity. However, in the open literature that is available, opinions on this Operation Allied Force issue vary.

DoD officials are quoted as saying that "we feel it important to provide our crews as much protection as we could provide" and that bombers could fly without jamming support if necessary.[51] The Air Force's Deputy Chief of Staff for Air and

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[48]Thompson, Loren B. Shaping the Battlespace: The Future of Airborne Electronic Warfare. *Sea Power,* March 2000: 41.

[49]Lt.Gen. John E. Rhodes, Commanding General, Marine Corps Combat Development Command. Testimony before the House Armed Services Committee, Subcommittee on Military Procurement, Hearing on the Lessons Learned in the Kosovo Conflict, October 19, 1999.

[50]B.Gen. Robert M. Flanagan, Deputy Commander II Marine Expeditionary Force, Testimony before the House Armed Services Committee, Subcommittee on Military Readiness, on Problems Encountered, Lessons Learned and Reconstitution following Operation Allied Force. October 26, 1999.

[51]Hebert, Adam J. B-2 Performed Better Than Expected Over Kosovo, USAF Officials Say.

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Space Operations, added, however that "The question I get frequently is, was ECM required for stealth assets? The answer is no, it is not required – depending on the risks you want to put the aircrews at. If you have the capability, then the prudent person would say, why not suppress the threat with Electronic Countermeasures as well as taking advantage of our stealth capability, which all totaled up to survivability for the platform. That is simply what we did."[52] BGen Robert Flanagan (USMC) testified that "EA-6Bs were incorporated into operations with low-observable aircraft. Due to the Marine Corps Prowler's presence during the build-up phase, they were briefed in and allowed to participate in these sensitive missions. As a result, every low-observable aircraft mission conducted during OAF had dedicated Marine Prowler support."[53]

The F-117 that was shot down in Kosovo was reportedly not properly supported by jamming aircraft. For a variety of reasons, "The EA-6Bs were too far from the F-117, they may not have been properly aligned with the (enemy) radars..."[54] The apparent use of EA-6Bs to support F-117 and B-2 aircraft during the Kosovo conflict lends credence to the "Stealth *and* EW" philosophy. A new issue regarding stealth and EW aircraft integration arises from this experience however – namely whether the intense secrecy protecting stealth aircraft operations might be hindering joint training and the development of operational concepts that would enable even better integration of EW and stealth aircraft.

Stealth technology has long been considered an important comparative military advantage for the United States. It is a silver bullet that only the United States employs pervasively. The standard operating procedure is to withhold F-117s from Air Force exercises and experiments such as "Red Flag." Thus, important details regarding how EW assets should best be integrated with stealth platforms are not universally understood. For example, what frequencies should they work on? Where should the jamming aircraft be positioned relative to the stealth aircraft? Where in the formation should the HARM-shooting aircraft fly? According to Gen. Richard Hawley, former commander of the Air Combat Command, this desire to classify and protect as much information about stealth technology as possible was most likely a factor in the F-117 loss and backfired on the services.[55] Some analysts recommend more consideration on how to better train, exercise, and experiment with stealthy aircraft in the "total force package" (including EW assets) while still safeguarding stealth technology secrets.

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[51](...continued)
Inside the Air Force. July 2, 1999.

[52]Grant, Rebecca. Airpower Made it Work. *Air Force Magazine.* November 1999: 34.

[53]B.Gen. Robert M. Flanagan, Deputy Commander II Marine Expeditionary Force, Testimony before the House Armed Services Committee, Subcommittee on Military Readiness, on Problems Encountered, Lessons Learned and Reconstitution following Operation Allied Force. October 26, 1999.

[54] Fulghum, David A. NATO Unprepared for Electronic Combat. *Aviation Week & Space Technology*. May 10, 1999: 35.

[55] Butler, Amy. Hawley: Poor Training for Mission Led to F-117 Loss. *Inside the Air Force.* December 3, 1999.

Response to Serbian Tactics. In many areas, including EW, Operation Allied Force was unlike Operation Desert Storm. In 1991, the United States destroyed most if not all of Iraq's key radars and SAMs early in the conflict, and kept the residual threat very low until the end of the war. In Operation Allied Force "Dedicated suppression of the Serbian air defenses was never completely accomplished."[56] Rather than continually sweeping the skies with their radars as the Iraqis had done, the Serbs turned on their radars sporadically. They exploited a vast network of observers to track U.S. aircraft, then turned on their radars just as the U.S. planes were passing overhead. While this tactic limited the effectiveness of the Serb system, it also made it extremely difficult for U.S. EW and SEAD assets to find, target and suppress or destroy mobile radars and SAMs.

At the campaign's end, only a fraction of Serbian early warning radar networks and SAMs had been destroyed. To illustrate how successful the Serb tactics were, NATO believes they only destroyed three of the Serb's 22 SAM batteries.[57] Consequently, bombing missions on Day 78 were potentially as dangerous as missions on Day One.[58] This need for continuous EW support kept EA-6B OPTEMPO high throughout the entire conflict.

Serbian tactics and the NATO allies' difficulty in countering them suggest that the United States may need to emphasize the acquisition of systems and the development of operational concepts optimized for finding, targeting, and destroying mobile radars and SAMs that aren't emitting.

Intelligent Decoys. While chaff, flares, and decoys have been part of aircraft self-protection suites for some time, their contribution to EW during the Kosovo conflict is noteworthy, with regard to the coming debate regarding EA-6B follow on options.

The ALE-50 towed decoy and the GEN-X expendable decoy are examples of a new generation of decoys that proponents argue will greatly increase aircraft survivability against radar guided missiles. These systems defeat guided SAMs by transmitting a decoy signal that looks just like that of the targeted aircraft, except bigger. The SAM is tricked into attacking the decoy, sparing the aircraft. These decoys would not protect an aircraft against unguided threats such as Anti Aircraft Artillery (AAA) or SAMs fired without radar guidance.

While decoys are not new, current systems are noticeably more sophisticated than their predecessors. They cover a much broader range of frequencies, can be

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[56]B.Gen. Robert M. Flanagan, Deputy Commander II Marine Expeditionary Force, Testimony before the House Armed Services Committee, Subcommittee on Military Readiness, on Problems Encountered, Lessons Learned and Reconstitution following Operation Allied Force. October 26, 1999.

[57]Haffa, Robert P. and Barry D. Watts. *Brittle Swords: Managing the Pentagon's Low-Density, High Demand Assets.* Northrop Grumman Corp. Washington, DC: 9.

[58] Haffa and Watts report that the Serb's are estimated to have fired over 670 SAMs during the 78-day war.

reprogrammed in flight by the aircraft's radar warning receiver, and can transmit more sophisticated decoy signals. The most intelligent decoys are towed with a fiber optic cable which allows information from on-board electronic countermeasures systems to pass from the aircraft to the decoy.

As of May 31, 1999, the Serbs had fired 30 SAMs at ALE-50-equipped B-1B aircraft flying missions as part of Operation Allied Force. Of those 30 missiles, 10 actually locked their radar homing devices on the B-1Bs. All 10 SAM missiles were diverted by the decoys. There are unconfirmed reports that two additional B-1Bs were similarly attacked and saved by their decoys.[59] The practical and monetary value of these decoys is significant. If the ALE-50s hadn't been deployed on the B-1Bs, or if they hadn't been successful, all 12 of the bombers could have been destroyed. In a worst case scenario, this could have resulted in the death of 48 crew members and the destruction of approximately $2.5 billion in materiel. The political ramifications of losing such a high value asset are more difficult to calculate; but probably significant as well. In a more likely scenario, after one or two aircraft were shot down, the B-1Bs would have been withdrawn from the campaign until an effective defense or counter-tactic was devised. This suggests that decoys could be an important component of an overarching EW strategy that could reduce the number and or types of dedicated EW jammers required.

EA-6Bs in Operation Enduring Freedom[60]

Thus far it appears that in many ways, Operation Enduring Freedom has placed fewer demands on the EA-6B fleet than did Operation Allied Force. First, a much smaller percentage of active and reserve Prowlers have been deployed to Afghanistan than were during Operation Allied Force. A maximum of two aircraft carrier-based EA-6B squadrons have flown missions at any one time, compared to the 10.5 squadrons deployed in Kosovo. This relatively low level of EA-6B deployment is likely due in part to the low number of attack aircraft sorties flown in this conflict vis-a-vis the number flown in Kosovo. Second, the EA-6B squadrons that are deployed to Afghanistan appear to have less SEAD work to do than those deployed in Kosovo. The Taliban's air defenses are notably inferior to Serbia's and that appears to be reflected in the number of support jamming missions. Press accounts claim that even on the first night of bombing "the strikes were aided by a relatively small number of support aircraft, such as EA-6B stand off jammers."[61] As U.S. air strikes took their effect on the Taliban's defenses, it appears that the need for escort jamming diminished further. Other press accounts say that unlike in Bosnia and Kosovo, strike packages began attacking Taliban targets without EA-6B support. Another indication

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[59]Hughes, David. A Pilot's Best Friend. *Aviation Week & Space Technology*. May 31, 1999: 25. Cook, Nick. Survival of the Smartest. *Jane's Defense Weekly*. March 1, 2000: 24.

[60]For additional information on air power issues in Afghanistan, see CRS Report RS21020 *Operation Enduring Freedom: Potential Air Power Questions for Congress*.

[61]Fulghum, David, and Robert Wall. U.S. Stalks Taliban with New Air Scheme. *Aviation Week & Space Technology*. October 15, 2001. p.32.

of the paucity of air defense targets is that EA-6Bs stopped carrying HARM missiles.[62]

Despite the Taliban's weak air defenses, it appears that the EA-6Bs deployed in Afghanistan are actively engaged in Operation Enduring Freedom. It has been reported that Prowler crews from the USS Carl Vinson and USS Theodore Roosevelt have begun exploiting a new technique in support of the war effort: using the ALQ-99 radar jamming system to disrupt enemy ground communications. The ALQ-99 can jam more frequencies, and deliver more jamming energy than the EA-6B's dedicated communication jammer, the USQ-113. Care must be taken to avoid accidently jamming frequencies used by friendly forces, particularly GPS guided munitions. When conducting communications jamming, the EA-6Bs are reportedly coordinating closely with other assets involved in communications jamming and electronic intelligence gathering, such as the EC-130H Compass Call, EC-130E Commando Solo, RC-135 Rivet Joint and EP-3 Aries. This new technique is said to be "particularly useful in supporting the Pentagon's 'hidden' special operations forces campaign."[63]

Another new development is the debut of night vision devices (NVDs) in the EA-6B fleet. The USS Theodore Roosevelt's EA-6B squadron, the VAQ-137 "Rooks", is using NVDs to increase their situational awareness. The NVDs help Prowler crews se other aircraft in a strike package and find refueling aircraft at night.

