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**Tilt-Rotor or Helicopter?
An Evaluation of the Way Ahead
for Marine Corps Medium-Lift Aviation**

**By: Stuart Day
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 December 2007**

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**TILT-ROTOR OR HELICOPTER?
A RECOMMENDATION ON THE WAY AHEAD
FOR MARINE CORPS MEDIUM-LIFT AVIATION**

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AN EVALUATION OF THE WAY AHEAD
FOR MARINE CORPS MEDIUM-LIFT AVIATION**

ABSTRACT

The purpose of this research project was to provide an evaluation of whether the V-22 Osprey is the best choice of aircraft to meet the Marine Corps' medium-lift assault support needs. The goal of this project was to base the evaluation on unbiased research using methods and techniques learned in the Naval Postgraduate School's MBA core curriculum. The evaluation is based on analysis of the V-22 Osprey and the EH-101 helicopter using net present value (NPV) of procurement cost, measures of overall effectiveness (MOE) for how each aircraft meets defined Marine Corps objectives, and a computer simulation to predict how each aircraft will perform given the same scenario. When considered together, the NPV, MOE, and computer simulation provide a comprehensive evaluation of whether the V-22 is truly the "best" aircraft to meet the Marine Corps' medium-lift needs.

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I. INTRODUCTION

A. BACKGROUND OF THE PROBLEM

In January of 2007, the U.S. Marine Corps proudly announced plans to conduct the first deployment of the MV-22 Osprey into a combat zone. Possible locations included Iraq, the Horn of Africa, or onboard one of the U.S. Navy's amphibious assault ships in the U.S. Central Command (CENTCOM) area of responsibility (AOR). In an interview with *Leatherneck* last fall, former Marine Corps commandant, General Michael Hagee, indicated that Al Asad Air Base in western Iraq would be an ideal location because the Osprey could "reach all the countries surrounding Iraq without refueling" (Hearst Newspaper, 2007). Indeed, in April 2007, the Marines officially announced that the Osprey's deployment destination would be Iraq (Wayne, 2007).

In contrast to recent news, however, the future of the V-22 Osprey did not always look bright. The Osprey has survived major cost overruns, numerous deadly crashes, a scandal over falsified maintenance records, and several attempts to cancel the program altogether by the Secretary of Defense during the George H. W. Bush administration in the early 1990s. Supporters argue the revolutionary aircraft has overcome its problems, and it is ready to carry the load as the Marine Corps' primary medium-lift platform. With strong backing from a coalition that includes members of Congress, the Marine Corps, and power players from private industry who are contracted to produce the aircraft, the Osprey has risen from the ashes so many times that it might justifiably be renamed the Phoenix (Jones, 2001).

Critics of the V-22 argue the Osprey offers only marginally more capability than existing helicopters and the nation could get much more bang for the buck by canceling the program to go with a cheaper alternative. Additionally, they contend the Osprey is susceptible to a phenomenon called Vortex Ring State (VRS), which places limitations on its rate of descent. While the Marine Corps counters that helicopters are just as susceptible to VRS as the Osprey is, opponents argue that other limitations make the V-22 and any troops and cargo it carries more susceptible to hostile fire than helicopters

are while landing in “hot” landing zones (LZs) (Jones, 2001). In the war on terrorism, hot LZs must not be looked at as the exception, but rather the rule. Given these negative aspects, opponents of the V-22 argue that it has become an inescapable burden and would more aptly be named the Albatross than the Osprey (Peña, 2001). Based on the thirty deaths resulting from crashes during the V-22’s development, other critics have dubbed it the Widow Maker (Gaillard, 2006).

B. DEFINING THE NEED AND CAPABILITY FOR THE V-22

Although opponents of the V-22 can argue against the aircraft’s procurement cost and performance capabilities, they cannot argue that the Marines need to replace the aging medium-lift helicopter fleet. To understand why the Marines have supported the V-22 with such conviction for over twenty years, a review of the vision, concepts, and doctrine that guide Marine aviation is in order.

1. Marine Corps Strategy 21

The overarching vision that provides insight to the future of Marine forces is Marine Corps Strategy 21, a document which presents a guiding framework for the Marines to continue meeting strategic objectives. Marine Corps Strategy 21 states that a key fundamental is “capitalizing on innovation, experimentation, and technology.” (MCCDC: Marine Corps Strategy 21, 2000, foreword). This vision is a way to build on many existing aspects of the Marine Corps.

Important to its success are core capabilities. A few of these are expeditionary culture, forcible entry from the sea, and combined-arms. In support of these capabilities is the Marine Air-Ground Task Force (MAGTF). Marine Corps Strategy 21 states that the MAGTF is an “integrated, combined-arms force that includes air, ground, and combat support units under a single commander.” (MCCDC: Marine Corps Strategy 21, 2000, pp. 2-3). These MAGTF’s vary in size depending on mission requirements, which range from humanitarian relief operations to major warfare. A key and vital element to

MAGTF's of all sizes is the role played by Marine aviation. One major concept which Marine aviation enables the MAGTF to execute is Expeditionary Maneuver Warfare (EMW) (MCCDC: Marine Corps Strategy 21, 2000, p. 5).

2. Expeditionary Maneuver Warfare (EMW)

The concept of EMW is derived from the vision of Marine Corps Strategy 21 and builds on a concept in which the Marine Corps thrive: projecting power within the littoral area and far inland. Key concepts in which EMW aids in transforming force capabilities are Operational Maneuver from the Sea (OMFTS) and Ship-to-Objective Maneuver (STOM) (United States Marine Corps, 2006, p. 32). Not coincidentally, these concepts also helped to justify development of the V-22. EMW serves as the cornerstone that will take the Marine Corps into future battles. It enables focus on core competencies and provides a means to contribute to joint operations. EMW provides the foundation upon which the Corps' MAGTF strategy is built and links strategic guidance to its expeditionary ethos. EMW aids in concept creation which continues to enhance the force through innovation and technology. Concepts including OMFTS and STOM, EMW establish the link to Marine Corps Strategy 21 vision (MCCDC: Expeditionary Maneuver Warfare, 2001).

3. Operational Maneuver from the Sea (OMFTS)

Operational Maneuver from the Sea (OMFTS) is a concept that focuses on the littoral regions of the world at the operational level. OMFTS stemmed from past concepts involving both maneuver and naval warfare and relies heavily on the use of sea-basing. The concept of maneuver from the sea is not new to the Marine Corps and is something they perform well. With OMFTS however, emphasis is placed on the littorals and deep penetration of areas inland. This entry from the horizon requires aviation assets with the ability to travel great distances from sea-bases while troops are embarked. The V-22's capabilities of speed, flight endurance and survivability would support this over the horizon concept very well, therefore the role the V-22 would play in OMFTS is significant (MCCDC: MCWP 3-2, 2000, pp. 8-1 & 8-2).

4. Ship-to-Objective Maneuver (STOM)

Traditionally Marine Corps operations have involved ship-to-shore movement to establish beach-heads or fortifications ashore. Ship-to-Objective Maneuver (STOM), on the other hand, is an extension of OMFTS and provides penetration past the shore with assault forces aboard aviation assets. STOM is reliant on aircraft that can fulfill multiple roles. Aircraft must be able to fly longer, with greater loads, and carry assault support forces required for applicable missions (MCCDC: MCWP 3-2, 2000, p. 8-2). STOM enables tactical employment of forces in support of OMFTS and integrates maneuver concepts with OMFTS goals. It projects MAGTF forces ashore in sufficient strength at critical locations to complete mission tasking. To facilitate this, the capabilities designed into the V-22 directly support STOM. A core capability of the V-22 is to fly large distances from littoral areas to locations deep inland from its sea-bases (MCCDC, MCWP 3-24, 1999, p. 6-1).

5. Marine Corps Warfighting Publications (MCWP)

The V-22 is designed to be the replacement aircraft for the aging medium-lift helicopter fleet of CH-46's and CH-53D's. It was founded on vision and concepts stemming from Marine Corps Strategy 21 and EMW. With these visionary concepts facilitating development of the V-22, a discussion of how the aircraft fits into Marine Aviation doctrine is in order.

Marine Air is the aviation arm of the MAGTF providing support from both sea and land bases. Marine Aviation is defined through six functions: offensive air support, anti-air warfare, assault support, aerial refueling, electronic warfare and control of aircraft and missiles. All six functions have purpose and are vital to the success of the MAGTF. Marine Aviation units serve one or more of these functions as their primary mission and can secondarily provide support for other functions (MCCDC: MCWP 3-2, 2000, pp. 2-1 - 2-7).

The doctrinal fit of the V-22 lies in the assault support function. The aging CH-46 and CH-53D are medium-lift helicopters that serve medium-lift requirements for the

function of assault support and they are currently being replaced by the V-22 as procurement occurs. Assault support calls for aircraft to be employed to provide mobility and logistics support to the force. It gives commanders the opportunity to use both speed and concentration to project combat power on the enemy. Assault support involves the following types of operational requirements:

- Combat Assault Transport – Transportation of MAGTF forces to decisive locations allowing for speedy upsurge in troops and ability to bypass obstacles.
- Air Delivery – Transportation of equipment and supplies.
- Aerial refueling – Transferring of fuel to other aircraft.
- Air Evacuation – Transportation of troops and supplies to secure areas.
- Tactical Recovery of Aircraft and Personnel – Recovery of troops and supplies with specialized aircrews when situations prevent other rescue means.
- Air Logistical Support – When transport exceeds limits of helicopters, fixed-wing aircraft execute transportation needs for the force.
- Battlefield Illumination – Ability to illuminate required areas as necessary. (MCCDC: MCWP 3-24, 1999, pp. 2-2 & 2-3).

All rotary and propelled aviation communities serve the assault support function, in whole or part of their primary mission (MCCDC, MCWP 3-2, 2000, p. 2-7). Some of these aircraft are better suited to perform these operational requirements than others. However, all can be integrated if necessary. The CH-46, CH-53D and their replacement aircraft (V-22) can meet the majority of these requirements. However, their main operational requirement lies in transportation of troops, equipment and supplies during combat assault missions.

There are a number of crucial factors to consider when planning which type of aircraft is best suited for a particular mission. These factors include radius of action, enemy defenses and escort support. Radius of action refers to the fuel quantity which in turn determines the amount of time an aircraft can remain overhead or on station. Enemy defenses refers to an enemy's ability to combat aircraft through means such as small arms, surface to air threats or other aircraft. Finally, escort support refers to support that

may be required when going into a hostile environment, such as attack aircraft to facilitate destruction or suppression of threats (MCCDC: MCWP 3-24, 1999, pp. 2-6 & 2-7).

C. STATEMENT OF THE PROBLEM

The debate over the V-22 Osprey is highly politicized and emotionally charged. Supporters of the program are quick to point out that the V-22's innovative tilt-rotor technology will revolutionize military aviation and will best meet the Marine Corps' medium-lift assault support mission. Opponents counter that the assault support mission is best supported by helicopters, and that the Osprey should be cancelled due to exorbitant costs and failure to meet key performance parameters. Since all parties involved in the debate are equally convinced that they are right, an evaluation of whether or not the V-22 is the best aircraft to meet the medium-lift assault support mission is warranted.

Given the recent history of shrinking defense budgets and increasing costs of the Global War On Terrorism, it is imperative that the Department of Defense (DoD) carefully scrutinize all weapons system procurement plans to ensure the best possible choices are made to meet mission requirements. The purpose of this research project is to provide an evaluation of whether or not the V-22 is the best aircraft to meet the medium-lift assault support mission. The evaluation will be based on analysis of the V-22 and an alternative helicopter, the EH-101, for procurement cost, measures of overall effectiveness in meeting key performance parameters, and performance in a computer simulation. A detailed history of the V-22 is provided in the literature review, including origins of the program and a synopsis of the viewpoints of key players in the Osprey debate.

D. RESEARCHER WORK SETTING AND ROLE

The researchers are students in the Naval Postgraduate School's Graduate School of Business and Public Policy. One member is a Marine Corps aviator, one is a Supply Corps Officer in the U.S. Navy, and one is an aircraft maintenance officer in the U.S. Air Force. Although not directly involved with the V-22 Osprey program, the researchers are

familiar with the DoD's weapon system procurement process. The researchers have also been educated in analysis of system procurement and life cycle cost, evaluating MOEs for alternative weapons systems, and computer simulation modeling. Considering their familiarity with the V-22 program without direct involvement or personal ties, along with their educational backgrounds, the researchers are of the opinion that they can provide an evaluation of whether or not the V-22 is the best aircraft to meet the medium-lift assault support mission.

E. LIMITATIONS TO RESEARCH

The most challenging limitation to this study was the lack of available maintainability and reliability information for helicopter alternatives to the V-22. The Lockheed Martin H-71, a derivative of the Augusta Westland EH-101, is the alternative helicopter chosen for our analysis because it has similar cargo and troop carrying capacity to the V-22. The H-71 is currently being procured as a replacement for the Marine Corps' presidential support mission so data available from DoD sources is limited. However, the EH-101 has been used by the Italian, Canadian, and British military services, so the authors were able to gain access to forecasted maintainability and reliability data for the H-71, which is directly based on historical data for the EH-101. For the remainder of this MBA project paper, the alternative helicopter in our study will be referred to as the EH-101.

Another limitation to this study is the maturity level of the V-22 as a weapons system. According to the V-22 2005 operational evaluation (OPEVAL) the system will not be considered mature until it accumulates 60,000 flight hours. In some instances the authors were forced to extrapolate or estimate data. Wherever possible, the benefit of the doubt was given to the V-22. As the program matures and mission capable rates and other performance data are updated, results from the MOE and computer simulation will likely change.

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II. REVIEW OF RELEVANT LITERATURE AND RESEARCH

In general, the availability of literature on the topic of the V-22 is limited, especially in favor of the aircraft. A search using the Defense Technical Information Center's (DTIC) Scientific and Technical Information Network (STINET) mainly yields official reports about the Osprey program from government agencies like the Government Accountability Office (GAO) and Congressional Research Service (CRS). For the most part, these reports provide objective feedback and recommendations on the status, including positive achievements and shortfalls, of the procurement and test and evaluation processes for the V-22.

The first part of this literature review discusses the lack of pro-Osprey articles available for review, as well as two research-based anti-Osprey articles that are regularly cited in various publications. The remainder of the review provides a historical overview of the V-22's origin and major program milestones.

A. ALL IN FAVOR, SAY AYE...

Support for the V-22 is abundant on the Internet, but most resources found by the researchers are opinion versus empirically based. The Naval Air Systems Command (NAVAIR) website provides a wealth of information about the aircraft's capabilities and touts the Osprey as, "The Most Flexible, Capable, and Revolutionary Combat Troop Transport Aircraft In The World" (NAVAIR, 2006). Presumably, this is based on results from formal operational testing and evaluation of the V-22, but no supporting documentation or evidence is provided to validate the claim. Similar claims can be found on Internet blog sites of Osprey supporters, but the search for empirically based studies which come out in favor of the V-22 proved to be fruitless.

B. ALL OPPOSED?

Literature from opponents of the V-22 is plentiful but, again, most of it is opinion based. Two research-based articles do stand out, however. The first article is entitled

“V-22: Wonder Weapon or Widow Maker?” and was written in October 2006 for the Center for Defense Information by Mr. Lee Gaillard. The second article is “V-22: Osprey or Albatross?” and was written by Charles V. Peña as a Foreign Policy Briefing for the Cato Institute in January 2003.

C. “WONDER WEAPON OR WIDOW MAKER?”

Gaillard’s 2006 monograph on the newest Department of Defense aircraft, V-22 *Osprey - Wonder Weapon or Widow Maker?*, was written for the Center for Defense Information (CDI). CDI’s mission statement is to “provide expert analysis on various components of U.S. national security, international security and defense policy.” To maintain a non-partisan view, they accept no government or defense industry funding and hold no policy positions (CDI, 2007). It is important to understand CDI’s mission prior to critiquing this article, since it lends a degree of independent muscle to the blatantly one sided argument it presents. It is also interesting to note that there are retired military officers on the CDI board, including retired United States Marine Corps General Anthony Zinni.

The main argument in the monograph is the V-22 is a dangerous aircraft that is not now, and will never be, combat ready. To quote Gaillard, “If deployed in combat, the price could be fatalities inflicted not just by enemy fire, but by flaws that were the result of omitted tests and basic design deficiencies pointed out but never addressed.” In fact, he suggests scrapping the entire Osprey fleet and using remaining procurement money to purchase existing helicopter technology (Gaillard, 2006, p. 46). Gaillard quotes numerous technical reports, articles, and testimony to support his claims.

The monograph is very well written, and laid out in a manner that is easy to follow. For anyone that has an interest in the V-22 this article is a “must read.” However, it is a decidedly negative view of the aircraft, and in Gaillard’s opinion there is no way to salvage any usefulness from the program. He simply claims that it must be scrapped, and the sooner the better. This partisan view of the aircraft, and the fact that it cannot be saved, is offset slightly by the position of the CDI as an unbiased source of information.

D. “OSPREY OR ALBATROSS?”

Although Peña’s article is over four years old, it is relatively young in relation to much of the literature available on the V-22 program. Most of the literature available about the Osprey is from the late 1980s to early 1990s, which is when the program was in a fight for survival during the George H. W. Bush Administration. Cost data in Peña’s article, though a bit dated, are still useful because they come from legitimate sources, such as the Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics (USD (AT&L)), and updated information is available from the same sources. The information provided regarding program history and aircraft capabilities are still relevant and provide a good cross-check for data gathered from other sources during research.