The exact pace and tempo of EA-6B support jamming missions is difficult to assess due to conflicting press accounts. One account claims that "typically, only one Prowler is flying at a time."[64] While another report indicates that six of the eight Prowlers in theater often operate at the same time. The long distances being flown also affect Prowler operations. Missions tend to last six to seven hours, including an aerial refueling, which is unusually long for the crew and the 30 year old airframes alike.

Potential Lessons or Assessment

Following Operation Allied Force a number of senior and respected military experts expressed concern about the state of U.S. EW. Retired Royal Air Force Air Vice Marshal Tony Mason wrote about severe jamming deficiencies in Kosovo. Retired Air Force Chief of Staff Gen. Michael Dugan said "We made a serious misstep," when deciding to retire the EF-111 Raven.[65] Current Air Force Chief of Staff Michael Ryan said the service was "embarrassed" during the Kosovo conflict for

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[62]Wall, Robert. EA-6B Crews Recast Their Infowar Role. *Aviation Week & Space Technology*. November 19, 2001. p.39.

[63]Wall, Robert. EA-6B Crews Recast Their Infowar Role. *Aviation Week & Space Technology*. November 19, 2001. p.39.

[64]Brinkley, Mark. Prowlers Assume Ground Jamming Role. *Defense News*. November 26, 2001 p.36.

[65]Experts: Retiring EF-111 to Give Jamming Mission to EA-6B was a Mistake. *Inside the Air Force.* August 20, 2000.

failing to provide enough EW support to EUCOM.[66] Military analyst Edward Luttwak said "It (the lack of EW aircraft) was the constraining element of the entire air campaign. It was like having 13 Cadillacs and one gallon of gas."[67]

A number of studies have been initiated to review the status of U.S. EW resources and develop recommendations on how to best meet future requirements. Three studies are noteworthy. On October 1, 1999 a team led by Dr. Natalie Crawford of RAND published the preliminary findings of a report on the USAF EW Management Process, which focused on structural changes to the Air Staff that would result in better sponsorship of the EW mission within the Air Force. The Crawford study concluded that the representation of EW programs and issues at senior levels of the Air Force is fragmented. This results in a lack of corporate focus and advocacy that is required for EW to compete with other important mission areas in terms of money and other resources.[68] This study is ongoing.

Air Force Chief of Staff Gen. Michael Ryan led an electronic warfare summit in July 2000 that brought together the Air Force's top EW experts. This panel was formed in response to the RAND study findings, and examined ways in which the Air Force might improve the end strength and skill level of the service's dwindling cadre of electronic warfare officers.[69]

A broader study, the Joint Service Airborne Electronic Attack Analysis of Alternatives (EA AOA) was established in February 2000. This Navy-led study has been tasked to examine the 2010 to 2030 timeframe and determine the best platforms and systems to fulfill joint EW requirements.

The EA AOA is led by an Executive Steering Group composed of general officers and senior level civilians with requirements, acquisition and test responsibilities. Working level integrated product teams (IPTs), composed of approximately 60 different representatives focus on threat, cost, technical, user and modeling and simulation issues.

The EA AOA's analysis was reportedly completed in September 2001, and is expected to be released in December 2001. According to one account, the EA AOA was directed to study options that would 1) provide at least ICAP-III level jamming capabilities, 2) be compatible with specific Service needs against all foreseen threats,

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[66]RAND Says Air Force Headquarters Should Take EW Lessons from AFSOC. *Inside the Air Force.* March 24, 2000.

[67]Europe, U.S. May Learn Opposing Lessons from Operation Allied Force. *Aerospace Daily*. August 17, 1999.

[68]Butler, Amy. Weak EW Management Prompts Call for New Oversight Structure. Inside the Air Force. March 3, 2000.

[69]Wall, Robert. Pentagon's EW Efforts Seen in Shambles. Aviation Week & Space Technology. April 24, 2000:29.

and 3) be available in sufficient numbers to avoid low density/high demand (LD/HD) problems. The EA AOA examined 23 different airborne electronic attack options.[70]

While the EA AOA's conclusions and recommendations have not yet been made public, conflicting reports have found their way into the trade press. Two articles based on discussions with unidentified sources claim that the EA AOA found the F/A-18G to be the likeliest option.[71] Another article cast doubt on the attractiveness of this options, saying that "the cost of developing and fielding such a system was among the highest of the different options..."[72] While the accuracy of these advanced reports is unclear, it appears likely that the EA AOA will present a "menu" of choices to replace the EA-6B rather than a single solution.

Congressional Action

Over the last five years Congress has supported the development of EW aircraft and capabilities by a variety of measures. From FY1996 to FY2000 Congress consistently appropriated more money than requested for EA-6B-related procurement, encouraging the Navy to upgrade the Prowler's airframe, radar jammer, and communications jammer and initiating the development of advanced "receptive" jamming techniques. Congress also vigorously debated the decision to retire the EF-111. In the 106th Congress, legislators sponsored the Joint Service Electronic Attack Analysis of Alternatives study that is analyzing the alternatives for a EA-6B follow on capability. Furthermore, members of the 106th Congress have formed an EW working group in the House to bring greater attention to EW issues. (See *Congressional EW Working Group* section, p.28 of this report)

FY1996-FY2001. The Fiscal Year 1996 defense budget request called for the termination of the EF-111 System Improvement Program and retirement of the EF-111 fleet in fiscal year 1997.[73] The Air Force testified that the EA-6B could satisfy all jamming requirements. Debate within the Senate Appropriations Committee regarding EF-111 retirement was vigorous. Some Senators argued that retiring the EF-111 was

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[70]Airborne Electronic Attack Analysis of Alternatives. *Study Overview*. November 2001. United States Air Force.

[71]Tiboni, Frank. Hornet Variant in Lead to Replace Prowler. *Defense News*. October 29, 2001. p.4. and Keeter, Hunter. Navy FY'03 Budget Plan Supports F/A-18G, 737 MMA as Best Options. *Defense Daily*. November 1, 2001.

[72]Wall. Robert. Tough Decisions Loom for EA-6B Replacement. *Aviation Week & Space Technology*. October 22, 2001.

[73]Congress recommended cancelling the EF-111 program in Defense Appropriations for FY1993. In the Senate Report 102-352 (July 31, 1992), appropriators concluded that "...the Navy should be assigned a mission for the entire Defense Department to provide standoff jamming for all tactical air operations, based on the strength of its modernization program and the flexibility of the EA-6B." Furthermore, "The committee believes the Air Force should inactivate its EF-111 aircraft and that the resources earmarked for the EF-111 squadrons in the Future Years Defense Program be transferred to the Navy to fund a stronger EA-6B program."

"an unwise and risky course of action," and "fraught with too many risks for our national security."[74]

In FY1996 authorization conferees expressed concern that the administration's budget request included no funds to either expand the Navy's fleet of EA-6B aircraft, improve its capabilities, or to accommodate the requirement of the EF-111by other means. Therefore, "The conferees agree that modernization of the Department's tactical electronic warfare aircraft fleet is a priority item of special interest."

The FY1996 Authorization Conference Report went on to admonish the Navy, noting the "inconsistent nature of the Navy's actions regarding airborne tactical EW in recent years" and saying that the conferees were "deeply concerned with the Navy's vacillating commitment and for meaningful upgrades to the EA-6B aircraft." To indicate the seriousness of their concerns, authorization conferees agreed that the Secretary of the Navy should not obligate more than 75 percent of funds appropriated for procurement of the F/A-18C/D for fiscal year 1996 until he had accomplished the modernization activities specified in the report.

Appropriations for FY1996 followed the authorization lead, providing $165 million for the modernization programs delineated in the authorization report. Appropriations conferees saw a particular need to procure the 9/10 band transmitters and encouraged the Navy to" buy these systems expeditiously."[75] In addition to the EA-6B modernization, the appropriators provided the Navy with $97 million in RDT&E funds for EW development.

In FY1997, Congressional conferees authorized $201.6 million for EA-6B procurement, $101 million more than the budget request. Conferees strongly expressed their concerns regarding the retirement of the EF-111 and the reliance on the Prowler as the Department of Defense's only dedicated radar jammer.

> Attack aviation continues to require a robust electronic warfare capability. The decision to retire the Air Force's EF-111s and rely on the EA-6B for the Department's tactical jamming mission makes it imperative that the EA-6B fleet be structurally sound and modernized to meet current requirements. The conferees note that the current jamming transmitters on the EA-6B have not changed substantially since originally designed in the 1960s, although there have been several generations of improved surface-to-air and air-to-air missiles since then, and many of these new systems operate in the high radio frequency range. Also, the great majority of current anti-ship missiles employ seekers in the band 9/10 frequency range. Consequently, the conferees agree to authorize an increase of $40 million to the budget request to procure 60 shipsets of these transmitters. The conferees agree to authorize an addition of $11 million to the budget request to acquire an additional 24 units of the USQ-113 communications jammer. The EA-6B's aluminum wing center sections have been found to be subject to

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[74] U.S. Senate. 104th Congress, 1st Session. Congressional Record Vol. 141 No. 49.141 Cong Rec S4050. Emergency Supplemental Appropriations and Rescissions Act. March 16, 1995.

[75] U.S. House of Representatives. 104th Congress 1st Session. Making Appropriations for the Department of Defense For the Fiscal Year ending September 30, 1996, and for Other Purposes. Conference Report 104-344. November 15, 1995: 82.

> embrittlement, which has led to stress cracks and resulted in the removal of a number of aircraft from active service. Consequently, the conferees agree to increase the budget request by $50 million to purchase ten of the twenty new wing center section in order to avoid a production break in the manufacture of this component.

Also, conferees noted that although funds were authorized and appropriated for FY1996 to initiate a reactive jammer program for the EA-6B, the Department of Defense chose not to initiate such a program, and elected instead to program funds for such an effort from fiscal year 1999 to fiscal year 2001. Conferees criticized the DoD's decision as "unacceptable," calling the EA-6B's jammers "obsolete." Conferees authorized an additional $32.0 million to initiate the reactive jamming program.[76]

Appropriations for FY1997 totaled $228.6 million for EA-6B modernization ($27 million more than was authorized), and another $127.2 million in the Navy's RDT&E account for EW development, to include Anti-Jam GPS ($3.5 million), jamming techniques optimization ($5 million), ALR-67 radar warning receiver ($8 million), and EA-6B reactive jamming ($32 million).