The Marines’ stance is that the V-22 is the best aircraft option to meet their medium-lift assault support mission needs over the next several decades. Opponents point out that since inception of the program in the mid-1980s, the Osprey has been marred by major cost and development timeline overruns, nearly 30 fatalities, and performance shortfalls. The findings and general contribution to knowledge of “V-22: Osprey or Albatross?” are important because they provide a well-organized counter-argument to the Marine Corps’ position on the Osprey. To be a fair debate, both sides must be heard.

Clearly, the Marine Corps has a special interest in making the case for the Osprey because they have a lot of time and money invested in the program. By the same token, researchers must be aware that the Cato Institute has a certain bias as well. The Cato Institute is a Libertarian-sponsored public policy research foundation whose core values include “American principles of limited government, individual liberty, free markets and peace” (Cato Institute, 2007). Evidence of the Libertarian slant can be found in the article during a discussion of alternatives to purchasing the V-22: “Alternatively, the United States could adopt a strategy of non-interventionism...Such a strategy—by eliminating or reducing such missions—would reduce or obviate the need for the V-22” (Peña, 2003, p. 6).

Both Peña's and Gaillard's articles are useful to V-22 Osprey researchers. Even if the arguments and evidence provided by the authors may not be completely unbiased, the articles are so well written and researched that proponents of the V-22 cannot afford to simply dismiss them as opinion or misrepresentation. Unfortunately for supporters of the Osprey, research has shown that equally well written articles in favor of the aircraft are almost non-existent.

E. BIRTH OF THE OSPREY: DESERT ONE

The need for an aircraft capable of performing long range assault missions is documented in J. H. Kyle's book *The Guts to Try* (Kyle, 1990). In April 1980, a daring attempt was made to rescue fifty-two American hostages who were being held in the American embassy in Iran. Personnel from all four services were involved in the rescue attempt, as well as twenty aircraft, including eight RH-53 helicopters. Among many other challenging aspects to the mission, the helicopters lacked the range to fly from the USS NIMITZ to the embassy in Tehran without refueling. The rescue plan called for the helicopters to rendezvous with three EC-130 refueling aircraft in the Iranian desert at a location designated as Desert One, after which they would fly Delta Force operators to Tehran to carry out the rescue. Following the rescue, the operators and hostages would be flown on the RH-53s to an airfield which had been secured by one hundred U.S. Army Rangers. The helicopters would then be destroyed, and all personnel would board C-141 aircraft to egress the country (Kyle, 1990, pp. 45-53).

What actually happened on the night of April 24, 1980 has come to be known as the Desert One disaster. Extreme brown-out conditions caused by a sandstorm delayed the refueling rendezvous, and the rescue mission was eventually aborted after several of the RH-53 helicopters experienced mechanical problems. While repositioning at Desert One, one of the helicopters flew into a parked EC-130, killing eight servicemen and destroying both aircraft. U.S. forces had no choice but to gather their dead and wounded and get out of Iran as soon as possible. Although the order was given to destroy the remaining helicopters before departing, it was overlooked during the chaos and confusion. As a result, several intact helicopters and some Top Secret plans fell into the

hands of the Iranians. The Desert One disaster was a national embarrassment for the United States and is unequivocally one of the darkest days in U.S. military history (Kyle, 1990, p. 255).

F. EVOLUTION: 1981-1989

The V-22 Osprey's origins can be traced directly to Desert One. The program began in 1981 as the Joint Service Advanced Vertical Lift Aircraft Program (JVX). One of the goals for the program was development of a common airframe that could support the vertical takeoff and landing (VTOL) missions of the Army, Navy, Air Force, and Marines (Peña, 2003). If aircraft developers could deliver on design requirements for speed, range, and the ability to take off like a helicopter but fly like an airplane, the V-22 would be ideal for carrying out future Desert One-like missions.

In August 1981, a memorandum from the Undersecretary of Defense for research and engineering specifically identified the "Army's electronic warfare mission, the Marine's assault mission, the Air Force's special operations mission, and the Navy's search and rescue mission" for potential use of a common airframe like the Bell XV-15 tilt-rotor experimental aircraft (U. S. GAO, 1986, p. 2). The services interpreted this memo as a green light to develop a concept that would meet the memo's intent.

The four military services formed a joint technology assessment group in February 1982 to explore possible designs for a joint aircraft. They concluded that the tilt-rotor design was the best fit for all four services. Furthermore, they agreed, conventional helicopters were less attractive in regard to speed and self-deployability, which is an aircraft's ability fly itself to a deployed location rather than being ferried by airlift or sealift. Proposals for contractors to submit aircraft alternatives (helicopters included) were solicited, and Bell Helicopter Textron and Boeing-Vertol teamed together to formulate a proposal for submission. In June 1982, a program manager was picked to manage this joint venture. A memorandum of understanding between the Army, Navy and Air Force was drafted establishing the Joint Services Aircraft Program and designating the Army as the lead service. The breakdown of shared funding for the project was Army 46%, Navy 42% and Air Force 12% (U. S. GAO, 1986, p. 2-3).

The Army started to fall behind in December 1982 and could not meet established deadline dates; therefore the Navy took over as lead service. Initial aircraft capability requirements were approved, stating that the aircraft would need to meet a speed capability of 250 knots, be self-deployable and have a range of 2,100 nautical miles without refueling. Since no helicopter in existence could meet all designated capability requirements, tilt-rotor technology was, by default, the only realistic course of action. The new shared funding levels were Navy 50%, Army 34% and Air Force 16%. Also at this point the Navy showed further commitment to development of the aircraft by appointing a contracting officer to the program (U. S. GAO, 1986, pp. 4-5).

The Acting Secretary of the Navy designated Naval Air Systems Command (NAVAIR) as the source authority of the program in early 1983. A second contracting officer was assigned to the project and a contract was awarded to Bell-Boeing in April 1983. This was the only proposal received in response to the joint proposal request. Other companies, such as Sikorsky, required more time to formulate a preliminary design because the capability requirements could not be met by a traditional helicopter, but the time was not granted. In interviews with the GAO, the Osprey program manager said he thought it was a fair competitive process for design proposals, but other officials within the program told them that capability requirements may have slanted the competition solely toward tilt-rotor technology (U. S. GAO, 1986, pp. 6-8). While other companies did not have experience with tilt-rotor aircraft, Bell had been involved with the technology since 1953 (Peña, 2001).

By this point, the Army had decided that a tilt-rotor aircraft was not the best fit for its mission and backed out of the joint venture completely. The Air Force decided to delete the combat search and rescue mission for the new aircraft, but stayed on board for their special operations helicopter missions. The Navy and Marine Corps were also still on board, thus the joint program was still approved for full funding by the Defense Resource Board. In late 1983, Congress agreed to further fund the program for fiscal years (FY) 1984 through 1986 and the program was named the “V-22 Osprey” (U. S. GAO, 1986, pp. 8-9).

In mid 1986, the Bell-Boeing team was awarded the full scale development (FSD) contract at a price of \$1.714 billion. The FSD contract called for 12 aircraft to be delivered, for which the Navy would allocate advanced procurement funds to cover costs of long-lead time material items (U. S. GAO, 1994, pp. 1-2).

G. FIGHT FOR LIFE: 1989-1992

The V-22 Osprey could not have come along at a better time as far as having money available for development is concerned. The defense buildup of the mid-1980s was a defense contractors dream. As Professors Jerry L. McCaffery and Lawrence R. Jones describe in their book, *Budgeting and Financial Management For National Defense*, “U.S. spending on defense during the entire Cold War era represented willingness...to spend what was necessary to counter what was perceived as an ever-expanding threat from the USSR” (McCaffery and Jones, 2004, p. 3). The mid-1980s represented the climactic period of Cold War defense spending. As with the stock market boom of the 1920s and the dot.com boom of the 1990s, however, the spending bubble had to burst sometime.

Christopher M. Jones describes how the V-22 program got caught up in the spending reduction in his article “Roles, politics, and the survival of the V-22 Osprey”:

In April 1989, shortly after the first flight of an Osprey prototype, Secretary of Defense Richard Cheney announced cancellation of the V-22 program....The incoming administration’s search for budget savings was driven by the reality that the massive defense spending of the Reagan era could not continue. After all, the Soviet threat was waning; the federal budget deficit was soaring; the president-elect had pledged ‘no new taxes;’ and the Congress was eager to reduce overall defense spending. It was within this environment that the new administration scrutinized several expensive weapons programs, including the V-22...As a result the FY 1990 defense budget fell from President Reagan’s request of \$305.6 billion to \$295.6 billion (Wilson, 1989a; Moore, 1989). Secretary Cheney decided to address this decline by ordering the Navy ‘to absorb almost half of the \$10 billion reduction’ with the major casualty being naval aviation. As part of the Department of the Navy, the Marines were impacted in the worst possible way when the V-22 was placed at the top of the hit list (Jones, 2001, p. 3).

Secretary Cheney's program cancellation announcement was the beginning of a battle between the administration and Congress (backed by the Marines and a powerful lobbying group organized by Bell-Boeing) that lasted nearly the entire term of President Bush.

Gaining general congressional support for the *idea* to cut defense spending was not a problem for the G. H. W. Bush Administration, but finding specific members of the House and Senate who were willing to sacrifice jobs in their home districts or states was another story altogether. The purpose of Christopher M. Jones' article is not to voice an opinion on the V-22 Osprey, rather it is to show that the bureaucratic politics paradigm (Jones, 2001) applies beyond just the executive branch of government,. Still, his research is extremely useful to our research because it provides an in-depth analysis of the perspectives held by the parties involved in the budgetary battle over the V-22. What follows is a synopsis of these perspectives.

1. Executive Branch: Office of the Secretary of Defense

When Dick Cheney started his job as Secretary of Defense (SECDEF), he tasked the Pentagon's Program Analysis and Evaluation (PA&E) office to provide recommendations for potential budget reductions. PA&E, which was responsible for monitoring design and cost of new weapons systems, was unpopular with the military services because it wielded significant clout during the 1970s. According to Christopher Jones, their role had been significantly muted during the defense build-up of the 1980s, however. PA&E's director, David S.C. Chu, had been arguing since 1983 that the V-22 was too expensive at a per unit cost of \$42.3 million (in FY91 dollars) and its mission could be satisfied by modified CH-53 and UH-60 helicopters at half the cost (ranging from \$15.8 to \$32.5 million per copy). Therefore, when the SECDEF came to Chu looking for recommendations to reduce the FY 1990 budget, it did not take long for him to propose cutting the V-22 program (Jones, 2001, p. 4).

During testimony before the House Armed Services Committee in 1991, Secretary Cheney presented three arguments for cutting the Osprey in favor of helicopters: "Cost is the driving issue, and the V-22 is too costly...At these budget

levels...we can afford to deploy only those technologies that offer the greatest combat capability payoff per dollar invested. The V-22 is not such a system.” (Jones, 2001, p. 8). Table 1 shows 1994 annual operating and support cost estimates for medium lift alternatives. Table 2 below shows 1994 procurement cost estimates for potential medium-lift aircraft alternatives.

Table 1. Annual Operating and Support Cost per Aircraft (From: U. S. GAO, 1994, p. 22).

Alternatives	Quantity	Annual Cost Per Aircraft (in millions)	Annual Fleet Cost (in millions)
V-22	356	\$2.276	\$810.300
CH-60(S) / CH-53E+	525	\$2.136	\$1,121.400

Table 2. USMC Medium-Lift Alternatives (After: U. S. GAO, 1994, p. 21)

USMC medium-lift assault aircraft	Aircraft acquired at funding level I (1)	Aircraft acquired at funding level II (2)
V-22	502	356
New Helicopter	634	450
CH-47M	673	527
CH-60(S) / CH-53E+	287 / 347	241 / 284
CH-46E+ / CH-53E+	317 / 336	252 / 259
Super Puma / CH-53E+	330 / 322	261 / 247
EH-101 / CH-53E+	252 / 335	201 / 257
Notes: 1) Funding level I was set at \$33 billion as the estimated cost for 502 V-22's to meet USMC requirements 2) Funding level II was set at \$24 billion as the estimated cost for the number of CH-60/CH-53E+ to meet USMC requirements (comparable to DOD's preferred substitute in early 1990's)		

The SECDEF next argued that the Marines would rarely, if ever, be asked to carry out missions like the Iran hostage rescue attempt of 1980, so the aircraft's range advantage over traditional helicopters was not as important as supporters argued. Finally, he declared, since the Army had decided in 1983 not to purchase any Ospreys, “the V-22 would not be the same multi-service, multi-mission aircraft it was intended to be” (Jones, 2001, p. 5).

Presenting arguments before congressional committees was not the only tactic used by OSD in its attempts to cut the V-22 program. Each year, according to Jones, the Bush Administration submitted its defense budget to Congress without funding for the V-22 program. It did, however, include requests for additional helicopters to be procured instead. Cheney and OSD also upset many in Congress when they “challenged budget authority” by ordering the Navy to cancel the V-22’s production contracts in 1989. Deputy Secretary of Defense Donald J. Atwood explained, “...it was not in the ‘public interest’ to spend advanced procurement funds when OSD had no intention of moving beyond the Osprey’s research and development phase” (Jones, 2001, p. 5). Congress saw this refusal to spend appropriated funds as a direct assault on their authority for “power of the purse”.

Although battle lines were drawn, all out war between the executive and legislative branches was avoided when the Bush Administration did a 180-degree turn on the Osprey program in 1992. At this time DoD accepted the compromise of Congress inserting RDT&E money for the V-22 into the defense appropriation. The likely cause of the sudden position change was speculation that Cheney’s opposition to the V-22 would hurt President Bush’s re-election campaign, especially in the key states of Texas and Pennsylvania, where the Osprey is manufactured (Jones, 2001). Politics, it seems, won out over the desire for fiscal responsibility.

2. Legislative Branch: Politics, Pork, and the “Power of the Purse”

Members of Congress have given a wide variety of reasons for supporting the V-22 Osprey over the years. Some support the notion that the V-22 is the most cost effective solution for the Marines medium-lift aircraft replacement needs. Others tout the tremendous potential for revolutionizing civilian transportation needs while taking advantage of public sector RDT&E funding. During the period from 1989 to 1992, some members of Congress who did not have a special interest in the aircraft were simply swayed by OSD’s refusal to spend funds appropriated for Osprey testing and development.

While OSD argued that the Osprey was a less cost-effective short-term solution for replacing the CH-46 than other helicopters, Congress argued in favor of the long-term prospects. In 1989, Representative Curt Weldon of Pennsylvania cited a report by the Institute of Defense Analysis which concluded that, over the 20-year life-cycle of the aircraft, the V-22 was the most cost-effective solution (U. S. Congress, 1989, p. 282).

Another position taken by members of Congress to justify development of the V-22 was the potential for use in civilian aviation. Some proponents envisioned tilt-rotor aircraft relieving congestion at municipal airports by increasing usage of downtown helipads. Senator Ted Stevens of Alaska, whose constituents often live in rural areas, argued, “the V-22’s speed and range would make rural and remote areas of the country more accessible” (Jones, 2001, p. 8). This “two birds with one stone” concept appealed to many members of Congress. Many critics suspected that was the primary motivation for private industry in pushing the V-22 was to take advantage of government financed RDT&E to expand marketability and profitability in the civil aviation sector. William Niskanen details how the private sector can benefit from publicly financed research:

A wide range of services financed by government are also marketed, or are potentially marketable, in the private sector. These services have the characteristic that there are more direct private benefits to their consumers and presumed benefits to a more general public...(Niskanen, 1971, p. 213).

As explained previously, some members of Congress saw OSD’s refusal to spend money appropriated for the V-22 as a direct attack on their budget authority. For those who were on the fence about whether to support the Osprey, OSD’s tactics helped make up their minds. Representative Marilyn Lloyd of Tennessee told the House Armed Services Committee in 1991, “The Department’s actions, in my judgment, amount to an unconstitutional attempt to exercise a line-item veto. This is not acceptable.” (Jones, 2001, p. 8). In 1992, the House Armed Services Committee finally decided to play hardball in order to put OSD’s stall tactics to an end—“for every month appropriations goes unspent the Pentagon comptroller’s budget will be reduced by five percent.” (U. S. Congress, 1993, p. 39). Clearly, Congress did not like having its authority challenged.

Although the reasons stated publicly by members of Congress for supporting the Osprey seem legitimate, one does not need to dig deep to realize that there is a more common and simple explanation—pork. Christopher Jones illustrates this common link:

The Engineering and Manufacturing Development phase, for instance, involved an estimated 1,800 to 2,000 subcontractors (Harrison, 1994). As of October 1994, nearly \$353 million in subcontracts had been distributed to businesses in forty-two states and 258 congressional districts. Twenty-five states had purchase orders or letter contracts in excess of \$500,000. Bell and Boeing calculated that there were 10,000 jobs tied to subcontracts (Bell-Boeing, 1994a and 1994b; Arnold, 1994) (Jones, 2001, p. 7).

In a February 2007 interview with *Gentlemen's Quarterly*, Senator Tom Coburn of Oklahoma explained why pork and mutual back-scratching are so pervasive in Congress: “Nobody wants to lose their own earmark. You have to go back to why people are in Congress...they put themselves second; or they’re here because they want power, and they put themselves first. The first question they ask is ‘How do I get reelected?’” (Hylton, 2007, p. 9). The V-22 Osprey program provides a textbook example of how politics, pork, and special interests rule the decisions of most members of Congress.

H. THE MARINE CORPS

Although the George H. W. Bush Administration’s preference was to select an alternative aircraft over the V-22, not everyone in the Executive Branch shared this viewpoint. The Marine Corps had been using the CH-46 “Sea Knight” helicopter for its medium-lift mission since the early 1960s. By the late 1980s, the Corps was desperate to find a replacement aircraft because the CH-46 was rapidly approaching the end of its service life. In a 1993 thesis titled “Medium Lift Replacement,” the Joint Task Force Commander for Operation Sea Angel, a humanitarian relief operation in Bangladesh, described the “Sea Knight’s” struggles in carrying out its mission:

The CH-46 is tired, it doesn't have the range we really need; and I can tell you that having just returned six months ago from commanding all the Marines in the Western Pacific, that with improved medium lift, we could have saved thousands of more lives, and responded much more quickly in bringing relief aid to Bangladesh (Wilcutt, 1993, p. 3).

To the Marines, the V-22 Osprey possessed all the capabilities the CH-46 lacked—it was a modern aircraft, had both speed and range, and had the ability to carry both the required cargo and troops necessary to conduct a variety of missions, from humanitarian relief to tactical assault on the battlefield (Lanahan, 1990, pp. 2-3). Testifying before Congress in 1989, Marine Corps Commandant Alfred M. Gray called the V-22, “the most important advance in military aviation since the helicopter” and “my number one aviation priority” (Scharfen, 1990, p. 180).

The Marines were so committed to the Osprey that they offered to forego procurement plans for the M-1 tank as a concession. Christopher Jones explains that there was more to the Marines’ dedication to the aircraft than met the eye, however. “It also demonstrated a strong desire to acquire a weapons system that would enhance its mission, as well as distinguish it from the Army at a time when the armed services were competing for post-cold war duties. Thus the V-22 was not merely critical to the Marine Corps’ strike force, but essential to its very existence” (Jones, 2001, p. 9).

Secretary Cheney and OSD rejected the Marines’ offer to give up the M-1 tank and pressed forward with plans to cancel the Osprey. Thereafter, Marine Corps leadership reverted to behind the scenes tactics in order to support the V-22. Although they never publicly contradicted OSD’s official stance on the program, the Marines were more than happy to answer questions before Congress as honestly as possible. As Jones writes, “leaders answered honestly about their mission needs...Committee members made reference to ‘gag orders’ and ‘subtle pressures’ from OSD...and lawmakers often countered OSD opposition by referencing the statements of Marine Corps leaders” (Jones, 2001, p. 10).

One probable reason the Marines were comfortable in relying on behind-the-scenes efforts to keep the V-22 alive was their wide-ranging support from Congress. The two main sources of this support were fiercely loyal former Marines who now served in Congress, and Congressmen who held the Corps in high regard because of their reputation for honesty and “telling it like it is” (Jones, 2007). Among the former Marines serving in Congress were Senator John Glenn of Ohio, a member of the Senate Armed Services Committee, and Representative John Murtha of Pennsylvania, chairman of the

House Subcommittee on Defense Appropriations. Support from Murtha was also emboldened by the fact that one of the plants that would manufacture the V-22 was in his home district (Jones, 2001, p. 9).

The Marine Corps found itself in a very touchy situation regarding the V-22 during the George H.W. Bush Administration. While they felt strongly about the need for the Osprey, Marine leadership was not willing to tarnish the Corps' reputation by publicly challenging the decisions of OSD and the Administration. The Marines' willingness to keep a low profile on the subject was likely strengthened by confidence that they could execute a successful "end run" against OSD with the help of two key groups--a large portion of Congress which had special interest in the Osprey and the powerful public relations machine organized by the primary defense contractors for the aircraft, Bell Helicopters and Boeing (Jones, 2001, p. 10).

I. DEFENSE CONTRACTORS

The Bell-Boeing team had a lot to lose if the V-22 Osprey program was canceled. According to Jones, "Bell and Boeing, as economic actors, saw the plane as a way to guarantee profits and employment in an era of shrinking defense budgets" (Jones, 2001, p. 10). They also stood to gain even more if civilian interest in tilt-rotor technology became a reality, as many industry experts predicted it would.

In order to improve the chances of selling the Osprey to the government, Bell-Boeing took an aggressive approach in development, sub-contracting, and marketing of the V-22. Before the government committed any money to the project, the team began full scale development in 1985 by using its own funds. They also entered a fixed-price development contract with the government in 1986, an effort to sweeten the deal by absorbing all costs over the ceiling price, thus transferring financial risk from the government to themselves (Jones, 2001, p. 10).

One of the most cunning moves Bell-Boeing made was subcontracting various systems of the V-22 to nearly 2,000 companies in over 40 states. "Once part of the Bell-Boeing team," Jones writes, "they [the sub-contractors] were encouraged to make congressional representatives aware of the program's impact on local employment"

(Jones, 2001, p. 20). Bell-Boeing was also able to enlist the support of labor unions that represented thousands of workers whose jobs were related to the Osprey, including the United AutoWorkers and the American Federation of Labor and Congress of Industrial Organizations, better known as the AFL-CIO (Jones, 2001, p. 10).

On the marketing front, the Bell-Boeing team took out full-page advertisements in newspapers and magazines to promote the Osprey (Jones, 2001, p. 11). They also worked closely with Representative Curt Weldon of Pennsylvania to found the Tilt-rotor Association, “a group of House members that met every week to plot ways to save the V-22. . . . In 1990, to boost the program's profile, the group staged a dramatic landing on the Capitol grounds of a tilt-rotor aircraft painted in red, white and blue” (Silverstein, 2006, p. 2).

J. SURVIVAL

Although OSD put up a valiant fight in its effort to cancel the V-22, they were up against a group of formidable foes. First there was Congress, who was not only influenced by OSD's direct challenge to its budget authority, but was also highly motivated to preserve the thousands of jobs in 258 districts across 42 states that would be lost if the program was cut. Congress also had the backing of the Marine Corps, which saw the battle over the Osprey as a fight for its very existence as a military service, not just procurement of a new medium-lift platform. Finally, Congress was also aided by an extremely influential group of lobbyists, led by the primary contractors of the V-22, Bell Helicopters and Boeing. After nearly four years of fighting against the Osprey, the Bush Administration changed course and gave its support to the program in 1992. The need to cater to constituents from the electoral vote-rich states of Texas and Pennsylvania, where the Osprey is manufactured, helped tip the scales. In the fall of 1992, the V-22 was finally ready to move on to the next stage of the procurement process. Meanwhile, the G. H. W. Bush Administration was voted out of office.

K. GROWING PAINS: 1992-2002

In October 1992, the FSD contract was ended and \$550 million was awarded to begin engineering, manufacturing and development (EMD) of a new Osprey. Due to problems with meeting promised delivery dates for the V-22, however, they also contracted for 8 helicopter studies to identify alternatives to the V-22. The full scale development phase was supposed to be completed by then, but only 5 aircraft had been delivered. Two of these had crashed (1 in 1991 with no fatalities, and 1 in 1992 with 7 fatalities) and many specifications had either not been met or failed testing (U. S. GAO, 1994, pp. 3-4). The acting Secretary of the Navy testified to Congress that the FSD V-22 could not be built to the joint requirements at the current funding. Therefore, the EMD V-22 variant was started and the contractor was required to build 4 V-22's to Marine Corps specifications by 1997. After successful tests by the Marines, 1 aircraft would be modified for the Air Force special operations variant (U. S. GAO, 1997, pp. 1-2).

The first EMD V-22 was delivered in April 1997 and in turn DOD approved the program to begin Low-Rate Initial Production (LRIP). This included contracts to purchase 25 V-22 aircraft in 4 LRIP lots with full rate production scheduled from FY 2001 to 2018. Overall procurement would result in V-22s fielded as follows: 425 for the Marine Corps, 50 for the Air Force and 48 for the Navy, with per unit costs ranging from \$40 to \$58 million each (U. S. GAO, 1997, pp. 1-2). By May 1999, the first of the LRIP lots arrived at NAS Patuxent River, Maryland, where operational testing was scheduled to be conducted from October 1999 through August 2000 (Navy Department Library, 2005, p. 6).

In April 2000, one of the LRIP V-22s crashed near Tucson, Arizona, killing all 19 Marines on board; the cause was determined to be a pilot-induced vortex ring state situation at an altitude that was unrecoverable. In October 2000, the Navy stated that the V-22 was operationally effective and fully suited for land operations. The following month the Marine Corps announced that the aircraft was also shipboard capable. In November of the same year, the DOD director of operational test and evaluation contradicted these views and announced an extension of the operational testing phase

(Navy Department Library, 2005, pp. 6-7).. He said “although operationally efficient the V-22 was not suitable, primarily because of reliability, maintainability, availability, human factors and interoperability issues.” (Navy Department Library, 2005, p. 7).

Another tragic V-22 crash occurred in December 2000 in Jacksonville, North Carolina killing four Marines. This time the cause of the crash was attributed to hydraulic problems. That same month an anonymous letter was sent to the media stating that V-22 maintenance records had been falsified over a 2-year period in order to keep the program on track. The subsequent investigation led to the squadron commander being relieved of command and three other Marines being found guilty of falsifying records in early 2001. In May 2001, a Secretary of Defense-appointed panel report recommended that development of the V-22 should continue, but the program needed to be restructured to address reliability and maintenance problems. As part of the restructuring plan, the number of aircraft to be procured was cut to a minimum so that funds could be used to address maintenance issues (Navy Department Library, 2005, pp. 7-9).

A December 2001 memorandum from the Undersecretary of Defense to the Secretaries of the Navy and Air Force and the U.S. Special Operation Command authorized the V-22 to resume testing. However, the report required the services to fix problems and demonstrate the need for the V-22 over other alternatives, specifically referring to reliability, safety, and cost effectiveness. It was not until mid-2003 that the DOD director of operational test and evaluation declared that certain improvements on the V-22 had been given the thumbs up. Concurrently, the Defense Acquisition Board (DAB) reviewed the Osprey’s developmental progress and approved plans to move toward fielding the aircraft (Navy Department Library, 2005, pp. 10-12).

L. READY FOR TAKEOFF: 2003-PRESENT

The current contract calls for a total of 458 V-22s to be procured. This number is broken down to 360 MV-22s for the Marine Corps, 50 CV-22s for the Air Force, and 48 HV-22s for the Navy.

In September 2004, the first MV-22 training squadron stood up as Marine Medium Tilt Rotor Training Squadron 204 at Cherry Point, North Carolina. The V-22 officially completed its operational evaluation in 2005, and full rate production was approved later that year. The Air Force stood up its first CV-22 training unit, the 71st Special Operations Squadron, at Kirtland AFB, New Mexico in August 2005. During 2006, three other operational squadrons stood up; two Marine Corps units at Cherry Point, and one Air Force unit at Hurlburt Field, Florida (NAVAIR, 2006).

The Marine Corps variant (MV-22) will be used to replace the aging medium lift fleet of CH-46E and CH-53D helicopters. The MV-22's mission is to provide medium-lift assault support for Marine Corps operations. The MV-22 will provide transport of troops, supplies and equipment (internal and external load) as well as secondary missions to include evacuation and recovery operations, special operations, and refueling / rearming operations in variable weather conditions, day or night (Global Security MV-22, 2007).

The Air Force variant (CV-22) will replace the aging MH-53J Pave low special operations helicopter. The CV-22's mission is that of special operations support. This could entail a variety of operations involving insertion, extraction and re-supply of Special Operations Forces (SOF). The CV-22 will operate clandestinely and in adverse weather conditions in multiple contingency theaters. Due to its mission and role in special operations, it requires special modifications, including an integrated aerial defense system and an upgraded mission computer. Although not its primary role, some versions may be used for CSAR as well as aerial refueling (Global Security CV-22, 2007).

The Navy variant (HV-22) requirements have not been fully formulated. However, the primary roles will most likely be combat search and rescue (CSAR), logistics support, and antisubmarine support (Global Security HV-22, 2007).

M. READY FOR DEPLOYMENT?

The details of how the V-22 Osprey came into the US aircraft inventory are now history. Whether the "end run" around Secretary Cheney's plan to cancel the program was manufactured by industry lobbyists, Congressmen bent on protecting constituents'

jobs, or military brass looking to secure post-Cold War missions for their service does not matter. The V-22 is currently deployed for the first time to a hostile environment in Iraq. The current debate is whether or not the Osprey can be flown in the same aggressive manner under hostile conditions as the aircraft it is replacing. According to Lieutenant General John Castellaw, the chief of Marine Corps aviation, it will be. "I came in ...yankin' and bankin' to avoid simulated fire, came in low, streaked into the zone. The aircraft is nimble, agile. You can yank and bank with the best of them." (Wayne, 2007, p. 2). However, if there are any incidents that cast doubt on the Osprey's survivability, the aircraft will likely be subject to restrictions that would severely limit the evasive maneuvering ability of the aircraft. Such restrictions would make it more susceptible to hostile fire (Gaillard, 2007, p. 45).

Due to the hazards of ground transportation in Iraq, US helicopter usage rose from 240,000 flying hours in 2005 to 334,000 hours in 2006. For 2007, helicopter flying hours are projected to top 400,000 hours (Susman, 2007). Once established in theater, the Osprey will be subject to a grueling flight schedule under less than optimal environmental conditions and less than friendly skies. Capt Drew Norris of Marine Medium Tiltrotor Squadron 23, nicknamed The Thunder Chickens, summed up the situation best. "I think our biggest challenge is the unknown. No one has ever deployed with this aircraft before, and every [aircraft] is different. When you're doing something for the first time, there are bound to be growing pains." (Price, 2006, p. 1). Only time will tell if the V-22 is the versatile, capable aircraft of the Marine Corps' dreams, or its worst nightmare come true.

N. ASSESSING THE OPTIONS

V-22 Osprey critics might fairly ask the question, "Since the V-22 is still relatively young in the full-rate production phase, does it make sense to continue the program if there is a cheaper technology that is as good or better for meeting medium-lift aviation needs?" A review of relevant literature produced an abundance of material which can be used to justify considering other options. The analysis focuses on the period from the V-22 program's second *Operational and Live Fire Test and Evaluation*

(OPEVAL) in 2005 to the present day. Sources of historical data include Department of the Navy (DON) Budget Estimates for Aircraft Procurement, as well as Government Accountability Office (GAO) and Congressional Budget Office (CBO) reports.

1. Department of the Navy (DON) Budget Estimates for Aircraft Procurement

Department of the Navy Budget Estimates examined for this analysis includes estimates submitted in 2004, 2005, 2006 and 2007. Focus is on program description, costs and quantity schedules. These data are based on a planned procurement quantity of 408 V-22's for the Navy and Marine Corps. The P-40 Sheet's (Budget Item Justification) description of the V-22 program is consistent across all fiscal years analyzed. The description details how the V-22 will be employed, core capabilities, and total quantities planned for each service. The total procurement quantity of 458 aircraft calls for 360 V-22s for the Marine Corps, 50 for Air Force and 48 for Navy (DON, 2004). The FY 2007 Budget Estimate highlights that the V-22 had completed milestone III (Operational Test and Evaluation) in 2005 and noted the budget contained provisions for multi-year procurement starting in FY 2008, in addition to \$100 million for cost reduction directives (DON, 2006).

Review of the P-21 Budget Production Schedule reveals the production rate, lead-time and schedule of acquisition. For the fiscal years examined, it is worth noting that the production rate and lead-times have remained steady and consistent with only minor changes. The minimum production rate from the manufacturer, Bell-Boeing, is listed as 11 aircraft per year, with a maximum of 44 aircraft per year and an optimal amount of 32 per year. Total lead-time, factoring in advanced contract and initial lead-times, is currently 39 months per aircraft (DON, 2007). In essence, this implies that if requisite funding is approved, Bell-Boeing can support the production of over 30 aircraft to a maximum of 44 each year, but a three year lead is required.

The span of fiscal year data included in the four budgets reviewed ranges from 2003-2013. Estimated cost and quantity within these budget years varies, requiring more analysis. Budgetary analysis of procurement, unit and program cost and quantity is discussed more in-depth later.

2. Government Accountability Office (GAO)

GAO Assessments of Selected Major Weapons Programs from 2005, 2006 and 2007 use knowledge-based methodology to provide DOD trends and reviews of major programs. GAO's approach to program development is derived from successful programs and is based on knowledge achievement at different levels. Each level of knowledge builds upon the next and sequence is crucial to success. Implications if requisite knowledge is not gained vary in systems issues and cost/schedule deviations (U. S. GAO, 2005, foreword). To help in understanding the GAO's charts, a description of their assembly is summarized below:

- **Knowledge Types** (vertical axis)
 - Technology Maturity – Occurs at programs start; corresponds with knowledge pt 1.
 - Design Maturity – Occurs at DOD's design review; corresponds with knowledge pt 2.
 - Production Maturity – Occurs at the production decision; corresponds with knowledge pt 3.
- **Critical Junctures** (horizontal axis)
 - Development Start – Represents technology maturity, setting foundation for knowledge pt 1.
 - DOD Design Review – Represents design maturity and stability and achievement of knowledge pt 2.
 - Production Decision – Determines dependability for production and achievement of knowledge pt 3.
- **Knowledge Points** (diamonds)
 - Knowledge Pt 1 – Suppliers resources satisfy customer requirements for funds, schedule and knowledge.
 - Knowledge Pt 2 – Product is deemed to meet customer requirements, cost and schedule.
 - Knowledge Pt 3 – Product can be produced within bounds of cost, schedules, quality and standards.
- **Best Practice Line** (dashed line) – Based on best realization of types of knowledge at knowledge points. The closer knowledge is to the line, the more likely the product falls within customer estimates.