For FY1998, Conferees authorized $15 million more for EA-6B procurement than had been requested, directing DoD to replace the wing center sections of five more EA-6Bs than the 10 DoD had planned to repair. Appropriators agreed with the need for 15 wing center sections to be replaced, and provided the required $15 million. Additionally, conferees appropriated another $15 million to support jamming upgrades. In FY1998, appropriators provided the Navy with $21.8 million for Electronic Warfare Technology, and $99 million for EW Development in RDT&E funds.

For FY 1999, authorization conferees provided $25 million more than the budget request to fund the acquisition of 9/10 band transceivers for the Prowler. As they had in FY1996 and FY 1997, legislators thus expressed their concern that the Prowler's jammers were not keeping current with emerging threats. Conferees appropriated $95.7 million for EA-6B upgrades, $5 million less than authorized, but $20 million more than requested. Appropriators also provided $37 million for common ECM equipment in the Navy RDT&E account.

For FY 1999 Congress passed a Supplemental Appropriations Act financing the cost of Operation Allied Force. This act provided $300 million for an operational rapid response fund, which DoD indicated would be used to finance a number of EA–6B near-term upgrades, including $45 million for band 9/10 jammers, $39 million for universal exciters, and $30.4 million for miniaturized automated tactical terminals/integrated data modems.[77]

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[76] U.S. House of Representatives. 104th Congress. 2nd Session. National Defense Authorization Act for Fiscal Year 1997. Conference Report 104-724: 567.

[77] U.S. House of Representatives. 106th Congress. 1st Session. Report of the Committee on Appropriations 106-244. July 20, 1999:145.

In FY2000, Authorization conferees increased the budget request by $25 million to procure additional 9/10 band transceivers. Conferees also expressed concern that DoD did not have a serious plan for potential follow-on capabilities. Therefore, conferees authorized an increase to the budget request of $5.0 million to initiate a joint service (Navy/Air Force) analysis of alternatives for a replacement for the EA-6B aircraft. The conferees further directed the Secretary of the Navy to establish a separate concept exploration/product definition and risk reduction program element for the program.[78]

The Electronic Attack Analysis of Alternatives (EA AOA) study was supported by appropriators, who also made available a total of $240 million for EA-6B improvements in FY 2000. They also made available in the Navy RDT&E budget $209 million for EW development (including the Integrated Defense Electronic Countermeasures system or IDECM, EA-6B connectivity, ICAP III spray cooling technology, GPS anti jam) and $36.1 million for electronic warfare technology.

The House appropriations committee report for FY 2000 (106-644, H.R. 4576) expressed strong concern that Operation Allied Force illustrated the on-going need for robust EW support of air operations, and the growing U.S. shortfall in this area.

> "With the retirement of the Air Force EF–111 aircraft, the EA–6B has become the Defense Department's primary escort jammer aircraft to support combat strike missions. The crews and aircraft of Navy and Marine EA–6B squadrons performed admirably during Operation Allied Force. However, due to the Department's overall lack of jamming aircraft, the forces were stretched, air crews were stressed, and the logistics support tail was strained."[79]

House Appropriators also concluded that stealth air operations and EW are complementary. According to House appropriators "This operation also made it clear that even advanced stealth aircraft benefit from escort jamming from the EA–6B, counter to assumptions made when the EF–111s were retired."[80]

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[78] U.S. House of Representatives. 106th Congress. 1st Session. National Defense Authorization Act for Fiscal Year 2000. Conference Report 106-301. August 6, 1999:625.

[79] U.S. House of Representatives. 106th Congress. 1st Session. Report of the Committee on Appropriations 106-244. July 20, 1999:144.

[80] U.S. House of Representatives. 106th Congress. 1st Session. Report of the Committee on Appropriations 106-244. July 20, 1999:144.

Table 3. Summary of Recent EA-6B Related Procurement Funding
(In millions of then-year dollars)

	Request	Authorization Conference	Appropriation Conference
FY1996	0.0	165	165
FY1997	100.6	201.6	228.6
FY1998	86.8	101.8	116.7
FY1999	75.7	100.7	95.7
FY2000	160.7	186	240
FY2001	203.1	186.3	189.3
Total	626.9	941.4	1035.3

The Navy's FY2001 budget request for EA-6B procurement was $203.1 million. The Navy's plan was to use this money to upgrade the Prowler's universal exciter, to upgrade some airframes to the Block 89A configuration (ICAP II) and others to the ICAP III configuration. This money was also earmarked to fund the procurement low-band transmitters. [81] Authorization conferees approved $186.3 million in EA-6B procurement funding. Appropriation conferees made $189.3 million available for FY2001 procurement.

FY2002. For fiscal year 2002, the Navy requested $137.6 million in procurement, and $84.8 million in RDT&E funds for the EA-6B.[82] In their report S. Rept. 107-62 (S. 1416, p. 56), the Senate Authorization Committee met the Navy's request for procurement funding, and increased it by $54.0 million. This money is to be used to purchase ALQ-99 band 9/10 transmitters ($38.0 million), and facilitate structural modifications and improvements to the EA-6B ($16.0 million). Senate authorizors also matched the Navy's request for EA-6B RDT&E funds.

[81]Department of the Navy. Fiscal Year (FY) 2001 Budget Estimates. Justification of Estimates. February 2000. Aircraft Procurement, Navy Volume II: Budget Activity 5.

[82]There are several additional Navy RDT&E programs that, while not focused entirely on the EA-6B, do affect that program. For instance, the Navy requested $5.4 million for work on the Mobile Electronic Warfare Support System and the Tactical Electronic Reconnaissance Processing and Evaluation System. $9.5 million was requested to complete GPS equipment testing on the EA-6B and HH-60H aircraft. $180 million wad requested to develop tactics and define the effectiveness of EA-6B jamming on anti-ship missiles. And, some increment of the $25.7 requested under the Aircraft Engine Improvement Program would apply to the EA-6B.

Table 4. Breakdown of FY2002 EA-6B Budget Request

R&D	$Millions	Procurement	$ Millions
Jammer & Techniques optimization	9	ALQ-99 Pods	22.2
ICAP III Development	56.3	J-52 Engines	8.4
EMD of Low Band Transmitter	5.5	Structural Improvements	49.2
Complete EA AOA	3	Block 89A Avionics	56.9
Update ICAP III to accommodate improved avionics	3	ICAP III	.9
Link-16 Development	8		
Total	**84.82**		**137.6**

The House Authorization Committee (S. Rept. 107-194, H.R. 2586, p.66) matched the Administration's request for procurement funding. The committee also matched the Navy's EA-6B RDT&E request, and added $10.0 million to "accelerate the development of an EA-6B successor." (p.188).

Like the Senate Authorization Committee, the Senate Appropriations Committee (SAC) increased the Navy's EA-6B's procurement request to purchase ALQ-99 9/10 band transmitters. However, the SAC made available $8.0 million for the transmitters, for a total procurement appropriation of $145.6 million. Senate appropriators also matched the Navy's EA-6B RDT&E request.

Congressional EW Working Group. Following Operation Allied Force, Members of the House Armed Services and Appropriations Committees have formed an EW Working Group to increase attention to and support of EW issues. The group is led by Representative Joseph Pitts. Co-chairs include Representative Norm Dicks also from the House Armed Services Committee and House Appropriations Committee members Representatives John M. Spratt, Jr., and Randy "Duke" Cunningham. The working group plans to make certain that budget initiatives are compatible with the broader goals of national security strategy. In a letter to Secretary of Defense William Cohen, the EW Working Group noted that despite the acknowledgment that electromagnetic spectrum control is vital to military supremacy, EW requirements have not received the attention they should in either the armed forces or in Congress.[83] In a June 21, 2000 letter to House Armed Services Chairman

[83]Electronic Systems Forecast, Email Market Alert. Forecast International/DMS. March 6, 2000.

Rep. Floyd Spence, this group recommended a series of hearings to address the state of EW within the Pentagon.[84]

Issues and Options for Congress

Issues

Based on the operational and force structure conditions noted earlier in this report, there appear to be three overarching issues of potential congressional interest regarding the EA-6B force.

First, when assessing the immediate deficiencies in DoD's EW capabilities, the following questions stand out: How might our existing airborne EW platforms be upgraded or augmented before the Prowler is retired in 2015? What approaches exist for increasing the number of airborne radar jamming platforms between 2000 and 2015? Are techniques or technologies available that would help defeat adversaries who employ their radars sporadically, as the Serbs did in Kosovo? When considering ways to improve DoD's radar jamming capabilities, issues include which options are available in the short term and which would most easily transition to, or facilitate the transition to longer-term solutions.

The second set of issues concerns options for replacing the EA-6Bs when they leave service sometime in the 2010-to-2015 era: What is the best long-term strategy for satisfying the airborne radar jamming requirement in the 2015 and beyond time frame? Which platform is best suited for future EW operations?

When considering options for replacing the EA-6B, relevant measures of effectiveness include (1) how "joint" the platform is, (2) the platform's cost, in terms of both unit platform cost and potential operations and sustainment (O&S), (3) the time frame in which the platform would be operational, and (4) characteristics such as range, speed, payload and stealth capabilities, which would determine the platform's operational effectiveness.

A third set of issues concerns the future of EW in the 2020 and beyond time frame. What are the longer-term capabilities that might supplant manned tactical aircraft as the backbone of DoD's radar jamming capability? What merit is there in basing radar jammers on very small UAVs or satellites? What are the primary strengths and weaknesses of each approach? What are the primary obstacles to turning these concepts into reality? If Congress were to appropriate R&D funds to nurture long-term concepts, would it get a good return on its investment? Options for each of these three time periods are discussed below.

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[84]Holzer, Robert. *Poor Management Plagues EW Programs*. Defense News. August 7, 2000:1.

Nearer-Term Options for Augmenting the EA-6B Fleet

Expedite ICAP-III Upgrades. One possible measure to improve the EA-6B's capabilities would be to speed up the Navy's plan for ICAP III upgrades. The current plan is to upgrade 123 aircraft over 10 years. Between the years 2000 and 2004 two Prowler airframes will be upgraded. Starting in 2005, the plans for ICAP III upgrades fluctuate between 18 aircraft per year (2005) to 23 aircraft per year (2009).[85] Congress may wish to examine the feasibility and costs of accelerating this plan. If, for example, the Navy were to enter into Low Rate Initial Production (LRIP) of the ICAP III upgrades earlier, say in 2004, it appears that they could upgrade 32 more EA-6Bs from 2004 to 2006 than is currently planned.