(U. S. GAO, 2005, pp. 7-12)

According to GAO's assessment of DoD program trends, about 30%-40% of programs exceed planned development costs, which results in reduced quantities purchased, production schedules being extended, and tradeoffs in aircraft performance. Moving programs through cycles without minimum key knowledge levels being attained causes costs to increase, resulting in decreased buying power for DoD and lesser capabilities provided for invested funds. GAO identifies the V-22 as one of many programs that has experienced post design review cost increases while in production (U. S. GAO, 2006, foreword & p 13). GAO (2007) also notes that original production estimates called for 913 aircraft at \$36.9 billion; now estimates call for 458 aircraft at \$50 billion (2007 dollars), a cost increase of 170% per unit.

Figures 1.a thru c, GAO charts, depict product knowledge from the 2005, 2006 and 2007 V-22 assessments. The 2005 chart shows that data was not obtainable to assess technology maturity at program start in 1986. GAO does not give insight on why, but it could be attributed to its knowledge-based approach not being used in its current form in 1986. It is also possible that tilt-rotor technology was so new that data were being developed as the program progressed, thus this technology was not mature. During the DoD design review in 2002, both technology and design maturities met criteria and achieved knowledge point 2. By 2005, however, GAO identified parts and reporting problems with manufacturers that could potentially impact production. Given these facts, GAO assessed that the level of knowledge for the V-22 had remained unchanged (i.e. showed no improvement), even as full-rate production neared (U. S. GAO, 2005, p. 117).

In 2005 the V-22 completed its OPEVAL, and full-rate production was granted in September of that year. The Osprey's design was noted as stable and the aircraft was deemed to be operationally effective and appropriate, with some deficient areas that would be rectified as production progressed. The production decision knowledge level remained at knowledge point 2 even after the production decision and the 2006 GAO review (Figure 1.b.). Typically, it is desirable to attain knowledge point 3 before full rate production begins. Despite issues with some manufacturer's parts, the decision was made to produce the V-22 (U. S. GAO, 2006, p. 113).

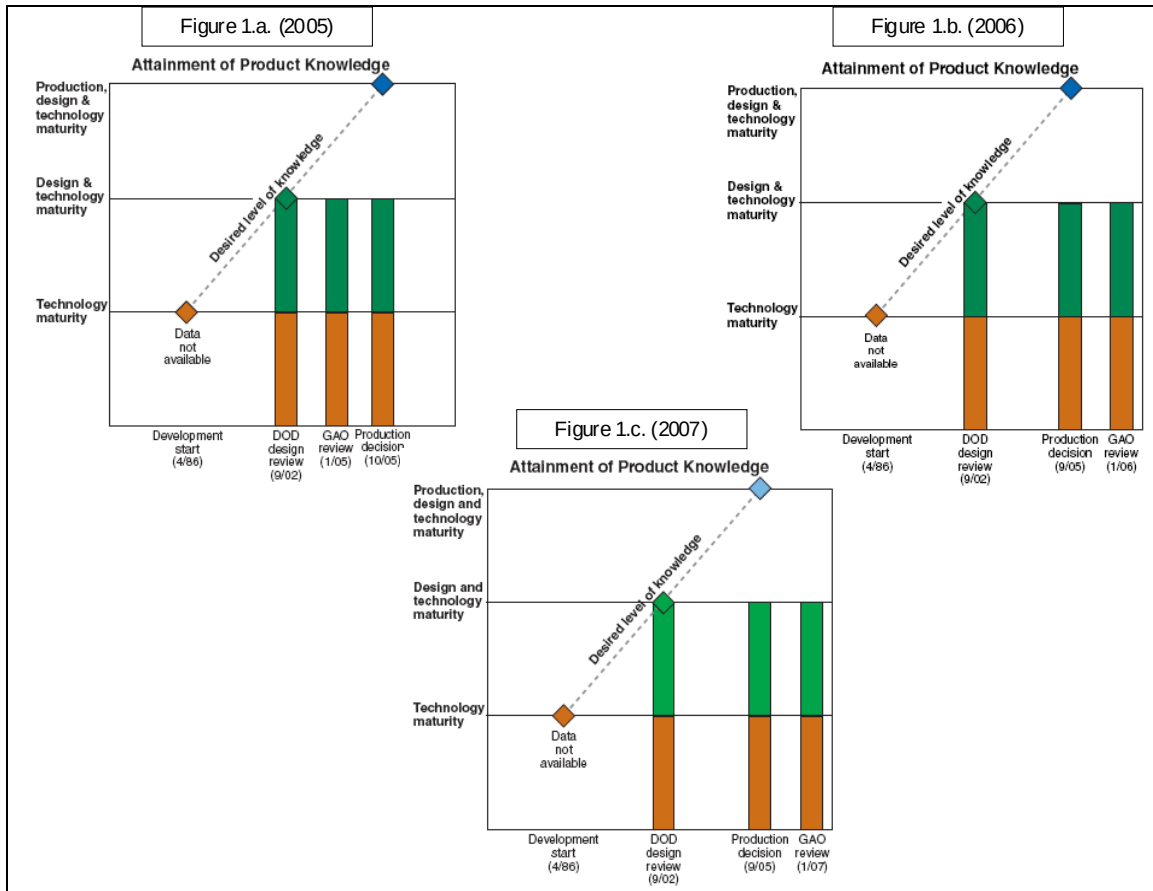


Figure 1. GAO charts: Attainment of Product Knowledge for the V-22 Program (After: U. S. GAO, 2005, p. 117, 2006, pp. 113 & 2007, p. 137).

In 2007 (Figure 1.c.), the knowledge level again remained a 2 vice an ideal 3. One contributing factor was that no statistical process control data was used, therefore it could not be evaluated. Viewing these charts, it is evident that the V-22 only met one out of three knowledge points on time, knowledge point 2. Also worth noting is a change in the estimated program completion date. In 2005, GAO estimated completion of V-22 production to be 2015. The date has now been extended to 2016.

GAO reports also provide useful data on overall percentage changes in cost for the V-22 program. This is done by comparing data from 1986 to those of 2005. Research and development cost increased by 209.5% over initial projections, and overall program cost increased by 35.6%. With the V-22 in full-rate production, funding for 185 V-22's was made available through a multi-year procurement plan requested in the FY

2007 Navy Budget. Also, ideas to aid in lowering costs and reducing risks associated with production were being developed (U. S. GAO, 2007, pp. 11 & 137). If GAO's knowledge-based methodology is accurate and reliable enough to aid in program evaluation, is allowing the V-22 to enter into full-rate production risking higher costs than necessary? It is clear that failure of a program to achieve required knowledge points on time leads to higher costs, which is exactly what has happened with the V-22.

3. Congressional Budget Office (CBO)

The majority of major weapons systems take years to field into the fleet. To shed light on the ramifications of extensive weapon system fielding times, the 2003 and 2006 Summary and the 2006 Detailed *Long-Term Implications of Current Defense Plans and Alternatives* by CBO analyzes the impacts of different programs. CBO reviews budget resources along with age and inventory of systems by looking at DOD planned purchases and the ability to stop severe aging tendencies. CBO utilizes two gauges to help decipher and explore these areas: half-life age and steady-state procurement, depicted in figures 2 through 5.

A half-life is half of a weapon systems anticipated service life. The area of concern is when an aircraft fleet's average age falls within this half-life area (represented by dashed lines in Figure 3). If the fleet's age is above this area, it indicates that the system in question will need replacement or drastic modification in the near future (CBO, 2003, p. xvii). Steady-state procurement is defined as the number of aircraft that would need to be purchased each year to sustain the fleet indefinitely (replacing aircraft lost to attrition or expired service life). Steady-state purchases are calculated by dividing planned inventories by anticipated service lives. To provide a final estimate of steady-state cost, steady-state purchases are then multiplied by unit cost from DOD/historical estimates (CBO, 2003, p. xx).

The CBO believes Marine Corps tilt-rotor and helicopter inventories face huge hurdles in age and procurement. Aircraft procurement in the 1980's averaged 21 per year, but the average was down to 13 per year in the 1990's. The CBO estimates that steady-state procurements should have been 20-30 aircraft per year to sustain fleet health

during this time period. As a result, the fleet's average age rose from 10 to 23 years by the end of the 1990s. The V-22 has proven to be a viable aircraft from its OPEVAL, but delays in development and subsequent lack of funding have resulted in failure to meet CBO's projections of procurements required to significantly reduce these aging trends (CBO, 2003, p. 66).

Since the V-22 OPEVAL in 2005, recent CBO reports provide more program insight. Evolutionary and transformational alternatives where older systems are upgraded instead of replaced are discussed. The transformational alternative increased procurement more than current plans. Intent of both is to give other options to the military. The 2006 evolutionary alternative cost was estimated more than that budget, but was 11% cheaper long-term over DOD current plans (CBO, 2005, p. 2).

CBO (2005) describes Marine Corps options as 1) DOD Current Plans, involving purchase of CH-53X (heavy-lift), UH-1N/AH-1W (utility/attack), and V-22 (medium-lift) aircraft; 2) and Evolutionary Plans involve purchase of CH-53X (heavy-lift), UH-1N/AH-1W (utility/attack) and terminate V-22 procurement in order to buy 408 new medium-lift helicopters (Lockheed Martin's EH-101 or Sikorsky's H-92) and acquire 80 additional CH-53X aircraft (CBO, 2005, pp. 28 & 35).

Figure 2 shows DOD Current Plans for procurement in 2006 estimating quantities and cost for various aircraft alternatives. The diagram shows that from the late 1990's to 2006 there were small numbers of V-22's bought, primarily due to its early developmental stage. The cost varied because of various program challenges. Quantities purchased from 2006 to 2011 are estimated to stair-step up to 38. By 2009 procurement quantities enter into steady-state (23-30), which CBO estimates will bring the fleet's average age below the half-life area. From 2012-2015 procurement is maximized (43) and program completion is projected for 2016. Overall cost increases steadily from 2004 at just under \$1 billion to 2013 at about \$2.7 billion.

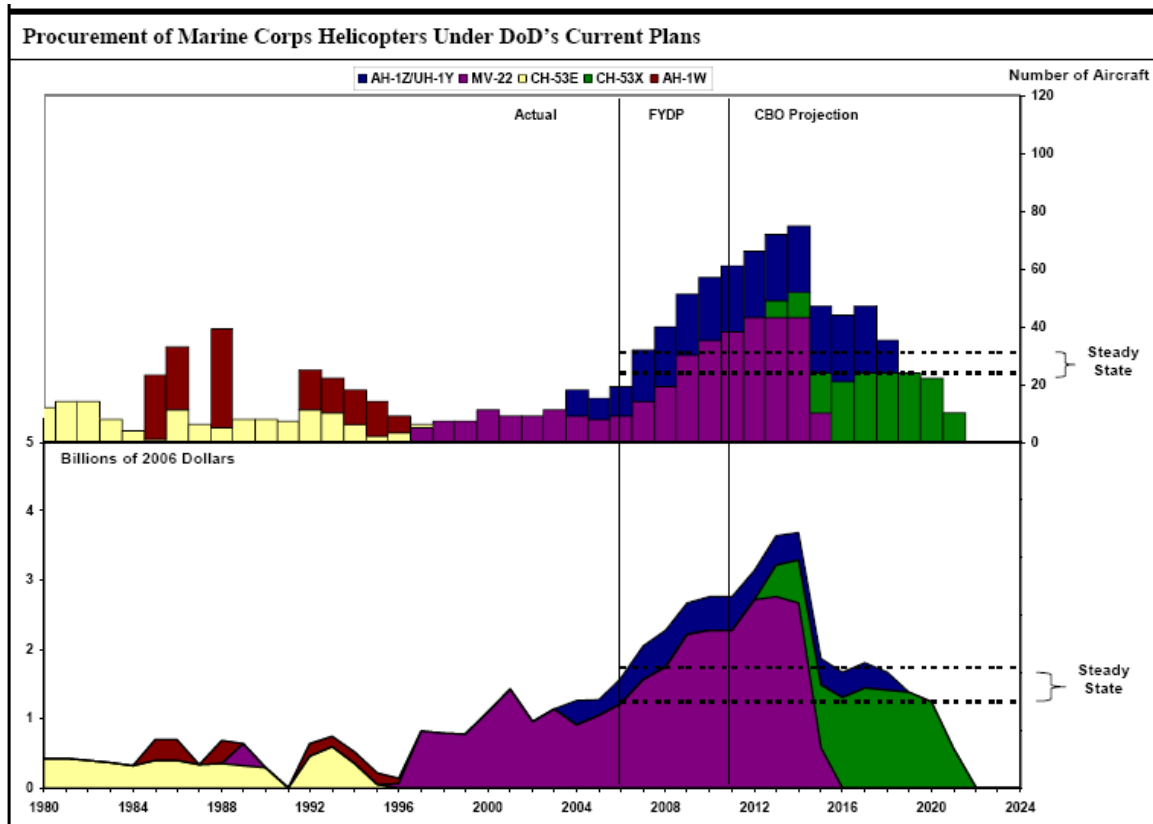


Figure 2. Procurement of Marine Corps Helicopters Under DoD's Current Plans (From: CBO, 2006, p. 42).

Figure 3 shows age and inventory of Marine Corps helicopters under Current Plans. Although focus of the inventory is for all rotary aircraft, the bulk of the fleet is comprised of V-22s. The average age of the inventory continues to increase steadily and peaks around 2007 at about 25 years, slightly above the half-life area. Age then quickly decreases, dropping below the half-life area at about 2013. It flattens out and rests around an average age of 10 years by 2024, just above CBO's 2004 projection. This decrease in age is due to the arrivals of the newly acquired UH-1N, AH-1W and V-22's. Worth noting is the solid line, which represents actual age of the aircraft fleet, flattens out at about 10 years due to production of only 43 V-22's per year. Had the CBO's recommended procurement plan from 2004 been followed (represented by the dashed plot line), the fleet's average age would have gone as low as about 5 years.

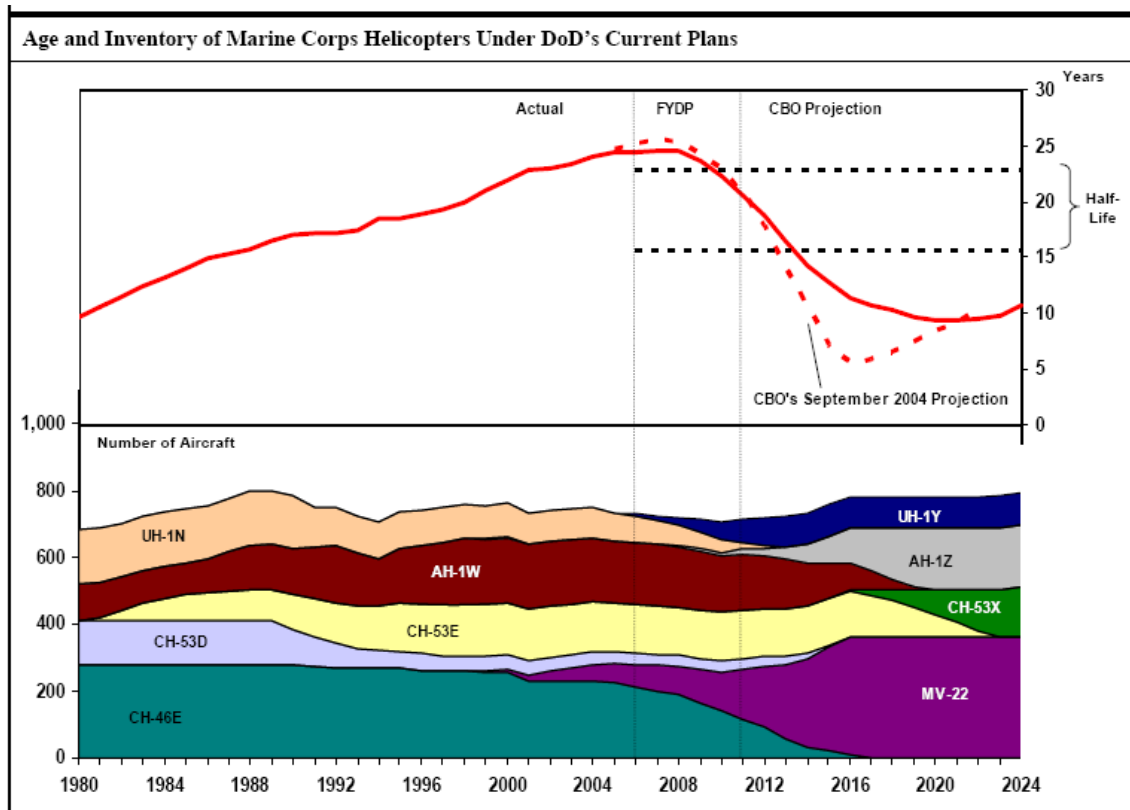


Figure 3. Age and Inventory of Marine Corps Helicopters Under DoD's Current Plans (From: CBO, 2006, p. 45).

Figure 4, which represents procurement under the Evolutionary Plan, indicates that V-22 production would cease around 2006. At this point additional CH-53X aircraft would be procured in greater quantity as well as a new medium-lift helicopter (EH-101 or H-92 variants). Procurement quantities would quickly jump to 60 per year by 2009 and surpass 80 per year through 2017, ending in 2018. The rapid procurement schedule is likely due to minimal research and development costs, since the EH-101 and H-92 aircraft are viable medium-lift aircraft already in use around the world. The overall costs for these procurements increase steadily from just under \$1 billion in 2007 to approximately \$3.5 billion in 2015.

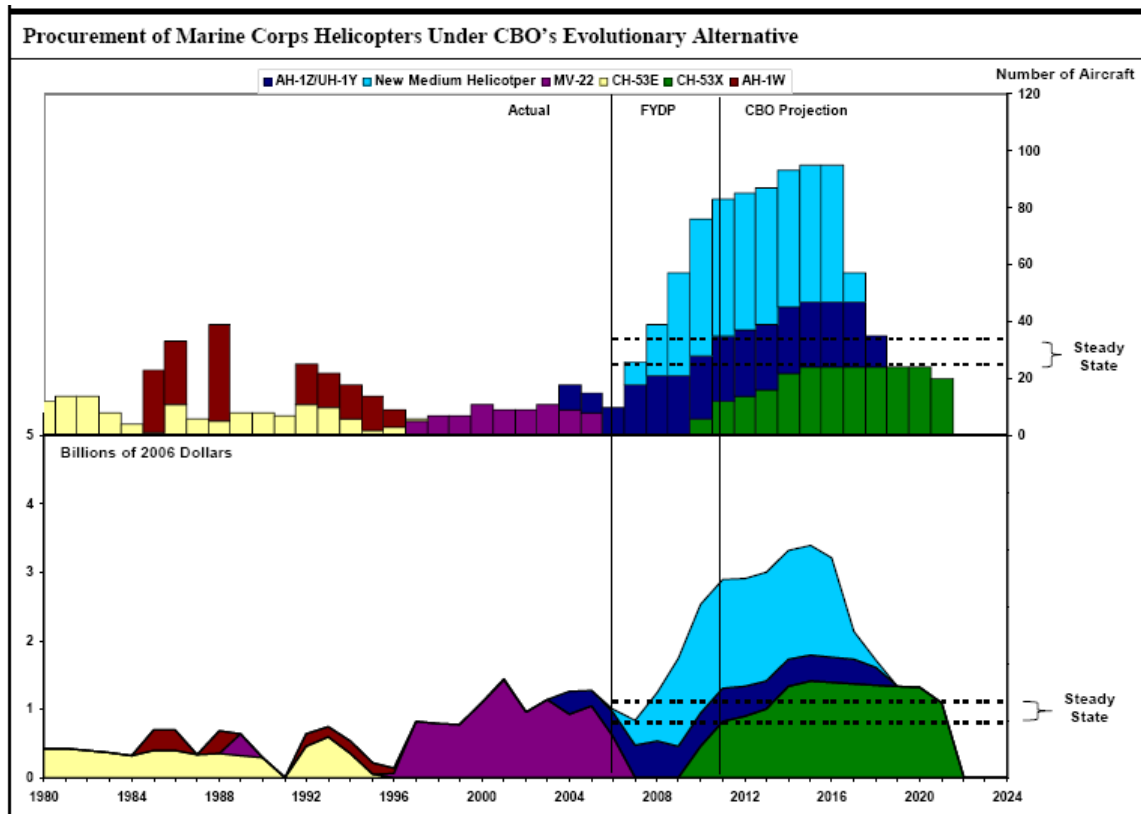


Figure 4. Procurement of Marine Corps Helicopters Under CBO's Evolutionary Alternative (From: CBO, 2006, p. 43).

Figure 5 shows the Evolutionary Plan's average fleet age and inventory size. The new medium-lift helicopter is indiscriminately labeled as H-92 and signifies the bulk of purchases instead of the V-22. Average age continues a trend similar to that of "Current Plans" and peaks around 2008 at approximately 28 years, above the half-life area and current plans. However, the age decreases at a faster rate, falling below the half-life area around 2013. This declining trend continues and follows the CBO 2004 estimate, leveling off around 2017 at about 6 years (vice 10 years in DOD's "Current Plans"), eventually coming to rest at about 9 years in 2023. This is below both the CBO's "Past Estimate" and DOD's "Current Plans".

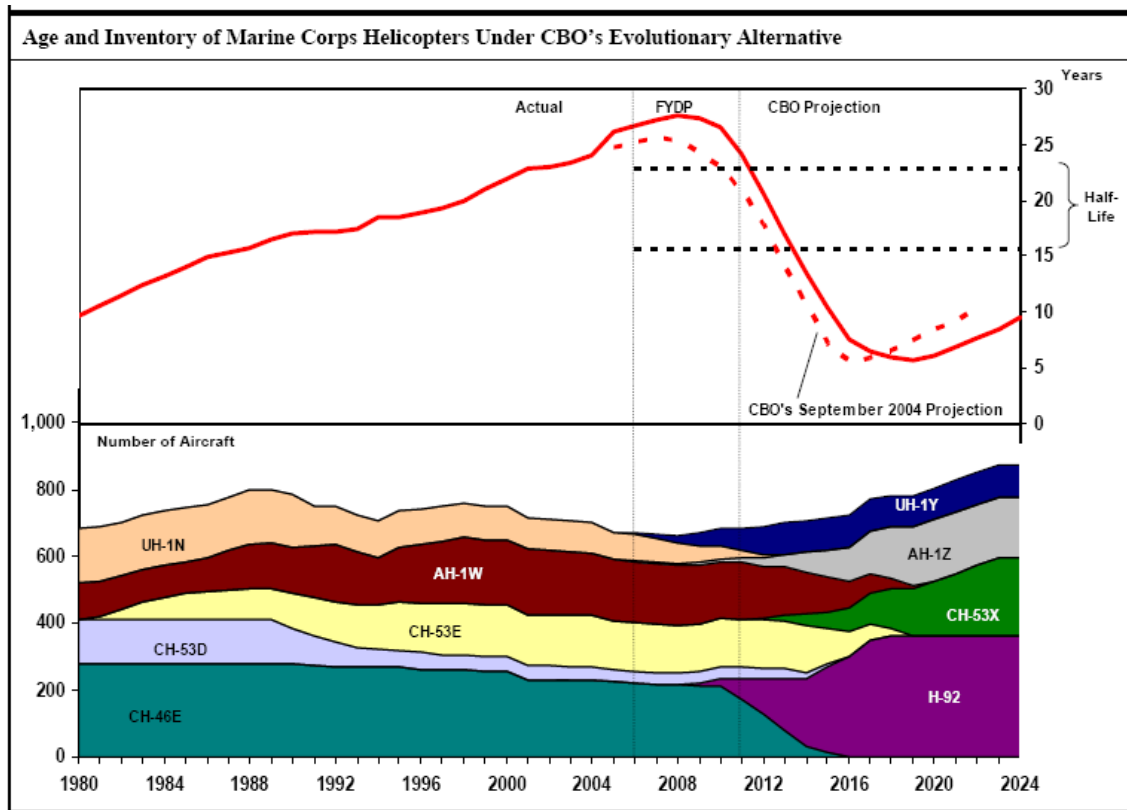


Figure 5. Age and Inventory of Marine Corps Helicopters Under CBO's Evolutionary Alternative (From: CBO, 2006, p. 46).

O. VALUE OF THE LITERATURE

Although the literature available on the V-22 Osprey is largely opinion-based, taken as a whole, it provides a wealth of valuable information on the origins and major historical milestones of the program. In the end, the review verifies the authors' opinion that a critical and empirically based evaluation on whether the V-22 is the best aircraft to meet the Marine Corps' medium-lift needs is warranted

P. STATEMENT OF THE HYPOTHESIS

There is little argument that the rapidly aging CH-46 fleet must be replaced with a more modern, more capable aircraft in order for the Marine Corps to continue to execute its medium-lift mission. The debate over which aircraft can best replace the CH-46 has

been raging for over twenty years, however. As defense budgets become more and more constrained and the Global War on Terrorism continues to heat up, the need to make wise decisions on which weapons systems to procure has never been more critical.

The approach taken in this research project is to assume that the actions and arguments of all parties associated with the V-22 Osprey, whether for or against the program, are guided by what they consider to be the best interests of the United States or serving the interest of the private sector firms involved in the production of the asset. With this in mind, the authors hypothesize that the V-22 Osprey is the “best” aircraft available to meet the U.S. Marine Corps’ medium-lift assault support mission. By combining MOE analysis, NPV of procurement costs, and computer simulation analysis to compare the V-22 with the EH-101, the authors will provide an empirical evaluation on whether the V-22 is the best aircraft to meet the Marine Corps’ medium-lift needs.

III. RESEARCH METHODOLOGY

A. PURPOSE OF THE STUDY

The purpose of this study is to provide an evaluation of whether the V-22 is the best aircraft to meet the Marine Corps' medium-lift needs

B. RESEARCH DESIGN

The EH-101 helicopter was chosen as an alternative to the V-22 because its cargo and troop carrying capacity are almost identical to those of the Osprey, and the helicopter is used by military organizations around the world for medium-lift missions. The aircraft comparison will be based on a combination of three different criteria: 1) Measures of Overall Effectiveness for how well each aircraft is able to meet multiple objectives and mission requirements defined by the Marine Corps; 2) Net Present Value of procurement costs for each aircraft; and 3) Performance of each alternative aircraft in a computer simulation model.

1. Measures of Overall Effectiveness

Making a fair comparison between the V-22 and the EH-101 is difficult because many factors must be considered. If the procurement decision was based strictly on unit cost of the weapons system, the Osprey would not even be in the debate. Likewise, a comparison based on speed or range alone would automatically keep all helicopters out of the discussion. To determine which aircraft is actually best, a comparison of multiple factors is required. This is known as a Multiple Objective Decision Problem. One highly effective method for solving such problems is a Measures of Overall Effectiveness (MOE) analysis (Wall, 2005).

According to Kent D. Wall, a Professor of Systems Engineering at the Naval Postgraduate School:

Effectiveness analysis provides a *practical tool for quantitative investigation* of all factors that may influence an answer. You will be able to determine *why* one alternative is more effective than all others. This analytical ability is very important because many real-life decision problems involve more than a single issue of concern beyond cost. This holds true for personal-life decisions, private sector business decisions and public sector government resource allocation decisions. Examples include selection of a new automobile; choosing from among several employment offers; or deciding between surgery and medication to correct a serious problem (Wall, 2005, p. 1).

Wall goes on to say that public sector decision making is not profit motivated, so a single monetary measure of benefit is not relevant. Therefore, when choosing what the best alternative is in a multiple objective decision problem, effectiveness analysis often proves to be quite useful (Wall, 2005).

a. Problem Formulation

The first step in applying the MOE decision making model is to determine the objective of the analysis. As Wall explains, “Every model of rational decision making employs a function, $v(j)$, representing the payoff, or value of the benefit, to the decision maker of the j^{th} alternative. The decision maker, being rational, desires to maximize its value by choosing the alternative with the highest payoff...the Measure of Overall Effectiveness” (Wall, 2005, p. 3).

For the purposes of this research project, there are only two alternatives; the V-22 and the EH-101. The objective is to determine which MOE function has the greatest value, $v(V-22)$ or $v(EH-101)$. “The ‘best’ alternative,” according to Wall, “is now defined as the one that provides the maximum overall effectiveness” (Wall, 2005, p. 3). Economics instructors in the Naval Postgraduate School’s Graduate School of Business and Public Policy illustrate the process for determining Measures of Overall Effectiveness for competing alternatives by using the example of the Army procuring a new tank. An overview of this example is provided in the next few pages.

b. Determining Objectives

In order to determine the value of each MOE function in a Multiple Objective Decision Problem, the decision maker’s objectives must first be defined.

Determining objectives is an iterative process that starts out with broad goals and continues until an objectives hierarchy for the new system is completed. For example, when procuring a new tank, Army leadership might set an objective to procure a system that is characterized by adequate firepower, mobility, and survivability. Thus, the best choice would be the tank alternative that meets or surpasses minimum requirements for each of these attributes, has the highest MOE value of all systems under consideration, and still allows the Army to stay within various constraints, such as limited procurement funds. Figure 6 represents the top three levels of the objectives hierarchy for the Army's tank example.

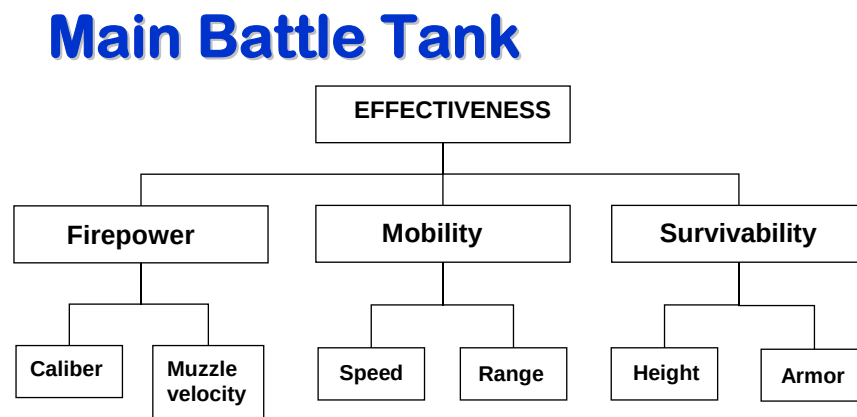


Figure 6. Objectives Hierarchy, Top Two Levels (After: Wall, 2005. Slide 55 from QDMP (Sloat and Tank) PowerPoint).

Professor Wall explains that after the main objectives and attributes of a Multiple Objective Decision Problem are defined, a subsequent iteration begins with the question, “What do you mean by that?” (Wall 2005, p. 7). For the Army’s new tank, defining “Firepower” might mean setting minimum caliber and muzzle velocity values for the tank’s howitzer; for “Mobility”, it might require setting minimum speed and range objectives; and “Survivability” might be defined by specifying height and protective armor requirements. The process of determining desired program objectives and attributes is not complete until the question “What do you mean by that?” results in definition of a unit of measurement for the previous echelon on the hierarchy. Under the

category “Mobility”, for example, “Speed” is ultimately measured in kilometers per hour (km/h) and “Range” is measured in kilometers (km) (McNab, 2006). Figure 7 shows the tank objectives hierarchy with units of measurement defined for each sub-attribute.

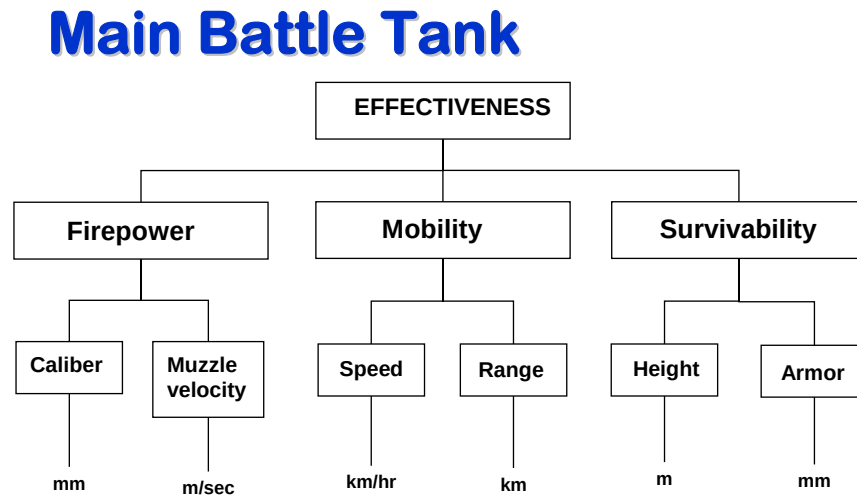


Figure 7. Objectives Hierarchy With Units of Measurement Defined (After: Wall, 2005. Slide 55 from QDMP (Sloat and Tank) PowerPoint).

c. *Assigning Values to Attributes*

After decision makers have defined specific design attributes for a new system, they must then design a process to determine a) how much of each attribute is enough (e.g. what is the minimum speed or cargo capacity required?) and which attributes are most important. This is done by assigning weighted values to each of the system’s design attributes. These weighted values represent the way decision makers prefer to trade off one attribute for another (McNab, 2006).

Once again using the example of the Army procuring a new tank, decision makers might specify minimum speed and range requirements when assigning values to the attribute “Mobility”. For the overall system, decision makers must assign weights to each major design attribute in order to determine which ones are most important. For example, is “Survivability” more important than “Firepower” and “Mobility” in a new

tank, or are these attributes equally important? The weighted values assigned to each attribute should reflect decision makers' preferences, i.e. higher weights reflect the most important attributes. As a general rule, the total value gained when summing the weights of each major attribute (Firepower, Mobility, Survivability) in the objectives hierarchy is equal to 1.

The same process for assigning attribute weights is continued down each echelon until the bottom of the objectives hierarchy is reached. For example, after the major attributes desired from a new tank have been assigned weighted values, all sub-attributes are also assigned weights. In the case of the "Mobility" category, the sub-attributes of "Speed" and "Range" would be assigned weighted values which, when added together, equal to 1. Under "Firepower", the weights assigned to "Caliber" and "Muzzle Velocity" also equal to 1 when summed, and so on. Figure 8 shows the objectives hierarchy of for the tank example with weights assigned to all attributes and sub-attributes.

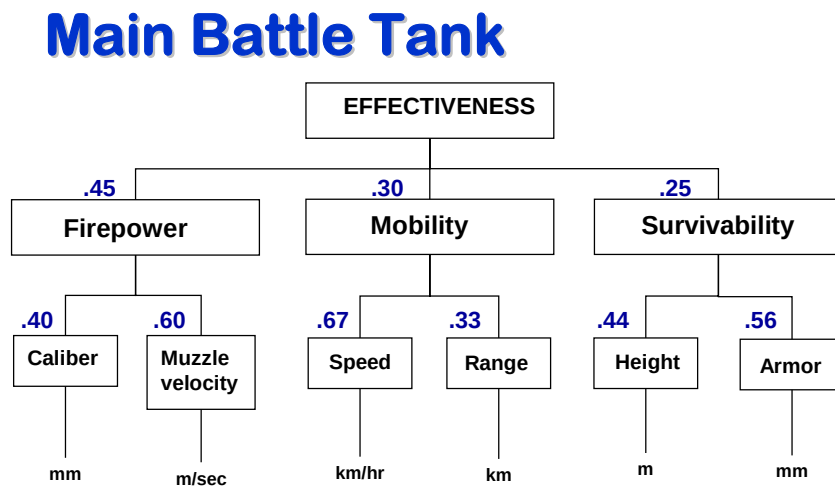


Figure 8. Objectives Hierarchy, Weighted Attribute Values Assigned (After: Wall, 2005. Slide 55 from QDMP (Sloat and Tank) PowerPoint).