When asked to identify "the number one thing that could be done to improve EA-6B effectiveness," current and former EA-6B crew responded "implement the ICAP III upgrade and incorporate Link 16"[86] Among other things, the ICAP-III upgrade will give the Prowler the ability to conduct electronic support measures (ESM) at the same time the Prowlers are jamming enemy radar emissions. Conducting ESM gives the Prowler crews heightened battlespace awareness, which in turn gives them the ability to conduct their missions in a more proactive manner, rather than letting the enemy take the initiative. The wide-band datalink Link 16 information distribution system would allow the EA-6B to more effectively disseminate electronic order of battle and other information to other Prowlers, SEAD aircraft, and AEW aircraft like the E-3 AWACS or the E-2C Hawkeye. In effect, Link 16 would enable these aircraft to work more as an EW team.

Inventory Management. There are 124 EA-6B airframes in the inventory. However, at any one time,14 Prowlers are either used for testing, or for fleet support, and do not fly operational missions. These 14 Prowlers are said to be "in the pipeline." While military aircraft will always need to be pulled from operational status and move through the pipeline for basic maintenance and upgrades, there may be measures that could be implemented to make the EA-6B pipeline "leaner" and thus keep more Prowlers flying EW missions. For example, reducing the number of EA-6Bs in the pipeline from 14 to 10 aircraft could create another operational squadron.

The Navy is developing an Integrated Maintenance Concept – which Congress could assess – that they hope will produce maintenance cost and schedule savings. This concept would include an examination of the amount of work performed at government maintenance facilities (Naval Aviation Depots, or NADEP) compared to commercial maintenance facilities as regulated by law (such as USC Title 10, Chapter 146, Section 2464).

There is also the issue of how the services manage their EA-6B fleets. Currently, the Marine Corps operates four EA-6B squadrons composed of five aircraft each. The Navy operates 15 squadrons of four Prowlers each. Can greater combat effectiveness

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[85]Source: Naval Aviation Systems Command (NAVAIR).

[86]Telephone conversation with EA-6B pilot, Naval Air Station Whidbey Island, May 18, 2000. Telephone conversation with retired EA-6B Electronic Countermeasures Officer, Washington, DC, May 26, 2000.

be realized by re-aligning Marine Corps and Navy EA-6B squadrons to serve national security interests better? That question appears to be on the minds of senior DoD officials. Secretary of the Navy Richard Danzig, was quoted as saying "We've got Marine EA-6Bs, we've got Navy EA-6Bs. How can we operate them together more efficiently?"[87]

Some have observed that land-based deployments overseas, such as Operations Northern and Southern Watch have disproportionately burdened some of the EA-6B squadrons. The Marine Corps squadrons and five Navy squadrons formed to fill the gap created by the EF-111's retirement have borne this burden, while Navy EA-6Bs assigned to aircraft carriers have seen relatively light service over the past several years. Some argue that it would make more sense to rotate all EA-6Bs through operational hot spots, and thus spread the flying hours and wear-and-tear proportionally through the fleet. Referring to the EA-6B squadrons, now-retired Commandant of the Marine Corps Charles Krulak said "Whether those requirements be for land-based or sea-based commitment, they should be filled on a longest home/next to deploy schedule. All of these aircraft in my view are a national asset and should be apportioned as such."[88] Others argue that deploying carrier-based EA-6B squadrons away from their aircraft carrier threatens the integrity of carrier airwings.

Increase Use of Smart Decoys. Another option would be to accelerate the introduction of radar decoys into the active Air Force, Navy, and Marine Corps inventories. As described earlier in this report, towed radar decoys such as the ALE-50 proved very successful in Kosovo, protecting B-1B and other aircraft from Serbian SAMs. However, these systems, though relatively cheap as well as effective are not deployed on every U.S. aircraft. Also, more sophisticated variants are experiencing developmental difficulties. For example, the joint Navy/Air Force IDECM with its fiber optic towed decoy (FOTD), has experienced a 14 month delay in engineering and manufacturing development (EMD) and 50 percent increases in the average procurement unit costs. The IDECM is slated to begin production in FY2004.[89]

Unlike towed decoys, tactical decoys can be launched from outside a theater and fly long distances to invade enemy airspace. The tactical air-launched decoy and the BQM-74 for example, were used effectively in Operation Desert Storm. More advanced decoys might be developed which could simulate U.S. aircraft more convincingly than today's decoys, but might also appear as multiple aircraft on enemy radars. The Air Force has begun converting some surplus AGM-86B air-launched cruise missiles into so-called "brilliant decoys." This decoy can resemble a single fighter or several can imitate an entire flight of aircraft (2-4 airframes). To add further realism to its ruse, the decoy can employ defensive countermeasures like a real

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[87]Castelli, Christopher J. Navy Secretary Optimistic Air Campaign Talks can Shape Budget. *Inside the Navy*. February 28, 2000.

[88]Holzer, Robert. EA-6Bs Stripped from Carriers. *Defense News.*July 12, 1999: 20.

[89]B-1 Bomber Upgrade Program Falters Again with New Delays, Expenses. *Inside the Air Force*. May 5, 2000. and Air Force Programs Included in DoD's Latest Selected Acquisition Reports. *Inside the Air Force*. April 14, 2000.

aircraft. It drops chaff when illuminated by a hostile radar. When targeted by an infrared (IR) guided missile, it can drop flares.[90]

Figure 4: EF-111 Stored at AMARC

In most military operations, planners avoid reliance on any one technique or system. Instead, they apply numerous, mutually reinforcing techniques and technologies to avoid single-point failure and increase the likelihood of achieving mission success. To ensure aircraft survivability against radar directed SAMs, U.S. aircraft will require not just stealth features and dedicated electronic jamming, but also smart defensive countermeasures such as towed and expendable decoys. All three of these assets together will enhance aircraft survivability against a wide and evolving set of threats much better than any one alone. Martin van Creveld writes, "In the case of electronic warfare as in any other kind of warfare, no weapon and no method is sufficient on its own. Not one is suitable for use under all conditions, and each separately is capable of being countered in ways which, if far from simple, are often obvious enough."[91]

Considering the inevitable waning of the EA-6B over the next 15 years another option would be to emphasize the defensive countermeasures leg of the "EW Triad." This would include producing and deploying decoys on many aircraft types. Many allied and friendly countries such as France, Germany, Sweden and the UK are also developing sophisticated decoys. If development problems with U.S. decoys preclude their timely and ubiquitous deployment, import of decoys from allied nations may be an option to consider when augmenting DoD's active jamming capability.

Resurrecting the Raven. Returning some EF-111 Ravens to active service might prove another useful short term measure to augment today's overworked EA-6B fleet. There are currently 33 EF-111s stored at the Aerospace Maintenance and Regeneration Center (AMARC), Davis-Monthan AFB, in Tucson, Arizona. (This

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[90]Zaloga, Steve. *World Missiles Briefing*. Teal Group Inc. March 2000.

[91] Van Creveld, Martin L. *Technology and War: From 2000 BC to the Present.* The Free Press, New York, 1991: 273.

facility is often referred to colloquially as the U.S. military aircraft "bone yard.") These aircraft began their internment at AMARC in September 1997. The process culminated in 1998 when the Raven was retired and withdrawn for service.[92]

The EF-111 Ravens at AMARC are currently being stored under a number of conditions. Some are in "Type 1000 Long Term Storage", where the integrity of the aircraft systems is maintained, aircraft are preserved every four years, and no parts can be scavenged from them without Air Staff approval. Other Ravens are in "Type 2000 Storage for Reclamation," where parts can be removed and either returned to active service, or exported to FMS (Foreign Military Sales) countries that still fly the F-111.[93] Returning EF-111s to service would entail more than just reconditioning the aircraft. The personnel (including both pilots and ground crew), maintenance and logistics support structures would also need to be revived.

EB-52. Another measure that might be considered to augment the EA-6B fleet in the near term is the potential use of the B-52 to perform stand-off jamming. The U.S. Air Force has initiated a study to assess the feasibility of converting nine B-52s into stand-off jamming platforms as a near term augment to the EA-6B.

Initial Air Force thinking on a concept of operations suggests that B-52s could fly a long range bombing mission and still have enough fuel to loiter outside the range of enemy SAMs and anti-aircraft guns and protect other fighters and bombers with radar jamming and deception as they enter, operate within, and exit hostile air space. It is estimated that the conversion program would cost approximately $334 million and would take about three years of testing and renovations to convert three B-52s to the new mission configuration. The remaining six bombers would be completed in another two years.[94]

One obstacle which must be overcome is that fact that the B-52 currently is fitted with older electronic warfare gear designed for self protection. More modern receivers and processing equipment would need to be integrated into the platform to allow it to effectively conduct electronic attack missions.

The B-52's large airframe presents engineers with a number of possibilities for integrating EW equipment. The Air Force study is examining "off-the-shelf" jamming equipment already in service rather than developing new systems. The jammer's antenna, for instance, could be located in a pod, mounted under a wing. The electronics required to generate the jamming signal could be installed inside the B-52's pressurized crew quarters.

The B-52 crew currently includes an electronic warfare officer, whose primary concern is protecting the B-52 by identifying threatening radars and missile launches and operating the bomber's missile and radar defenses. The proposed new mission

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[92]Lt.Col. Robert Feliz, USAF Office of Legislative Affairs, Weapons Division.

[93]Telephone conversation with Mr. Harry Brannam, AMARC.

[94]Telephone conversation with Maj. Robert Schwarz, USAF. EB-52 Program Manager. Air Combat Command.

would require the electronic-warfare officer to watch over a wider area and help protect planes other than his own B-52 by using signals from the jamming equipment to deceive enemy weapons.[95]

Re-Starting the EA-6B Production Line. EA-6Bs produced in the early 2000s could incorporate modern manufacturing techniques that might reduce cost, and the aircraft could surely be upgraded with modern electronics and engines. The primary obstacle to this approach is that the last Prowler was delivered in 1991. In effect, the EA-6B production line has lain fallow for 10 years.

The atrophy of an aircraft production line's people, processes, and technologies, including subcontractors and specialized human expertise, gathers momentum over time. Proponents of re-opening the EA-6B production line would argue that production lines have been resurrected in the past and that the EA-6B line could be functioning in approximately five years.[96] Opponents would counter that the only aircraft production lines that have successfully been restarted did so after only a short pause, such as the E-2C Hawkeye which was re-opened after a two year hiatus.[97] Re-starting the EA-6B production line at this stage would not be cost effective, they would argue, because the resulting aircraft would be very expensive. The cost of restarting the line would be amortized over a short production run.