There are many ways to assign weighted values to the various attributes of a weapons system. Professor Wall's article describes several methods, including Direct Assessment, Equal Importance, and Rank Reciprocal. Direct Assessment, the simplest method of assigning values, consists of decision makers specifying how much weight to put on each of the new system's attributes. For the new tank example, Army leadership might tell analysts to weight mobility as a 0.5, firepower as a 0.3, and survivability as a 0.2.

Another frequently used method of assigning attribute values is called Equal Importance. As Professor Wall describes, "Direct assessment may result in the decision maker stating that, "All Individual measures are equally important" (Wall, 2005, p. 17). In the new tank example, this would mean that mobility, firepower, and survivability each have a weighted value of $1/3$, one-third of a total possible value of 1 for the system. Caution must be used when continuing the iterative weighting process below the first level of the hierarchy. It is best to have leadership clarify whether or not the subcomponents of each attribute are also to be weighted equally. For example, under firepower, are caliber and muzzle velocity of the tanks weapons equally valued? Failure to get clarification from leadership on such a question can lead to an inaccurate assumption on the part of analysts and, as a result, analysis that does not accurately answer the question, "Which is the best tank?" (Wall, 2005).

One final method of assigning values to a system's attributes is Rank Reciprocal. This process starts by having decision makers rank order the attributes in order of importance. For the Army's new tank, let's assume that Mobility is ranked 1, Firepower 2, and Survivability 3 (Wall, 2005). The next step is to get the reciprocal of each rank order value, i.e. mobility = $1/1$, firepower = $1/2$, survivability = $1/3$, followed by summing up the reciprocal values. Before summing the reciprocal values, a common denominator of 6 is established. In this case, the sum of reciprocal values is $6/6 + 3/6 + 2/6 = 11/6$. The final step in the Rank Reciprocal process is to divide each reciprocal rank by the sum of all three to get a weighted value for each attribute. For the tank example, the weighted values would be:

Mobility: $(6/6) / (11/6) = 6/11 =$ **.545**

Firepower: $(3/6) / (11/6) =$ **.273**

Survivability: $(2/6) / (11/6) =$ **.182**

System Total Value: 1.0

d. Normalizing Measurements

The final step required before determining which alternative has the highest Measure of Overall Effectiveness is to normalize the units of measurement at the bottom of the objectives hierarchy. According to McNab of the Naval Postgraduate School, if you don't normalize the measurements to the same scale, one attribute can dominate the conversation (McNab, 2006). In essence, this eliminates the problem of "comparing apples to oranges", such as comparing "Muzzle Velocity" (measured in meters per second) to "Speed" (measured in kilometers per hour). After being normalized, the measurements identified in the last echelon of the objectives hierarchy will have a value ranging between 0 and 1, with 0 being the minimum (worst) and 1 being the maximum (best) value possible for a particular measurement. In the example of the Army's new tank, a normalized value of 0 for the "m/sec" measurement under "Muzzle Velocity" means that the system being considered does not meet the minimum value desired by decision makers for this category.

There are three primary approaches that are used when normalizing measurements of different attributes. First, there is the "More is Better" approach, such as more speed is better than less speed. Second, there is the "Less is Better" approach, which is used when trying to keep certain attributes to a minimum, such as weight or radar cross-section. Finally, there is the "Yes or No" approach, which is applied when an alternative system either does or does not meet certain desired criteria.

Before calculating normalized measurements for the desired attributes of a weapons system, performance characteristics for all alternative systems being considered must be determined. For the tank procurement example, specific measurements for caliber (mm), muzzle velocity (m/sec), speed (km/hr), range (km), height (m) and armor (mm) are provided in Table 4 below for tank alternatives A through E.

Table 3. Performance Characteristics for Tank Alternatives A through E (After: Wall, 2005. Slide 54 from QDMP (Sloat and Tank) PowerPoint).

	FIREPOWER		MOBILITY		SURVIVABILITY	
	Muzzle					
Tank	Caliber	Velocity	Speed	Range	Height	Armor
A	120	1650	46	440	2.38	1724
B	120	1370	40	442	2.50	1930
C	120	1650	72	550	2.42	1620
D	125	1615	50	450	2.20	1397
E	120	1700	50	550	2.30	1450

After performance characteristics for each alternative system are available, normalized measurements can be calculated for each of the design attributes and sub-attributes identified by decision makers. We will use Tank Alternative A to illustrate these calculations.

(1) When More is Better. The “More is Better” approach to calculating normalized measurements is used for attributes such as speed or range of a weapons system. The formula used to calculate a normalized “More is Better” measurement is:

$$\frac{\text{Attribute value} - \text{worst}}{\text{Best} - \text{worst}}$$

The “Attribute Value” used in the formula comes from the performance characteristics of the alternative being considered. The “Best” and “Worst” values are the maximum and minimum desired values for each attribute, usually defined by decision makers. Applying the “More is Better” formula to the category “Speed” for

Tank Alternative A, we use an Attribute Value of 46 km/hr, a Best speed value of 72 km/hr, and a worst speed value of 20 km/hr. As shown in the Figure 9 below, the normalized value of Tank Alternative A's speed measurement is 0.5.

When “more is better”—ie. Speed

- Minimum = 20 Km/hr (No Value; Worst)
- Maximum = 72 Km/hr (Complete Value; Best)

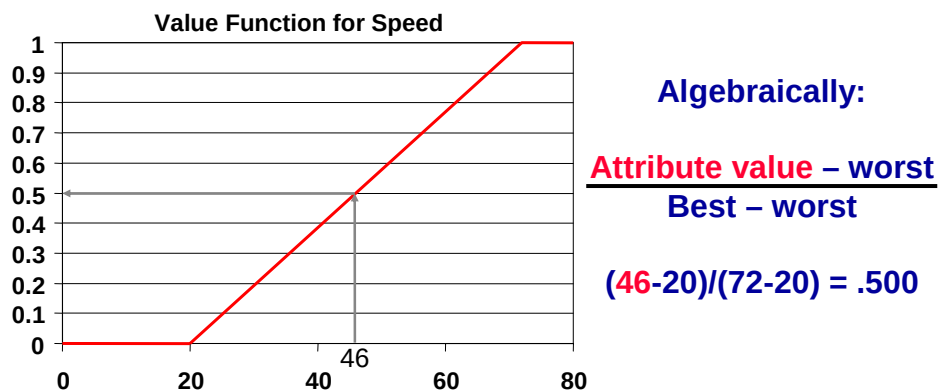


Figure 9. Calculation of Normalized Speed Measurement for Tank Alternative A (After: Wall, 2005. Slide 49 from QDMP (Sloat and Tank) PowerPoint).

(2) When Less is Better. For the “Less is Better” example, we will calculate the normalized value for Tank Alternative A's height. Using this formula for height makes sense because the higher a tank is off the ground; the more visible it is to enemy spotters. The formula for “Less is Better” calculations is the same one used for “More is Better”:

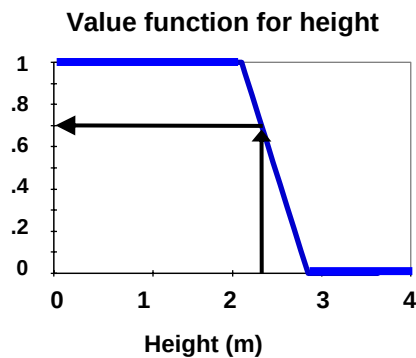
$$\frac{\text{Attribute value} - \text{worst}}{\text{Best} - \text{worst}}$$

In this case, Alternative A's Attribute Value for "Height" is 2.38 m, the minimum (best possible) desired height is 2.2 m, and the maximum (worst possible) desired height is 2.8 m. As shown in Figure 10 below, Alternative A's normalized value for "Height" is .700.

When "less is better"—ie. Height

→ Minimum = 2.2 m (Complete Value; Best)

→ Maximum = 2.8 m (No Value; Worst)



Algebraically:

$$\frac{\text{Attribute value} - \text{worst}}{\text{Best} - \text{worst}}$$

$$(2.38 - 2.8) / (2.2 - 2.8) = .700$$

Figure 10. Calculation of Normalized Speed Measurement for Tank Alternative A (After: Wall, 2005. Slide 50 from QDMP (Sloat and Tank) PowerPoint).

(3) Yes or No. The "Yes or No" approach to calculating normalized attribute values is the most straightforward—either the system has the desired attribute or it does not. For example, suppose decision makers identified the need for the Army's new tank to be equipped with Global Positioning System (GPS). Using the "Yes or No" approach, alternative systems equipped with GPS would be given a normalized value of 1, and systems not equipped with GPS would be given a normalized value of 0.

Final normalized values for each of the desired attributes identified in the Army's tank example are provided for tank alternatives A through E in Table 5 below.

Table 4. Performance Characteristics for Tank Alternatives A through E (After: Wall, 2005. Slide 54 from QDMP (Sloat and Tank) PowerPoint).

NORMALIZED EVALUATIONS						
Tank	FIREPOWER		MOBILITY		SURVIVABILITY	
	Caliber	Muzzle Velocity	Speed	Range	Height	Armor
A	0.500	0.929	0.500	0.560	0.700	0.800
B	0.500	0.529	0.385	0.568	0.500	1.000
C	0.500	0.929	1.000	1.000	0.633	0.699
D	1.000	0.879	0.577	0.600	1.000	0.483
E	0.500	1.000	0.577	1.000	0.833	0.534
Best:	125	1700	72	550	2.2	1930
Worst:	115	1000	20	300	2.8	900

2. Calculating Final Measures of Effectiveness

Once normalized values are determined for each of the defined measurements in the objectives hierarchy, final MOEs can be calculated for each alternative under consideration. The final MOE value is calculated by multiplying the assigned weights of desired attributes by the normalized measurement values. Figure 11 below shows how the final MOE value of Tank Alternative A, .686, was calculated.

Alternative A MOE Calculation

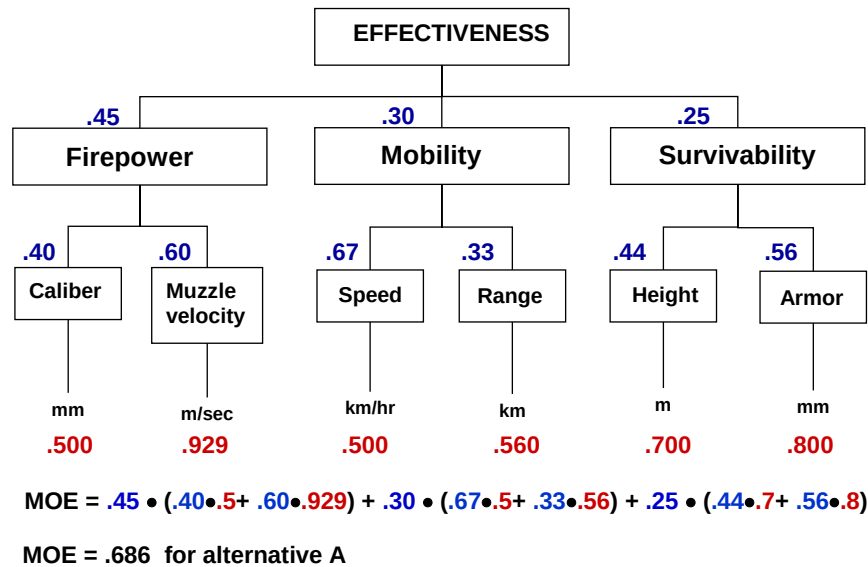


Figure 11. Calculation of Final MOE Value for Tank Alternative A (After: Wall, 2005. Slide 55 from QDMP (Sloat and Tank) PowerPoint).

3. Interpreting MOE Results

Figure 12 provides a visual display of the final MOE results for Tank Alternatives A through E. As previously discussed, MOE Analysis can be used to help decision makers quantify the best choice in Multiple Objective Decision Problems. For weapons system acquisition, such as the Army tank example, multiple objectives are represented by various desired attributes which leaders must decide how to best make tradeoffs between, such as firepower, mobility, and survivability. The result of MOE analysis is a normalized, quantified value for each system under consideration. The “best” choice for decision makers is the system which has the highest MOE value. As displayed in Figure 12 below, Alternative C has the highest MOE of all tanks under consideration with a value of .808. Purely based on MOE, Tank C would be considered the best option.

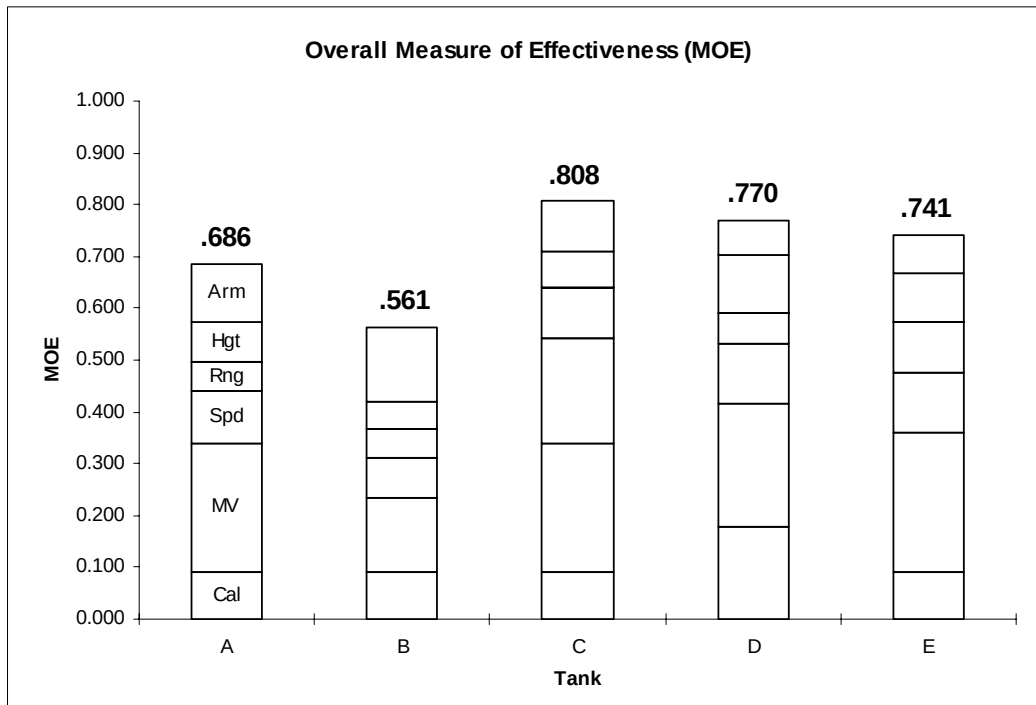


Figure 12. Comparison of Final MOE Values for Tank Alternatives A through E (After: Wall, 2005. Slide 56 from QDMP (Sloat and Tank) PowerPoint).

In reality, MOE analysis is only one factor that is considered when making a decision between alternative weapons systems, but it can be a very valuable tool in helping decision makers distinguish between seemingly similar alternatives. Other areas to consider include Net Present Value of procurement costs for each alternative system, as well as how well each system performs under realistic conditions during operational test and evaluation.

C. NET PRESENT VALUE

To effectively evaluate the V-22 and the EH-101 in monetary terms the authors will rely on a Net Present Value calculation. The term Net Present Value is used often, sometimes flippantly, but what does it really mean? In essence the NPV allows us to take the future costs and benefits of both systems into account (Stokey, 1978, p. 160). It further allows equal comparison between two projects that have different costs, or cash flows, over a certain period of time using dollar values for a common base year. These costs could be investments in production, annual operating costs, and cost for supply

support. Research and development for both systems has been completed and therefore considered a sunk cost not included in our calculations. Since both models are new to the U.S. inventory life cycle data is unavailable, maintenance and life cycle costs for both airframes are assumed to be similar and not applicable to our calculations (potential ramifications of this assumption being incorrect are discussed later in the paper). Purchase costs are drastically different for the EH-101 and V-22, making them hard to compare without some form of discounting.

The discount rate is a crucial component in NPV calculation. A small change up or down by as little as a tenth of a percent can have large effect on the final calculation. Since the benefits and costs of one platform or another are of greater value the sooner they are experienced, the higher the discount rate, the lower the present value of any future cash flows. The Office of Management and Budget (OMB) delineates a 7% discount rate for most government projects, which is the rate the authors will use for all NPV calculations in this paper (OMB, 1992, pp. 5-6).

The OMB discusses Cost Effective Analysis in great detail, stating that it should be used when “it is impractical to consider the dollar value of the benefits provided by the alternatives under consideration” (OMB, 1992, p. 3). The comparison of the V-22 and the EH-101 clearly falls into this category, since there will be no “monetary” benefit from either aircraft.

The computation of the Net Present Value for the V-22 and EH-101 will be performed using the standard formula in Figure 13 performed in an Excel spreadsheet. The Excel spreadsheet will consist of cells including the number of aircraft built per year and cost per aircraft. Dollar values for training and manning will not be included since they are assumed to be equal for both systems (again, ramifications of an incorrect assumption are discussed later in the paper).