Extending the EA-6B's Service Life. Another option would be to extend the EA-6B's service life beyond 2010 or 2015. This may be feasible, but it might also be expensive. By the 2015 time frame, many EA-6Bs will be more than 40 years old. To achieve this long life span, the EA-6B has been given almost continuous upgrades since the early 1970s including modifications to the central wing sections.[98] Many would argue that the EA-6B has already experienced its SLEP (service life extension program), and that keeping the Prowler flying past 2015 will realize diminishing returns.

Those in favor of SLEPing the EA-6B past 2015 might point out that the B-52, which entered the operational force in 1955 is older than the EA-6B and is projected to fly even longer than 2015. Why not the Prowler? First, unlike the B-52, the EA-6B is a very high demand aircraft. As discussed in the *Current Status* section of this report, the EA-6B accompanies every U.S. air strike. As described in the section of this report on Kosovo, the Navy and Marine Corps literally flew the aircraft around the clock. Second, the EA-6B lands on aircraft carriers. The violence of carrier take off and landings puts stresses on the EA-6B airframe that the land-based B-52 never experiences. Also, the maritime environment itself is harsh on sea-based aircraft. Finally, the B-52 flies a relatively benign flight profile compared to the Prowler. It

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[95] Rolfsen, Bruce. B-52's Next Mission: Radar Jammer. *Air Force Times*, March 20, 2000:24.

[96] Haffa, Robert P. and Barry D. Watts. *Brittle Swords: Managing the Pentagon's Low-Density, High-Demand Assets.* Northrop Grumman Analysis Center. Washington, DC. July 2000: 12.

[97] Telephone conversation with Mr. John Vosilla, Northrop Grumman Public Affairs, June 6, 2000.

[98] See *EA-6B Upgrades* section at the front of this report.

does not fly tactical missions that often put heavy stress on the airframe from high rates of acceleration or maneuvering. The EA-6B has more occasion to fly stressful flight profiles.

Converting A-6s to EA-6Bs. A final possibility would be to transform the A-6 Intruder aircraft into EA-6Bs. Most defense analysts concur, however, that this conversion would not be economically feasible because the Prowler was developed concurrently with the A-6, not derived from it.[99] The Prowler is a four seat plane versus the two seat A-6. It has a longer, sturdier fuselage to accommodate a much heavier "bring back" weight to the aircraft carrier. In addition to the additional crew, the EA-6B possesses distinguishing characteristics such as its pod-shaped fairing at the top of the vertical fin which holds sensitive surveillance receivers. An EA-6B derived from a pre-existing A-6 would cost as much as a brand new EA-6B, but the airframe would already have the "milage" of the original A-6 aircraft.[100]

Mid-Term Options for Replacing the EA-6B in 2015

While some of the options detailed above might usefully shore-up current EW capabilities, they would not provide DoD with a long-term, joint airborne EW capability to replace the EA-6B.The Marine Corps and the Navy have stated their desire to continue conducting this mission in the post-Prowler era, and the Air Force is re-examining its stance on this issue. This section will focus on several platform options for replacing the Prowler in the 2015 time frame. When considering fixed wing aircraft to replace the EA-6B Prowler, five aircraft designs are most frequently discussed: the F/A-18G Super Hornet, the Joint Strike Fighter, the F-15E Eagle, F-16 Fighting Falcon and the F-22 Raptor. Building a new aircraft, one designed specifically to conduct the EW mission or employing UAVs for EW are also options to be assessed. Each of these are discussed later in this section.

Assessment Criteria. A number of attributes might be usefully assessed in considering the merits of various EA-6B replacement options. These attributes are: (1) aircraft unit cost; (2) operations and maintenance considerations; (3) degree of "jointness", (4) number of crew (for manned aircraft options); (5) initial operating capability and service life; and (6) a variety of operational characteristics that would affect the plane's ability to penetrate enemy airspace and escort attack aircraft into and out of the target area. These attributes are described below, and will be used as a framework to assess the pros and cons of various EA-6B replacement options.

Cost. All things being equal, an EW aircraft that costs less than another is obviously advantageous. However, data on potential procurement cost is generally available, but information on annual operating and maintenance (O&M) costs is generally not available, making it difficult to make comparative calculations.

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[99]Abolufia, Richard. Teal Group Inc. *World Civil and Military Aircraft Briefing*. Fairfax, VA. April 2000.

[100]Hebert, Adam. Experts See No Immediate Solutions to Jamming Capability Shortfalls. *Inside the Air Force*. April 23, 1999.

Every aircraft in the services' inventory (in fact, every military platform) requires an operations, maintenance, and logistical support structure. Much of the cost and equipment in the military is associated with what is often called the "tail" (e.g. those systems that don't go into combat) as opposed to the "tooth" (e.g. those systems that do go into combat). The "tail" is usually larger than the "tooth." Therefore, by reducing the number of different kinds of aircraft, DoD can sometimes reduce operations and maintenance costs. The EF-111 for instance, was able to use the same maintenance facilities as the F-111. The maintenance crews responsible for taking care of the F-16 didn't require additional or unique training to maintain the F-16CJ. If four S-3 Viking aircraft took up a given amount of space in an aircraft carrier hangar, four ES-3As consumed the same amount of space. All existing U.S. EW aircraft, whether attack jammers such as the EF-111, EA-6B, and EC-130H; ELINT or ECM aircraft such as the RC-135 and EP-3E; or SEAD aircraft such as the F-4G and F-16CJ are variants of "parent" aircraft.

Jointness. If DoD uses one aircraft to replace the EA-6B it almost certainly will be a joint aircraft. A joint aircraft would be one that could land on aircraft carriers, and satisfy the expeditionary needs of the Air Force and the amphibious needs of the Marine Corps. This assessment will therefore consider a particular aircraft's degree of "jointness" as a measure of merit. However, it may prove impossible to procure a single, joint aircraft that satisfies all future DoD EW needs. Instead, it may prove most practicable for each service, or at least the Air Force and Navy, to base their EW capabilities on aircraft specific to their service. In this case, however, it also appears likely that the EW gear itself could be joint – the pods, antennas, transmitters, exciters and computers -- or at least should maintain a very high degree of commonality.

Crew Number. Aircraft that originally have only a pilot would need to be converted to a two crew configuration, increasing cost and potentially degrading aircraft performance. While increased automation and the use of computer decision aids will reduce the need for a four crew aircraft such as the EA-6B, it is probably infeasible for a single pilot to effectively operate an EW aircraft. Flying the aircraft, monitoring the electronic spectrum for "pop-up" threats, directing jamming signals, and modulating the wavelength and frequency of the signals would be too much work for one person to perform effectively. (UAVs face an even greater challenge in this regard)

Initial Operating Capability (IOC). A gap in U.S. EW capabilities would put U.S. forces at unnecessary risk. As discussed earlier, the Prowler is planned for retirement in the 2010-to-2015 time frame, and its high operational tempo will make extending this date unlikely. The exact number of aircraft required to replace the EA-6B has yet to be determined. This number will depend on a variety of factors, including assumptions on future military threats and the types of conflict the U.S. is likely to face. As a rough planning factor, however, one can assume that DoD will require more EW aircraft than the 124 Prowlers that exist today. It is there fore important to assure that replacements are fielded at a rate that would insure a smooth transition. Some analysts recommend the 2006 - 2007 time frame. Converting existing operational aircraft to the EW mission could be advantageous in terms of IOC and availability compared to developing new aircraft. However, new aircraft would have the advantage of a longer service life.

Operational Characteristics. The most effective strike package of the future envisioned by many analysts would be one where all the aircraft, not just the attack aircraft, were stealthy. This strike package, including the EW plane would use their low observability to evade enemy early warning and tracking radars and achieve tactical surprise over the target. Optimally, the EW aircraft would only turn on its jammer at the last moment to increase the strike package's survivability and to protect the aircraft after they released their payloads and egressed the target area. Of course, the EW aircraft would also use its jammer earlier in the mission if the strike package were detected and threatened. To operate along these lines, the EW platform would not just need to be stealthy, but also would require the range, speed, and maneuverability to keep up with the attack aircraft. Inherent in this assessment is an assumption that the aircraft has sufficient payload capacity to carry the required EW equipment. The ability to carry the equipment internally, as opposed to in external pods is also advantageous, as this would help maintain a stealthy profile.

F/A-18G.[101] The F/A-18 aircraft is manufactured by the Boeing Company at its McDonnell Douglass plant in St. Louis, Missouri. An EW variant of the F/A-18E/F (dubbed the "Growler) is favored by many parties to replace the EA-6B Prowler. Chief of Navy Aviation, RADM John Nathman has said that he thinks the F/A-18G is "the most pragmatic solution for Navy."[102] He has been quoted in the press as having said "A very good answer for us is a Growler...an F-18E/F-based aircraft. It uses the ICAP III capability of the EA-6B...It's a tailhook aircraft, its also a striker, its an aircraft that provides for, I think, much more compatibility with the strike force because of the equal speeds."[103]

Proponents of the F/A-18G as a follow-on to the EA-6B would emphasize the following attributes. First, the F/A-18F is a large, two seat aircraft. The aircraft can carry almost 18,000lbs of external payload, more than enough to accommodate the ALQ-99 and other jamming equipment. Second, the Super Hornet is a "tailhook" aircraft that can land on aircraft carriers. Although the F/A-18F hasn't been designed with specific Air Force specifications in mind, it can be just as "joint" as the Prowler, which is flown by Air Force crews. Third, the F/A-18E/F is already going to be part of carrier fighter wings, so making an EW variant will realize O&M savings throughout the force. Finally, and perhaps most importantly, the Super Hornet is a real aircraft, its supporters would argue. It has been in production since 1997, and is expected to enter service in 2001. It will be available in sufficient numbers in the Prowler's planned retirement window.

Opponents of an F/A-18G variant to replace the EA-6B would argue that the Super Hornet is not a joint aircraft. Only the Navy is buying it. Opponents would also say that although the Navy's purchase of hundreds of Super Hornets will result in some O&M economies of scale, the JSF will, by way of comparison, be bought in

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[101]See CRS Issue Brief IB92035: *F/A-18E/F Super Hornet Aircraft Program* for more details.

[102]Conversation with Rear Admiral John Nathman,, Director, Air Warfare Division (N-88) Office of the Chief of Naval Operations. April 4, 2000.

[103]Skibitski, Peter J. Nathman Favors 'F/A-18G' Alternative as EA-6B Prowler Complement. *Inside the Navy*. March 27, 2000.

thousands of units across three services. Making an EW variant of this aircraft would result in much greater O&M savings than the Growler variant. Furthermore, at approximately $73 million per aircraft, the F/A-18G is more expensive than other EW options.

Also, opponents of the F/A-18 option would argue that the Growler may have operational shortcomings compared to other aircraft candidates that would result in difficulty executing the optimal strike package operational concept described earlier. For instance, the F/A-18 is not a stealthy aircraft. It also has a short range compared to other attack aircraft. Finally, the GAO[104] and others have criticized the Super Hornet's lack of maneuverability, and chronic wing vibrations that damage externally carried armaments. What effect might this vibration have on delicate EW gear? All of these deficiencies, the F/A-18s opponents would argue, would make it difficult for the Growler to escort attack aircraft into, around, and out of enemy territory.

Joint Strike Fighter.[105] Two teams are competing to produce the Joint Strike Fighter. The Boeing Company and its subcontractors are pitted against a team led by Lockheed Martin and Northrop Grumman. It has been reported that "The Marine Corps wants to retain the electronic attack mission; and the service has proposed using the Joint Strike Fighter."[106] While the JSF Program Office has yet to sponsor any official studies of a JSF EW variant, the contractor teams (led by Lockheed Martin and Boeing) have initiated internal studies of how the aircraft could be modified to fill the gap created by the EA-6B's retirement.

Those in favor of creating an EW JSF variant would point out first that the JSF is a truly joint aircraft, designed with all the services' requirements in mind. It can land on an aircraft carrier or, if need be, unfinished runways and similar rough surfaces. Also, since the current plan is to buy a very large number of the aircraft (almost 3,000 units) the JSF option will generate more O&M savings than any other theater aircraft. Buying even more of them to perform the EW mission will only add to the infrastructure savings. Furthermore, with a projected cost of $30-$41million a copy, (in FY2001 dollars) the JSF could be a less expensive fighter or attack EW aircraft than anything else that hasn't already been built, and perhaps even competitively priced with legacy aircraft.

Second, proponents of the JSF would highlight the aircraft's favorable operational capabilities. The JSF's stealthy profile will be second only to first tier stealth aircraft such as the B-2 and F-22. It will have good range and maneuverability, which, in addition to its low observability, will enable the JSF EW variant to escort an attack package throughout the mission flight profile. Also, depending on which version of the JSF is chosen for production, the JSF could have a large internal weapons bay (140 cubic feet, enough for two 2,000 lb bombs) which

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[104]See for instance GAO Report NSIAD-96-98.

[105]More information on the JSF can be found in CRS Report RL30563: *Joint Strike Fighter (JSF) Program: Background, Status, and Issues.*

[106]Skibitski, Peter J. Nathman Favors 'F/A-18G' Alternative as EA-6B Prowler Complement. *Inside the Navy*. March 27, 2000.

could accommodate the EW gear and thus not degrade the aircraft's stealthy profile with externally mounted hardware.

Finally, the JSF's proponents would note that the aircraft is an advanced system in the early stages of development. This is advantageous on two levels. First, EW components could be more easily incorporated directly into the aircraft design rather than added on to an existing airframe in retrospect. Second, as a next generation, joint airframe, the JSF is based on versatile and modular designs. This makes future retroactive modifications to the aircraft relatively easy.

Those against building JSF EW aircraft would point out that the JSF is currently envisioned as a single-seat aircraft. Regardless of the aircraft's modular foundation, adding another seat would require aeronautical tradeoffs in the airframe and would likely increase the JSF's unit cost.

Finally, JSF opponents would also make the basic point that the JSF simply does not exist. The program is in the early stages of development and in fact there are no guarantees that it ever will be built. Defense Appropriations for FY2001 reduced JSF funding by $150 million and has delayed the program by three months. Even in a best case scenario, the JSF's 2010 IOC would likely leave a real gap between the EA-6B's retirement and a fully functioning EW JSF force. The United States needs to take tangible steps today to replace the EA-6B and the JSF development and production timelines do not make this aircraft a viable option, its opponents would argue.

F-15E Strike Eagle. The F-15 is manufactured by the Boeing Company at its McDonnell Douglass facility in St. Louis, Missouri. The F-15C is currently the premier air superiority fighter in the Air Force inventory. The current plan is to replace the F-15C with the F-22 Raptor for air superiority missions. The F-15E Strike Eagle is a heavily modified, two-seat dual role variant with both air-to-air and air-to-ground capability. Forty eight Strike Eagles were used against Iraq in the 1991 Persian Gulf War, primarily hunting Scud missile launchers using its LANTIRN (Low-Altitude Navigation and Targeting Infrared for Night) system.[107] It is expected that the Joint Strike Fighter, and to some degree the F-22, will assume the F-15E's air-to-ground duties in the future. There were no funds in the administration's FY2001 budget request for F-15C or F-15E aircraft.

Those in favor of replacing the EA-6B with an F-15E variant would make the following points. First, the Strike Eagle is an operational aircraft currently in the U.S. inventory and could be given an active EW capability well prior to the Prowler's retirement. Also, the Strike Eagle is a battle proven and effective airframe, with good range and payload capability.

Second, the F-15E has other qualities that make it a promising candidate for the EW role. It is, for instance, a two seat aircraft. Also, Strike Eagle crews are already operating sophisticated EW gear. The F-15E uses an integrated countermeasures system called the TEWS (tactical electronic warfare system). A Strike Eagle's TEWS can jam radar systems operating in high frequencies, such as radar used by short-range

[107]There were no confirmed kills of mobile Scud missile launchers during this conflict.

surface-to-air missiles, AAA, and airborne threats. TEWS is being upgraded to give it the ability to jam threats in mid-to-low frequencies, such as long-range radar systems.

Third, F-15E proponents would argue that the Strike Eagle offers cost savings compared to other EW platform options. At approximately $55 million each, the Strike Eagle would be less expensive to produce than either the F-22 or the F/A-18G. Furthermore, it was reported in June 2000 that a Boeing study concluded that new manufacturing technologies should enable Boeing to reduce the cost of building F-15 aircraft by about half.[108] If this were true, a $27.5 million Strike Eagle would make an even stronger argument.

Finally, proponents would argue that, although not a new aircraft, the F-15E is robust and can be expected to be operationally useful for decades. It has a strengthened airframe for increased gross weight at takeoff and can maneuver at high gravities (Gs). The F-15E structure is rated at 16,000 flight hours, double the lifetime of earlier F-15s.

Opponents of an EW variant of the F-15E would point out that the Strike Eagle is neither designed to land on aircraft carriers nor is it a joint aircraft. Second, the F-15E is an old design. Although upgraded significantly in the 1980s, its basic design and technology derive from work in the 1960s. The F-15E is not a stealthy aircraft, its opponents would observe.

While the F-15E might appear to have a lower cost than some other potential EA-6B replacement options, the Strike Eagle will require significant upgrades and modifications to make it a useful jammer. This could drive up the unit price, opponents would argue.

F-16 Fighting Falcon. The F-16 is manufactured by Lockheed Martin of Fort Worth, Texas. The F-16 is described as "a compact, versatile, and low-cost multirole fighter aircraft that is highly maneuverable and has repeatedly proved itself in air-to-air combat and air-to-surface attack....The F-16 is the workhorse of the USAF fighter fleet."[109] Although a very successful aircraft, both in terms of performance and numbers manufactured and exported, the F-16 is slated to be replaced by the Joint Strike Fighter in the 2010 time frame.

Those in favor of building an EW variant of the F-16 would probably point out first that this aircraft already has been optimized to conduct the suppression of enemy air defenses (SEAD) mission. Approximately 100 F-16CJ (1 seat) and F-16DJ (2 seat) models employ the AGM-88 HARM missile, HARM Targeting System (HTS) and the ALQ-119 electronic self protection jamming pod. While the SEAD mission is not synonymous with the active EW mission, the technologies and operational concepts employed are similar to active radar jamming. For instance, crew operating the F-16J can autonomously locate enemy threat radars and launch the HARM missile. This

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[108]Mulholland, David. "F-15 Costs can be slashed, says Boeing report." *Jane's Defense Weekly*. June 14, 2000.

[109]Air Force Magazine, *2000 USAF Almanac*, May 2000: 140.

aircraft and the crews already have capabilities in the EW realm that make them good candidates to replace the EA-6B, proponents would argue.

Another argument in favor of the F-16 is its unit cost. By far, proponents contend, the F-16 is the most reasonably priced fighter in the U.S. inventory. Unit costs are affected by a variety of factors, such as the number of units procured, but even at its highest estimates ($25 million) the F-16 is tens of millions of dollars less expensive than the lowest estimate for the JSF, and one seventh the cost of the F-22. Also, operations and maintenance costs would likely be kept to a minimum since the F-16 is already copiously represented in the U.S. Air Force inventory.

Opponents of an EW variant of the F-16 would make the following points. First, this is a USAF aircraft. It is not joint, and not found in the inventories of the Marine Corps nor the Navy. Furthermore, the F-16 can not land on aircraft carriers and is thus unsuitable for the Navy.

More important, opponents would say, the F-16 is an old design. Although it has performed admirably, it is based on 1960s technology and won't last much past the JSF's IOC in 2010. As an older aircraft, it doesn't incorporate stealthy designs and future efforts to reduce its aircraft signature will be difficult, especially because the aircraft has no internal weapons volume, and all EW gear will need to be hung from underwing.

F-22 Raptor.[110] The F-22 is built by Lockheed Martin in Marietta, Georgia and Fort Worth, Texas. The Boeing Military Airplanes Division in Wichita, Kansas is a major sub-contractor. The F-22 Raptor is a next-generation fighter/attack aircraft using the latest stealth technology to reduce detection by radar. Equipped with more advanced engines and avionics than the current F-15 Eagle, the F-22 is expected to maintain U.S. Air Force capabilities against more sophisticated aircraft and missiles in the 21st century. The current plan is to buy 341 Raptors.

Those in favor of creating an EW variant of the F-22 would point out that the Raptor's expected IOC of 2005 would make it available well in advance of the EA-6B's retirement. Also, the aircraft's good range and excellent stealth capabilities would enable it to escort a strike package through the most hostile airspace. Furthermore, the F-22's payload capability (enough internal storage to carry two 1,000 lb bombs, and four underwing hardpoints capable of carrying 5,000 lbs each) should be sufficient to carry the required EW equipment, proponents would argue.

Proponent's main argument would probably be that the F-22 will be the world's most advanced aircraft and will already be outfitted with the most powerful and capable computers and radars. These systems will combine with the requisite EW apparatus to create a very effective EW capability.