Net Present Value

$$P = \sum_{t=1}^n \frac{F_n}{(1+r)^n}$$

F_n = future value in period n
 P = present value
 r = compounding rate
 n = number of periods

Figure 13. Net Present Value Formula (After: McNab, 2006. Slide 33 from Cost Concepts and Analysis PowerPoint).

D. COMPUTER SIMULATION MODEL

The hypothesis of our research project is that the V-22 Osprey is the best aircraft available to meet the U.S. Marine Corps' medium-lift assault support aircraft mission. A review of literature relevant to the V-22 has produced detailed information on procurement costs and performance characteristics of the Osprey and alternative helicopters. Making a determination of which aircraft is "best" for the medium-lift mission based on the literature is next to impossible, mainly because most articles about the V-22 are heavily biased in favor of or against the aircraft. The most conclusive method for determining which aircraft best meets the Marine Corps' medium-lift needs would be a head-to-head competition between aircraft under the exact same mission situations and scenarios.

Arranging such a competition for the purposes of our research project is cost prohibitive and unrealistic, but a simulation model that incorporates a realistic mission with mean time between failure data and notional repair times can provide information that is valuable in absence of an actual competition. The simulation is based on two separate scenarios, one simulating the V-22 and the other the EH-101 operating in the

same environment. The results of such a simulation will be taken into consideration with previously gathered aircraft performance data to make an objective determination on the best aircraft available to meet the Marine Corps' medium-lift mission.

Any aircraft attributes that are similar, such as payload and troop carrying capacity will not be included in the model, since they add no value. Only characteristics that differentiate each aircraft, such as mean time between failures, speed, and mean time to repair will be modeled. In-flight refueling is not required by either type of aircraft for the distances flown in the model, so it was not included as a factor in the simulation. Likewise, opponents of the V-22 argue that the aircraft is more susceptible to hostile fire than helicopters during takeoff and landing. Since the authors could not find any research-based evidence to support this argument, susceptibility to hostile fire was not included in the simulation. The simulation is built and run using Arena simulation software.

IV. ANALYSIS

A. MEASURES OF OVERALL EFFECTIVENESS ANALYSIS

1. Problem Formulation

Problem formulation for this MOE analysis can be traced to the Marine Corps' declaration of the need to replace the CH-46 as its primary medium-lift aircraft in the mid-1980s. In 1990, former Commandant of the Marine Corps, General Alfred M. Gray, testified before the House Armed Services Committee that finding a medium-lift replacement was the most pressing issue for the Marines.

While [the CH-46] has served us well, we can no longer expect it to carry Marines in harm's way on the modern battlefield. Precision-guided munitions and hand-held surface-to-air missiles place the 30-year-old helicopters and the Marines they carry at risk" (Peña, 2003, pp. 4-5).

In addition to the survivability concerns described by General Gray, the Marines also indicate that the CH-46 is inadequate in the areas of payload, range, and speed; threat detection and self-protection; and reliability, maintainability, and operational availability (Peña, 2003, p. 5).

2. Determining Objectives

Given the numerous aspects in which the Marines consider the CH-46 to be deficient, it is clear that multiple objectives have been set for the service's new medium-lift aircraft to meet. For the purposes of this analysis, these multiple objectives are grouped into three main attributes: Mobility, Survivability, and Reliability. The Direct Assessment method of assigning weighted values was applied by the authors. Direct Assessment weights are based on attribute preferences of Marine Corps leadership as interpreted from the literature review for this research project. From highest to lowest weight, the three main attributes are Mobility (0.50), Survivability (0.30), and Reliability (0.20).

3. Assigning Values to Attributes

Mobility is broken down further into the sub-attributes of a) Speed (measured in knots/kts), b) Range (Nautical Miles/NM), and c) Payload (number of passengers and/or pounds of cargo the aircraft can carry). The main factors cited by the Marine Corps as to why the V-22 was chosen over alternative helicopters were its speed and range advantages. Once steady-state operations are established in a deployment location, however, the V-22's range advantage over helicopters is minimal because most missions flown are in close proximity to the main operating base. Therefore, the Mobility sub-attribute of Speed is weighted most heavily (0.40), followed by Range (0.30) and Payload (0.30).

Survivability has the sub-attributes of a) Maneuverability (Yes or No; it either is or is not capable of executing defensive maneuvers), b) Countermeasures (number of countermeasure systems installed—more is better), and c) Defensive Weaponry (Yes or No; either does or does not have defensive weapons installed). For this analysis, Maneuverability has the highest weight (0.50) among the three sub-attributes, mainly because it calls for active measures to be taken by pilots against threats. Countermeasures (0.30) is weighted second out of the three sub-attributes, followed by Defensive Weaponry (0.20).

Reliability is broken down further into a) Mission Capable (MC) Rate (number of aircraft mission capable divided by number of aircraft assigned), b) Maintenance Man Hours per Flight Hour (MMH/FH) (number of maintenance man-hours divided by number of flight hours), and Mean Time Between Failures (MTBF) (number of operating hours between failures that make the aircraft non-mission capable). Although these three sub-attributes are all important, Mission Capable Rate is ultimately the most important measure because it represents operational availability of the system. Therefore, MC Rate is weighted most heavily (0.40), followed by MMH/FH and MTBF (both 0.30).

A complete objectives hierarchy for our MOE analysis is shown in Figure 14 below.

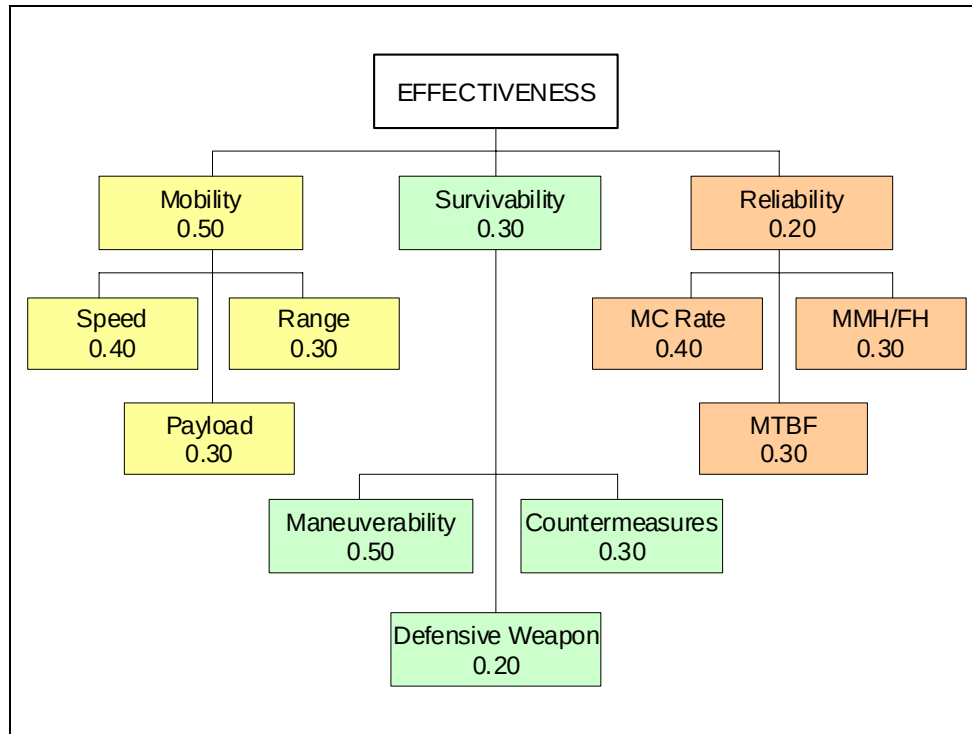


Figure 14. Objectives hierarchy for Measures of Effectiveness Analysis with Weighted Attributes (Authors, 2007).

4. Normalizing Measurements

As discussed previously, all measurements considered in a Multiple Objective Decision Problem must be normalized to ensure that analysis is not dominated by one particular attribute (the apples to oranges comparison). The result of this normalization is a unit-less value for each individual sub-attribute on the bottom of the objectives hierarchy (Speed, Range, Payload, etc). These values, which are eventually plugged in to the Measures of Overall Effectiveness equation to determine which aircraft is “best”, will range between a lowest possible score of 0 and a highest possible score of 1 for each sub-attribute. Calculations resulting in a value greater than 1 are rounded down to 1. The sources used to assign values to attributes are listed below, unless otherwise noted. CH-46 data was retrieved from Headquarters Marine Corps’ website under Aviation/Aircraft/Rotary Wing (United States Marine Corps, 2007, CH-46 aircraft page), V-22 data was retrieved from the V-22 Osprey Program report on Operational and Live

Fire Test and Evaluation (OPEVAL) in 2005 (DOT&E Report, 2005, pp 15, 26-29) and the EH-101 data was retrieved from Jane's website (Jane's, 2007, pp 12-13 & 15-16).

a. Speed

For the Marines' new medium-lift aircraft, more is considered to be better for the Mobility sub-attribute Speed. Therefore the following formula is used to normalize speed measurements for the MV-22 and the EH-101:

$$\frac{\text{Attribute value} - \text{worst}}{\text{Best} - \text{worst}}$$

For the purposes of this analysis, the minimum speed desired is 145 kts, which is the speed of the current medium-lift helicopter, the CH-46 Sea Knight. The maximum, or best possible value for this category is 255 kts, which is the advertised speed of the V-22. The EH-101 has a Speed of 150 kts.

V-22	EH-101
$\frac{255 - 145}{255 - 145}$	$\frac{150 - 145}{255 - 145}$
V-22 = 1.0	EH-101 = .045

b. Range

As with Speed, the more is better rule applies to the Range sub-attribute of the Mobility category. The minimum value for range, 132 NM, is again based on the range of the current medium-lift platform, the CH-46. The maximum range is 200 NM in accordance with the desired range listed in the 2005 V-22 operational evaluation. The MV-22 has a range radius of 230 NM with a load of 24 combat-equipped troops. Efforts to determine the range of the EH-101 with the same load proved fruitless. However, Jane's provided a range of 350 NM for the EH-101 to pick up 26 survivors on a search and rescue mission (Jane's, 2007, p. 16). Assuming that no passengers are onboard the EH-101 during the outbound leg of the mission, and that the survivors on the return leg are not combat-equipped, we estimated the aircraft would have a range of less than 350

NM if carrying 24 troops. Using these assumptions, the final estimated range used for the EH-101 is 300 NM. Despite these assumptions, both the V-22 and EH-101 have ranges that are greater than the maximum desired value of 200 NM, so both aircraft end up with an MOE value of 1 for this sub-attribute.

V-22

$$\frac{230 - 132}{200 - 132}$$

$$\text{V-22} = 1.441$$

(Rounded to 1.0)

EH-101

$$\frac{300 - 132}{200 - 132}$$

$$\text{EH-101} = 2.471$$

(Rounded to 1.0)

c. Payload

The more is better principle also applies to the Mobility sub-attribute Payload. The minimum payload value is 16 troops, 4,000 lbs external (CH-46) and the maximum is 24 troops, 10,000 lbs external. The V-22 payload is capable of 24 troops, 10,000 lbs external. The EH-101 payload is capable of 24 troops, 12,000 lbs external.

V-22

Troops

$$\frac{24 - 16}{24 - 16}$$

$$\text{V-22} = 1.0$$

EH-101

$$\frac{24 - 16}{24 - 16}$$

$$\text{EH-101} = 1.0$$

Externals

$$\frac{10000 - 4000}{10000 - 4000}$$

$$\text{V-22} = 1.0$$

$$\frac{12000 - 4000}{10000 - 4000}$$

$$\text{EH-101} = 1.333$$

(Rounded to 1)

d. Maneuverability

The Yes/No principle of whether the aircraft is or is not capable of executing defensive maneuvers applies to the Survivability sub-attribute Maneuverability. Both the V-22 and the EH-101 attribute values are Yes. The V-22

utilizes a low acoustic signature, delays aircraft conversion mode until late in landing approach, and tactical defensive maneuvers are taught to all pilots. The V-22 OPEVAL noted its tactical maneuvering, however, is limited to low to medium threat environments and that its flight envelope is more limited than conventional helicopters. The EH-101 is able to utilize a more flexible and adaptable style of defense maneuvering due to it being a conventional style helicopter capable of tighter maneuvers. By our criterion, however, both aircraft receive a normalized Maneuverability value of 1.

$$\mathbf{V-22 = 1}$$

$$\mathbf{EH-101 = 1}$$

e. Countermeasures

The more is better principle applies to the Countermeasures sub-attribute. The minimum for this sub-attribute would be at least 1 countermeasures system installed and the maximum is 5. The V-22 incorporates integrated radar warning receivers (RWR), missile warning system, laser warning system and chaff and flare countermeasures system; thus yielding a total of 4 systems installed. The EH-101 can utilize RWR sensors, chaff and flare dispensers, laser warning receivers (LWR), missile approach warning system (MAWS) and directed infrared countermeasures (DIRCM); thus yielding a total of 5 systems installed.

$$\mathbf{V-22}$$

$$\mathbf{EH-101}$$

$$\frac{4 - 1}{5 - 1}$$

$$\frac{5 - 1}{5 - 1}$$

$$\mathbf{V-22 = .75}$$

$$\mathbf{EH-101 = 1.0}$$

f. Defensive Weaponry

The more is better principle applies to the Survivability sub-attribute Defensive Weaponry. The minimum value for this sub-attribute is 0 if no guns are installed, and the maximum value is 3. The V-22 did not possess a defensive weapon during the OPEVAL in 2005, but it has since been outfitted with a 7.62mm M240G machine gun, so it has a Defensive Weaponry value of 1 (Hoellwarth, 2007). The

EH-101 can possess pinnacle mounted machine guns on the doors and/or rear, a 12.7mm chin turret machine gun, and/or stub wings for rocket pods; therefore its assigned a Defensive Weaponry value of 3.

V-22	EH-101
$\frac{1.0 - 0}{3.0 - 0}$	$\frac{3.0 - 0}{3.0 - 0}$
V-22 = .333	EH-101 = 1.0

g. Mission Capable (MC) Rate

The more is better principle applies to the Reliability sub-attribute of Mission Capable Rate. The threshold MC rate from the V-22 OPEVAL utilizes a goal of 82% or better and a maximum of 100%. During its OPEVAL in 2005 the V-22 achieved a rate of 86%. Although no OPEVAL data is available for the EH-101 yet, historical reliability and maintainability data exceeds that achieved during the V-22 OPEVAL. Data was extrapolated from AgustaWestland's 2005 report on reliability predictions for the VXX helicopter (AgustaWestland, 2005, p. 18). With higher reliability, it follows that system availability will also exceed that of the V-22. Therefore, the EH-101 is assigned a Mission Capable Rate of 87% in our calculation.

V-22	EH-101
$\frac{.86 - .82}{1 - .82}$	$\frac{.87 - .82}{1 - .82}$
V-22 = .222	EH-101 = 0.278

h. Maintenance Man Hours per Flight Hour (MMH/FH)

The less is better principle applies to the Maintenance Man Hours per Flight Hour sub-attribute. The V-22 OPEVAL utilized 20 hours or less as an acceptable threshold for MMH/FH. The value used as best for this attribute is 2.78 MMH/FH, which is what the EH-101 has historically achieved. During the OPEVAL, the V-22

achieved 7.2 hours for its MMH/FH. EH-101 information is based on AgustaWestland's 2005 report on maintainability predictions for the VXX helicopter (AgustaWestland, 2005, p. 12).

V-22	EH-101
$\frac{7.2 - 20}{2.78 - 20}$	$\frac{2.78 - 20}{2.78 - 20}$
V-22 = .743	EH-101 = 1.0
	(Rounded to 1)

i. Mean Time Between Failures (MTBF)

The more is better principle applies to the Mean Time Between Failures sub-attribute. The V-22 OPEVAL utilized .9 hours as acceptable threshold for MTBF and best would be 10 hours, based on maintenance requirements. The V-22, during the OPEVAL achieved 1.4 hours for its average operating hours between failures. The EH-101 has historically achieved 6.02 operating hours between failures. The EH-101 information was extrapolated from AgustaWestland's 2005 report on reliability predictions for the VXX helicopter (AgustaWestland, 2005, p. 18).

V-22	EH-101
$\frac{1.4 - .9}{10 - .9}$	$\frac{6.02 - .9}{10 - .9}$
V-22 = .055	EH-101 = .563

5. Calculating the Final Measures of Effectiveness

As stated earlier, the final MOE value is calculated by multiplying the assigned weights of desired attributes and sub-attributes by the normalized measurement values. Below are the calculations for our analysis of the V-22 and EH-101 measures of effectiveness. One note to point out is that the underlined numbers indicate scores above the maximum value of 1.0, signifying that the aircraft is able to reach higher than the associated threshold target; therefore 1.0 is utilized for the calculation.