Those against creating an F-22 EW platform to replace the EA-6B would point out first that the Raptor will be a relatively expensive aircraft. At an estimated $183

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[110]For more information on the F-22 Raptor see CRS Issue Brief IB87111: *F-22 Raptor Aircraft Program*

million each, the F-22 is a "silver bullet" asset and is simply too expensive to be used for EW missions. Furthermore, the F-22 is a single seat aircraft and making it a two seat aircraft would likely increase costs even further.

Also, opponents would argue, the F-22 is not a joint aircraft and is not designed to land on aircraft carriers. While the F-22 does have a small amount of internal storage space, it is probably not enough to house all the required EW gear and hanging EW equipment from the Raptor's wings would compromise its stealthy design.

Table 5. Summary of Estimated Capabilities and Characteristics of Potential Fixed-Wing Aircraft EW Jammers[111]

	F/A-18E/F	JSF	F-15E	F-16	F-22
Estimated Unit Cost[112] (millions)	$73	$30-$41	$55	$17-$25	$183
Inventory[113]	548	2,912	204	1431	341
IOC	2002	2010	1989	1979	2005
Crew	2	1	2	1/2	1
Joint Aircraft	No	Yes	No	No	No
CV Capable	Yes	Yes	No	No	No
Stealth	Modest	Good	None	None	Excellent
Combat radius	410 nm	772 nm	687 nm	740 nm	869 nm
EW Payload Volume internal/	none	large	none	none	limited
external	large	moderate	large	moderate	moderate

[111]Information in this table derived from CRS Report RL30563, *Joint Strike Fighter (JSF) Program: Background, Status, and Issues*. CRS Issue Briefs IB87111: *F-22 Raptor Aircraft Program*, IB92035: *F/A-18E/F Super Hornet Aircraft Program*. Air Force Magazine, 2000 USAF Almanac, May 2000, and Aboulafia, Richard, *World Military & Civil Aircraft Briefing*, Teal Group Inc.

[112]DoD portrays JSF unit costs in terms of a Fly Away cost of $25-$30 in 1994 dollars. Adjusting for inflation generates a cost of $30.5-$41.4 in FY2001 dollars. Costs for other fighters in FY2000 dollars. F-15E estimate does not account for reported ability to reduce cost by 50%. F-16 cost derived from DoD's 1994 Selected Acquisition Report (last SAR for F-16).

[113]Inventories for F-15, F-16 are actual. Inventories for F/A-18, JSF and F-22 are planned.

All-new Aircraft Design. Another option to consider would be to develop an entirely new airplane design. Given the 15- to 20-year period that might be needed to develop a new aircraft design, such a program, if begun now, might permit the first new-design aircraft to begin procurement around 2015 or 2020, when the EA-6Bs are scheduled to leave service. Developing an all-new design might also permit DoD to develop a joint EW aircraft that reflects input from all the services on desired operational characteristics. Such a plane could offer life-cycle cost advantages to DoD by permitting the use of common training and maintenance facilities and spare parts supplies for the EW planes operated by all the services.

An entirely new aircraft design, however, would likely require several billion dollars, and possibly more than 10 billion dollars, to develop. This substantial development cost would be amortized over a somewhat limited production run of perhaps less than 200 aircraft, adding tens of millions of dollars to the average acquisition (i.e., development plus procurement) cost of each aircraft. The acquisition cost of these aircraft would be further increased by virtue of them being the first aircraft built to this basic design. Industry may need to acquire new tools, jigs, and other equipment to build the aircraft, and the entire aircraft production run would be at or near the top of the manufacturer's learning curve for producing the design.[114] Lastly, these aircraft, being of a different basic design from existing DoD aircraft, would not be able to take advantage of the training and maintenance facilities and spare parts supplies already established for existing DoD aircraft types. In this sense, an all-new design, even if it employs a common set of training and maintenance facilities and spare parts supplies for EW aircraft operated by all the services, might still incur higher operating and support costs than an EW aircraft derived from an existing aircraft design, making this option potentially disadvantageous to DoD in terms of life-cycle costs.

The potentially high costs associated with developing, procuring, and supporting a limited number of all-new aircraft appear to be the major reason why periodic DoD examinations in recent years of this option have resulted in decisions not to pursue it, and why there is little if any discussion of this option today. Given the costs of this option, the most likely scenario for pursuing it would be a determination (not currently anticipated by most observers) that EW aircraft derived from existing aircraft designs would be operationally inadequate in some way.

UAVs. A final option would be to deploy EW UAVs as replacements for the manned EA-6B. Current UAVs and those now under development appear to lack the size and power needed to carry today's EW jammers and antennas. The EW UAV option would thus appear to involve developing a new UAV design with adequate

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[114]The production learning curve plots the progressive reduction in labor-related costs associated with manufacturing many copies of a particular item in succession. As more units are produced, workers learn how to perform their steps in the production process more quickly, and labor-related costs are reduced. For a discussion of the learning curve in defense acquisition programs, see CRS Report 96-785 F, *Navy Major Shipbuilding Programs and Shipbuilders: Issues and Options for Congress*, by Ronald O'Rourke. Washington, 1996. (September 24, 1996) p. 95-110. This discussion focuses on learning curve effects in shipbuilding but can be applied to learning-curve affects in aircraft manufacturing, where learning-curve theory was first developed.

size and power, possibly in conjunction with a parallel effort to develop new EW jammers and antennas that are smaller and require less power to operate.

The EW UAV option might be broadly consistent with the policy goal set forth during a Senate Armed Services Committee hearing on February 8, 2000 by Sen. John Warner, for the armed serves to have unmanned vehicles account for one-third of all their strike platforms by the year 2010. Consistent with this goal, the services are now pursuing programs to develop strike-capable UAVs known as unmanned combat air vehicles (UCAVs). If the services in the future deploy UCAVs, it might be operationally appropriate for these unmanned vehicles to be escorted and supported by unmanned EW UAVs rather than manned EW aircraft. It might also be viewed as broadly consistent with the earlier history of developing U.S. manned EW aircraft (the EF-111 and EA-6B) from existing manned attack aircraft (the F-111 and A-6).

The technical feasibility of the EW UAV option in this time frame is not clear. DoD UAV development programs are generally regarded as having proceeded slowly and haltingly since the early 1980s. On the basis of DoD's rather limited rate of progress in developing and fielding UAVs over the last 20 years, it might be reasonable to question whether DoD could develop and begin procuring a new EW UAV by 2015 or 2020. Some observers, however, argue that DoD's relatively slow progress on UAVs in the past has been due to lack of enthusiasm (or outright opposition to) UAVs on the part of DoD, rather than any technical difficulties associated with UAVs. Indeed, DoD's efforts to manage its UAV development programs have been criticized by Congress and others on several occasions. On these grounds, it might be argued that an EW UAV (just like a new EW manned aircraft) could be developed in 15 or 20 years – provided that the effort received adequate emphasis and support from DoD and Congress.

Even with adequate support, however, developing an EW UAV might pose significant technical difficulties. The EW functions performed by the crew members of EA-6Bs are complex. Automating these functions might require the development of very sophisticated UAV hardware and software, and extensive system integration. Given DoD's recent experiences with other sophisticated weapons acquisition programs, the software development and system integration work might pose particular challenges, even in a program with a 15- or 20-year time schedule. A parallel effort to reduce the size of today's jammers and antennas might also pose technical challenges, even with continued advances in electronics.

The potential cost implications of the UAV option are difficult to assess. Developing a fully capable EW UAV might require several billion dollars. A parallel effort to develop smaller and lower-power jammers and antennas would add further to development costs. Once developed, however, an EW UAV could have a unit procurement cost lower (perhaps substantially lower) than that of a manned aircraft due to the avoidance of costs associated with crew-related design elements such as the cockpit, display systems, and life-support systems. Once fielded, EW UAVs would not incur the operation and support costs associated with maintaining a pilot and other airborne crew members, but there would be offsetting costs associated with maintaining the ground-based personnel that would likely be needed to remotely operate the aircraft. EW UAVs would also require their own training and maintenance facilities and spare parts, unless these could be made common with those of other UAV and UCAV programs.

An EW UAV, like a UCAV, might offer potential operational advantages in terms of greater stealth (due to reduced size, the avoidance of the need for having a cockpit, which is a potential source of radar reflections, and the ability to locate other features, such as the landing gear doors, in places where they are better hidden from radar) and the ability to perform more stressful maneuvers than can be performed by manned aircraft. And as with UCAVs and other UAVs, an EW UAV, if shot down, would not risk the loss or capture of any crew members.

As with other UAVs, however, an EW UAV, even if equipped with sophisticated on-board systems, might not be as operationally flexible – might not be able to react quickly to changing battlefield conditions – as a manned aircraft whose on-scene crew can observe conditions at first hand and make rapid decisions on how to react to them. Given the potential for enemy forces to employ mobile air-defense systems, decoys, and other deceptive techniques, the more limited operational flexibility of an EW UAV could be a significant operational disadvantage.

Longer-Term Options for 2020 and Beyond

It is probably not too early for Congress to consider how DoD will conduct EW in the post 2020 time frame. Considering the length of time it currently takes to field a major weapon system, today's R&D investments will probably have a tangible impact on the programs that emerge in the second decade of the 21st century. There are two areas that are frequently discussed as post-2020 EW options. These areas are (1) space-based jamming, and (2) micro UAVs.

Evaluating Future EW Platform Effectiveness. There is a fundamental physical principle that dominates EW platform design, operations, and effectiveness. This principle is often referred to as R^2 (pronounced "r-squared") and it refers to the dissipation of radar energy. Understanding this concept helps illustrate the pros and cons of basing EW jammers on small UAVs or in space, and why these are long-term options.

Jamming energy density decreases rapidly with distance from the jammer. The amount of radar energy that must be transmitted to jam a given radar increases at the square of the distance from the radar. Therefore, a jamming platform that is twice as far away from the target as another jamming platform requires four times as much power to have the same effectiveness, while a jammer four times farther away as another requires *16 times* the power to have the same effectiveness.

There are two ways to increase jamming power. The first method is to transmit more radar energy. This energy is measured in the number of watts, kilo watts, or mega watts. The second method of increasing jamming energy is to increase the physical size of the antenna (also known as the radar aperture).[115]

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[115] A more detailed explanation of R^2, including the exact mathematical equation can be found (continued...)

Given this principle that the energy required to jam an enemy target increases at the square of the target range, platforms that can penetrate enemy territory and jam enemy transmissions from very close range have a big advantage over those platforms that cannot. Because they would require one quarter the power (either in terms of watts of energy transmitted or in terms of the antenna size) of those platforms that operate twice as far away, penetrating jamming platforms might also be much smaller, and potentially less costly. Currently, power supply is one of the heaviest and most costly components of military platforms, and large antennas present aeronautical design complications.

A stand-off jammer, one that operates from a distance has the advantage of increased survivability. It has a lower likelihood of being successfully attacked and destroyed by an adversary. However, because of R^2 the stand-off jammer pays a heavy penalty in terms of power. The greater the distance, the greater the penalty.

Micro UAVs. As noted earlier, DoD does not yet have an operational UAV radar jammer and size and weight limitations challenge the feasibility of making today's UAV's effective jammers. However, because the R^2 principle affords great advantage to EW platforms that can get very close to their targets – as micro-UAVs potentially could – small UAV jammers may merit attention.

There have been recent advances in developing very small, low power UAVs to jam radars. One example is a four year old program run out of the Navy Research Laboratory (NRL). Using commercially available technology, NRL scientists have developed a simple jamming module that weighs approximately 12 grams. Mounted on a UAV with an eight inch wingspan, this jammer has proven the ability to totally obscure the radar screens of search radars from as far away as 50 yards. It is estimated that the jamming modules on these small UAVs could cost as little as $100 each.[116]

The United States isn't the only country conducting research in UAV radar jammers. The German Parliament, for example, has allocated DM153.9 million to complete development of the German Army's Taifun attack unmanned air vehicle (UAV). An electronic countermeasures variant, the Mucke is expected to provide the German Army with the capability to jam enemy transmissions from a range of 100km and should be in service by 2005.[117]

In addition to the advantage of not exposing a pilot to SAMs, micro UAV jammers might also have some operational advantages *vis-a-vis* manned EW aircraft. For instance, a manned EW aircraft escorting a strike package might effectively obscure enemy radars, but the adversary has little doubt of the general direction of

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[115](...continued)
in Toomay, J.C. *Radar Principles for the Non-Specialist*, Lifetime Learning Publications. Bellmont, CA. 1982: 5.

[116]Email communication with NRL Tactical Electronic Warfare Division personnel.

[117]Moniac, Rudiger. Germany funds final phase of Taifun UAV. *Jane's Defense Weekly*. April 26, 2000: 3.

attack (certain sectors of the enemy radars will be more powerfully obscured than others, indicating attack angle) and the timing of the attack (because you can't loiter indefinitely). Thus, even if the enemy can't see the U.S. aircraft with radar, they have a good idea of the direction and timing of the attack, and might be able to shoot at U.S. aircraft using different sensors.

Micro UAV jammers on the other hand, could be covertly emplaced days or weeks prior to an attack by flying them (or launching them) into the area where the IADS system is located. They could then be activated remotely just prior to the real attack and used to confuse the radar operator. For instance, the micro-UAV could emit radio signals that would mimic those of attacking U.S. aircraft, but from the opposite direction of the real attack. This would confuse the adversary, seduce them into directing their attention in the wrong direction, and increase the U.S. forces' tactical surprise. If employed in large numbers and effectively networked, micro-UAVs might be able to spoof or jam entire enemy radar networks, paving the way toward uncontested U.S. aerial attacks.

Space-Based Jamming.[118] The Department of Defense is increasingly expanding the use of outer space as a base from which to conduct military operations. Space-based or "overhead" assets already contribute greatly to military (as well as civil and commercial) communication, navigation, and observation activities. Basing an asset in space often gives it advantages of scope and perspective that are difficult to realize on the Earth's surface or even in the atmosphere. Space-based systems can also enjoy access to solar energy unimpeded by the earth's atmosphere and cloud cover. However, placing objects in Earth's orbit is expensive and typically only those commercial and military systems that can realize an advantage over surface- and air-based systems are launched into space. According to studies at NASA and elsewhere, however, the cost of placing and maintaining objects in Earth's orbit is expected to drop significantly in the next 15-20 years due to advances in materials, energy, and miniaturization technology.

If these advances take place, by the year 2020 it could be possible to consider effective space-based jamming satellites. These space-based jammers might be able to overcome the R^2 problem in two ways. First, the jammer would collect huge amounts of solar energy and convert it into up to four megawatts of power. (For comparison purposes radio communications transmissions, a frequent target of jamming operations, are typically in the 10,000 to 100,000 watts of power. A four megawatt jammer would be 40 to 400 times more powerful than these radio transmissions.) Second, the jammer could possibly employ antennas much larger than those currently employed on aircraft, perhaps up to 40 meters in diameter. As discussed earlier, increasing antenna size is a basic way of increasing the power of jamming signals. So, even though the jamming signal would dissipate at the square of a very long distance from the target (i.e. low Earth orbit or LEO), the power with which it was transmitted could more than make up for this challenge and effectively shut down enemy transmissions.

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[118]The information in this section was primarily derived from conversations with Mr. Ivan Bekey, President Bekey Designs and former Director of Advanced Programs, NASA.

Such space-based jammers could be built today, but they are not economically feasible. The cost of building solar arrays or alternative power sources would need to be reduced by a factor of 100. The cost of building jamming transmitters and the miscellaneous spacecraft components would need to be reduced by a factor of 10. There are also operational challenges associated with all LEO-based satellites in terms of keeping the satellite in orbit, and ensuring the systems are positioned over the appropriate theater of operations at the right time.

Although it is not an EW jamming satellite, DoD's Discoverer II satellite program is grappling with many of the technical challenges that would be faced by a space-based jammer. Thus, its success or progress may be indicative of the future attractiveness of space-based jammers. The Discover II program is attempting to design, fabricate, and launch two prototype satellites which would perform the same ground surveillance function as today's E-8 JSTARS aircraft. As with an EW jammer, the Discoverer II satellite will have to overcome cost and operational challenges associated with launching and employing a large antenna (eight meters in diameter), powered by large solar panels.

Appendix A: Abbreviations and Acronyms

A-6	*Intruder*, Attack Aircraft
AAA	Anti-Aircraft Artillery
ADVCAP	Advanced Capability
AESA	Active Electronically Steered Array Radar
AEW	Airborne Early Warning
AGM-86B	Conventional Air Launched Cruise Missile
AGM-88	High Speed Anti-Radiation Missile (HARM)
ALE-50	Towed Decoy
AMARC	Aerospace Maintenance and Regeneration Center
AN/ALQ-99	Electronic Warfare Radar Jammer
AN-ALR-56	Radar Warning Receiver
AN-ALR-69	Radar Warning Receiver
AN/USQ-113	Electronic Warfare Communications Jammer
AOA	Analysis of Alternatives (Electronic Attack Study)
B-1	*Lancer*, Tactical/Strategic Bomber Aircraft
B-2	*Spirit*, Stealthy Tactical/Strategic Bomber Aircraft
B-52	*Stratofortress*, Tactical/Strategic Bomber Aircraft
BQM-74	*Chukar*, Unmanned Decoy
C^2	Command and Control
CAP	Combat Air Patrol
CONUS	Continental United States
DoD	Department of Defense
E-2	*Hawkeye*, Airborne Early Warning Aircraft
E-3	*AWACS*, Airborne Early Warning Aircraft
E-8	*JSTARS*, Ground Surveillance Aircraft
EA-6B	*Prowler*, Electronic Attack Aircraft
EC-130H	*Compass Call*, Electronic Attack Aircraft
ECM	Electronic Countermeasures
ECMO	Electronic Countermeasures Officer
EF-111	*Raven*, Electronic Attack Aircraft
EMD	Engineering, Manufacturing and Development
EP-3E	*Aries*, Electronic Warfare Support Aircraft
ES-3A	*Shadow*, Electronic Warfare Support Aircraft
EUCOM	U.S. European Command
EW	Electronic Warfare
EWO	Electronic Warfare Officer
EXCAP	Expanded Capability
F-15	*Eagle*, Multi-role Fighter Aircraft
F-16	*Fighting Falcon*, Multi-role Fighter Aircraft
F/A-18	*Hornet*, Multi-role Fighter Aircraft
F-22	*Raptor*, Air Superiority Fighter Aircraft
F-117	*Night Hawk*, Stealthy Tactical Bomber Aircraft
FMS	Foreign Military Sales
FOTD	Fiber Optic Towed Decoy
FY	Fiscal Year
GAO	General Accounting Office

GEN-X	Expandable Decoy
ICAP	Improved Capability
IOC	Initial Operational Capability
IR	Infrared
JSF	Joint Strike Fighter
LD/HD	Low Density/High Demand
LRIP	Low Rate Initial Production
MCAS	Marine Corps Air Station
NADEP	Naval Aviation Depot
NAS	Naval Air Station
NATO	North Atlantic Treaty Organization
NRL	Navy Research Laboratory
NVD	Night Vision Device
OAF	Operation Allied Force (Kosovo)
O&M	Operations and Maintenance
OPTEMPO	Operational Tempo
PERSTEMPO	Personnel Tempo
RC-135	*Rivet Joint*, Electronic Warfare Support Aircraft
R&D	Research and Development
RDT&E	Research, Development, Test and Evaluation
SAM	Surface to Air Missile
SEAD	Suppression of Enemy Air Defenses
SLEP	Service Life Extension Program
TALD	Tactical Air-Launched Decoy
TEWS	Tactical Electronic Warfare System
UAV	Un-Piloted Air Vehicle
USAF	U.S. Air Force
USMC	U.S. Marine Corps
USN	U.S. Navy

Appendix B: Selected EW Systems and Manufacturers

System	Manufacturer	Location
AGM-88 HARM	Raytheon, Texas Instruments	Lewisville, TX
AGM-86B ALCM	Boeing	Seattle, WA
ALE-50 Decoy	Raytheon	Goleta, CA
ALQ-99 Jammer	AIL Systems	Deer Park, NY
ALQ-119 Jammer	Northrop Grumman	Baltimore, MD
ALQ-126 Jammer	Sanders BAe	Nashua, NH
AN/USQ-113 communications jammer	Sanders BAe	Nashua, NH
BQM-74 Drone	Northrop Grumman	Hawthorne, CA
EA-6B Prowler	Northrop Grumman	El Segundo, CA
F-15 Eagle	Boeing	St. Louis, MO
F-16 Fighting Falcon	Lockheed Martin	Fort Worth, TX
F/A-18E/F	Boeing	St. Louis, MO
F-22 Raptor	Lockheed Martin	Marietta, GA, Fort Worth, TX
Gen-X Decoy	Raytheon, Texas Instruments	McKinney, TX
Harm Targeting System	Raytheon, Texas Instruments	Tucson, AZ
IDECM	Sanders Bae	Nashua, NH
Joint Strike Fighter	Lockheed Martin	Fort Worth, TX