The V-22 calculation:

$$\text{MOE Mobility} = \text{Mobility Weight (Speed Weight x Speed Value + Range Weight x Range Value + Payload Weight x Payload value)}$$

$$\text{MOE Mobility} = .5 (.4 \times \underline{1.0} + .3 \times \underline{1.0} + .3 \times 1.0) = .5$$

$$\text{MOE Survivability} = \text{Survivability Weight (Maneuverability Weight x Maneuverability Value + Countermeasures Weight x Countermeasures Value + Defensive Weapon Weight x Defensive Weapon value)}$$

$$\text{MOE Survivability} = .3 (.5 \times 1 + .3 \times .75 + .2 \times .333) = .2375$$

$$\text{MOE Reliability} = \text{Reliability Weight (MC Weight x MC Value + MMH/FH Weight x MMH/FH Value + MTBF Weight x MTBF value)}$$

$$\text{MOE Reliability} = .2 (.4 \times .222 + .3 \times .743 + .3 \times .055) = .0656$$

$$\text{V-22 MOE} = \text{MOE Mobility} + \text{MOE Survivability} + \text{MOE Reliability}$$

$$\text{V-22 MOE} = .5 + .2375 + .0656 = .8031$$

The EH-101 calculation is:

$$\text{MOE Mobility} = \text{Mobility Weight (Speed Weight x Speed Value + Range Weight x Range Value + Payload Weight x Payload value)}$$

$$\text{MOE Mobility} = .5 (.4 \times .045 + .3 \times \underline{1.0} + .3 \times \underline{1.0}) = .309$$

$$\text{MOE Survivability} = \text{Survivability Weight (Maneuverability Weight x Maneuverability Value + Countermeasures Weight x Countermeasures Value + Defensive Weapon Weight x Defensive Weapon value)}$$

$$\text{MOE Survivability} = .3 (.5 \times 1.0 + .3 \times 1.0 + .2 \times 1.0) = .3$$

$$\text{MOE Reliability} = \text{Reliability Weight (MC Weight x MC Value + MMH/FH Weight x MMH/FH Value + MTBF Weight x MTBF value)}$$

$$\text{MOE Reliability} = .2 (.4 \times .278 + .3 \times 1.0 + .3 \times .563) = .116$$

$$\text{EH-101 MOE} = \text{MOE Mobility} + \text{MOE Survivability} + \text{MOE Reliability}$$

$$\text{EH-101 MOE} = .309 + .3 + .116 = .725$$

B. NET PRESENT VALUE ANALYSIS

The basic NPV analysis (see Table 5) starts by selecting a timeframe for procurement of the aircraft. Current production of the V-22 is funded through FY08, therefore the NPV calculation starts in FY09, when the first decision point will take place (i.e., make more or stop production). That production cycle is extended eight years through FY16. Number procured per year assumes steady state production of 30 per year in the first seven years, with the remaining 27 purchased in year eight, for a total of 237 aircraft purchased. This gives the USMC the 360 aircraft fleet requested in the 2007 budget estimate for aircraft procurement.

Cost per aircraft of \$88.298 million is the cost per copy over the total program schedule in FY2007 dollars, taken from the 2007 budget estimate. This amount is the unit cost averaged across all budget years of the V-22 program, representing then year, real dollars. The discount factor of seven percent was taken from the Office of Management and Budget Circular A-94 (OMB, 1992, pp. 5-6), as discussed earlier in the research methodology section of this paper. The NPV per aircraft is then multiplied by the number of aircraft purchased for that year to get a yearly total. The yearly totals are then added together to get a total NPV for the procurement period.

Table 5. V-22 NPV Calculation

V-22 Net Present Value (Option 1 - all V-22 Fleet)						
FY	Year (n)	QTY V-22 Purchased	Future Value	Discount Factor	NPV (per unit)	NPV (all units)
2009	1	30	\$ 88,298,000	7.00%	\$ 82,521,495	\$ 2,475,644,860
2010	2	30	\$ 88,298,000	7.00%	\$ 77,122,893	\$ 2,313,686,785
2011	3	30	\$ 88,298,000	7.00%	\$ 72,077,470	\$ 2,162,324,098
2012	4	30	\$ 88,298,000	7.00%	\$ 67,362,121	\$ 2,020,863,643
2013	5	30	\$ 88,298,000	7.00%	\$ 62,955,254	\$ 1,888,657,610
2014	6	30	\$ 88,298,000	7.00%	\$ 58,836,686	\$ 1,765,100,570
2015	7	30	\$ 88,298,000	7.00%	\$ 54,987,557	\$ 1,649,626,701
2016	8	27	\$ 88,298,000	7.00%	\$ 51,390,240	\$ 1,387,536,478
		237				
						\$ 15,663,440,745
						V-22's acquired to 2008
						123
						V-22's 2009 to completion
						237
						Total V-22 Fleet
						360

An alternative to sole V-22 procurement or sole EH-101 procurement is a mixed fleet. Since there are a number of V-22 aircraft already acquired, another option could possibly be that of half V-22's and half EH-101's. The NPV analysis for the mixed fleet (see Table 6) follows the same basic methodology as the basic V-22 NPV calculation. The main exception is the combination of the two aircraft into a single fleet. The plan for this option is to continue to produce Ospreys through 2011. The main goal is to allow EH-101 production time to mature and reach a steady state. This will also allow V-22 production to slowly ramp down, and allows for the possibility of transitioning production lines from one aircraft to the other. EH-101 production will begin in FY09 and continue through FY14, cutting a full two years of the production timeline for a pure V-22 fleet. After executing this option there would be a mixed fleet of 360 aircraft per the Marine Corps' goal; equating to 180 V-22's and 180 EH-101's.

The cost per copy of the EH-101 was extrapolated from various sources, since a current purchase price could not be obtained by the authors. The main source was the Canadian Government's Depository Service Program Website, which is a public document sharing site for the Canadians (Rossignol, 1998). According to the Canadian government information, they purchased 50 EH-101 helicopters for \$5 Billion Canadian in 1993. Of those 50 helicopters, 35 were a more expensive anti-submarine warfare variant, and the remaining 15 were standard utility helicopters. The document further explains that half of the \$5 Billion Canadian purchase price was for the anti-submarine warfare systems, therefore 50 base utility helicopters would have cost only \$2.5 Billion Canadian. That equates to roughly \$50 Million Canadian per EH-101 utility aircraft.

In order to convert that value into U.S. dollars the authors used the Federal Reserve System historic conversion rates for U.S. currency (Federal Reserve System, 2001). The Canadian dollar was worth 1.1571 U.S. dollars in 1992, so the purchase price of an EH-101 variant utility helicopter would have been \$43,211,476. Since this is representative of FY 1992 dollars, establishing a base year for comparison is required. Since the V-22 amount is from the 2007 budget estimate, representing an average in then year dollars across the program, the same methodology was used for the EH-101 variant. The 1992 then year dollars were converted to 2007 then year dollars for comparison. To

facilitate this conversion the Naval Center for Cost Analysis websites' inflation indices were used. Using this index, the FY 1992 dollar amount of \$43,211,476 was converted to FY 2007 dollars and calculated to be \$56,033,449. This dollar amount was utilized for the V-22/EH-101 NPV calculation. This is for the base utility package, but since it is for military use, it would have been equipped with military grade avionics and countermeasure systems. It is assumed here that those systems would be comparable to the package required by the Marine Corps.

Table 6. V-22/EH-101 NPV Calculation

Combined Net Present Value (Option 2 - mixed V-22/EH-101 Fleet)						
FY	Year (n)	QTY V-22 Purchased	Future Value V-22	Discount Factor	NPV (per V-22)	
2009	1	15	\$ 88,298,000	7.00%	\$ 82,521,495	
2010	2	20	\$ 88,298,000	7.00%	\$ 77,122,893	
2011	3	22	\$ 88,298,000	7.00%	\$ 72,077,470	
		57				
FY	Year (n)	QTY EH-101 Purchased	Future Value EH-101	Discount Factor	NPV (per EH-101)	NPV (all units)
2009	1	30	\$ 56,033,449	7.00%	\$ 52,367,709	\$ 2,808,853,710
2010	2	30	\$ 56,033,449	7.00%	\$ 48,941,784	\$ 3,010,711,390
2011	3	30	\$ 56,033,449	7.00%	\$ 45,739,985	\$ 2,957,903,902
2012	4	30	\$ 56,033,449	7.00%	\$ 42,747,850	\$ 1,282,429,499
2013	5	30	\$ 56,033,449	7.00%	\$ 39,951,075	\$ 1,198,532,242
2014	6	30	\$ 56,033,449	7.00%	\$ 37,337,453	\$ 1,120,123,590
		180				\$ 12,378,554,333
					V-22's acquired to 2008	123
					V-22's 2009 to completion	57
					EH-101's 2009 to completion	180
					Total Combined Fleet	360

C. SIMULATION PERFORMANCE ANALYSIS

The simulation is broken down into entities (what moves through the simulation), attributes of those entities, and processes (what acts upon the entities). The model was kept as basic as possible to generate raw data that is easily comparable between the two aircraft. The main elements of the simulation are listed below:

1. Entities

Aircraft: V-22 or EH-101

2. Attributes

Cruising speed: V-22 is 255 knots and EH-101 is 150 knots.

3. Processes

Repair: Time to repair was triangularly distributed. The average V-22 repair time is 9 hours according to the OPEVAL in 2005. Average repair time for the EH-101 was not available and was therefore extrapolated using man hours per flight hour data, which was available for both aircraft. If the mean time to repair a V-22 is 9 hours and the man hours required per flight hour is 7.2, and if the EH-101 requires 2.78 man hours per flight hour, the corresponding mean time to repair is 3.47. Minimum and maximum repair times for both aircraft are 2 and 72 hours, respectively.

Failures are created based on Mean Time Between Failure (MTBF) data for both aircraft. MTBF for the V-22 and EH-101 are 1.4 and 6.02 hours, respectively. The failure entity is looped back around after every repair when triggered by a signal.

Sortie: The sortie time was calculated using a cruising speed of 255 kts for the V-22 and 150 kts for the EH-101. The sortie is based on a 200 NM flight (100 NM one way). Time was calculated for each aircraft based on a ten knot headwind, no wind, and a ten knot tailwind, forming a triangular distribution. The loading/unloading time for both aircraft uses a uniform distribution with a minimum of five minutes and maximum of fifteen minutes.

The formula for the time to complete a sortie for the EH-101 is:

$$\text{TRIA (1.4286, 1.333, 1.25)} + \text{TRIA (1.4286, 1.333, 1.25)} + \text{UNIF (.01667, .25)} + \text{UNIF (.01667, .25)}$$

The formula for the V-22 to complete the same sortie is:

$$\text{TRIA (.7547, .7843, .8163)} + \text{TRIA (.7547, .7843, .8163)} + \text{UNIF (.01667, .25)} + \text{UNIF (.01667, .25)}$$

4. Resources and Setup

Flight Window: The model simulates a daily 8 hour “Fly Day.” Meaning 8 hours out of every 24 hour day are available to conduct flying operations; the remaining 16 hours of the day are dedicated to crew rest, aircraft repair, and flight planning. Total run time for the simulation is 30 days, or 720 total hours. 100 replications of each simulation were completed prior to data collection. Figures 15 and 16 are screenshots of the base model for both aircraft.

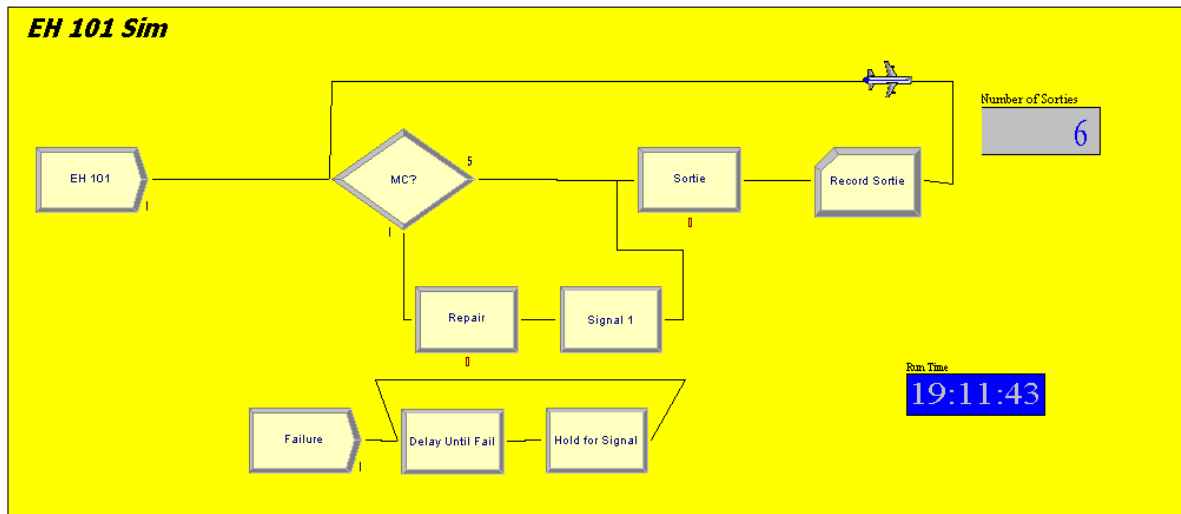


Figure 15. EH-101 Arena Simulation (Authors, 2007).

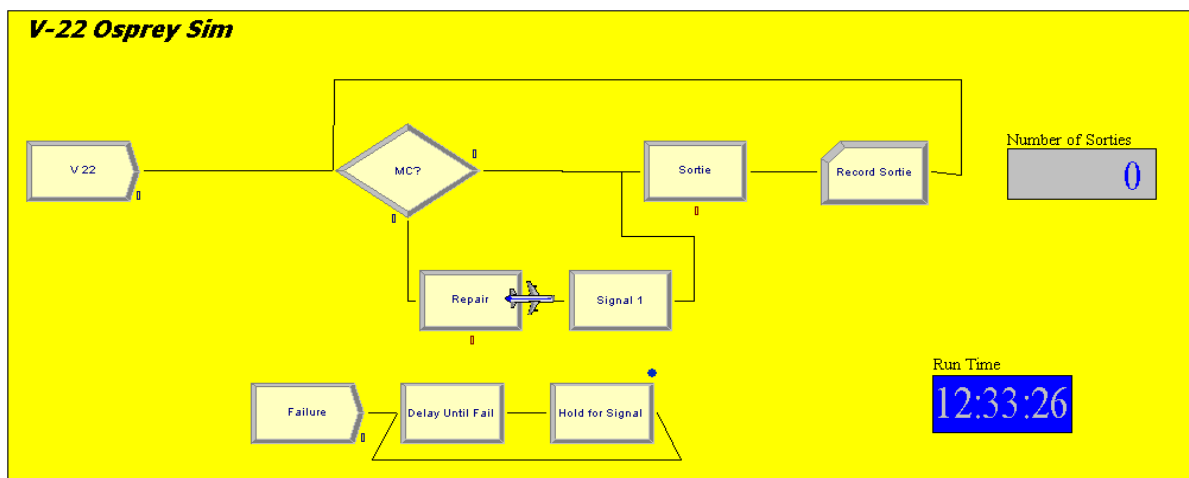


Figure 16. V-22 Arena Simulation (Authors, 2007).

D. BUDGETARY ANALYSIS

Utilizing the Navy budgets and simple calculations across budget years provides additional perspective of budget estimate variations in the V-22 program. Narrowing the focus to FY 2005 through 2011 provides better interpretation of changes to procurement estimates made during this period and is summarized in Table 7. Although procurement cost during this period decreases, this savings in procurement is due to a reduction in quantity. In sum, the trend of decreasing procurement cost between FY 2005-2011 could create financial savings in those years, but it is facilitated by extending the procurement further into the future. This in turn creates an increase in unit cost *and total program cost*.

Table 7. FY 2005 – 2011 Budget Estimate Comparison (After: Department of the Navy, 2004, 2005, 2006 and 2007)

Navy FY's Budget Estimate Comparison: V-22 (Note 1)				
	Procurement Cost	Total Program Cost	Unit Cost	Quantities
2005: Calculated from FY's 2005 and 2007	-0.5%	0.4%	-0.5%	0.0%
2006: Calculated from FY's 2005 and 2008/2009	-13.3%	11.8%	8.4%	-20.0%
2007: Calculated from FY's 2005 and 2008/2009	-31.0%	11.8%	42.9%	-51.7%
2008: Calculated from FY's 2005 and 2008/2009	-14.9%	11.8%	21.5%	-30.0%
2009: Calculated from FY's 2005 and 2008/2009	-3.2%	11.8%	6.5%	-9.1%
2010: Calculated from FY's 2006/2007 and 2008/2009	-3.2%	6.5%	12.9%	-14.3%
2011: Calculated from FY's 2006/2007 and 2008/2009	-9.8%	6.5%	14.2%	-21.1%
Note 1 - Data taken from DON FY 2005, 2006/2007, 2007 and 2008/2009 (V-22) Budget Estimates, P-40 Sheets				

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V. RESULTS

A. NET PRESENT VALUE

As shown previously in Table 5, calculations for V-22 procurement cost reveal an NPV of \$15,663,440,745. This amount is from FY2009 to FY2016, when 237 V-22's are projected to be added to the fleet of 123 aircraft. Upon program completion there would be 360 V-22 medium-lift aircraft.

Since the Marine Corps is procuring the EH-101 for Presidential support, a proposed mix of V-22 and EH-101 aircraft was explored by the authors as a hypothetical alternative to the full procurement of 360 V-22's. Under this scenario V-22 procurement would cease upon acquiring 180 aircraft. This V-22 ramp down was proposed from FY2009 to FY2011 and in turn EH-101 medium-lift utility helicopters would be procured from FY2009 to FY2014. The EH-101 would be procured at a constant rate of 30 per year through 2014. The proposed final fleet size is still 360 medium-lift aircraft, but is comprised of 180 V-22 and 180 EH-101 aircraft. The NPV calculation from the combined procurement cost of this scenario, as seen in Table 6, was \$12,378,554,333.

Our NPV analysis shows that full procurement of the V-22 yields a higher cost than the combined procurement cost of a mix of V-22 and EH-101 aircraft. The difference in NPV between the two scenarios is \$3,284,886,410. Therefore, based solely on procurement cost, a mixed fleet of medium-lift aircraft would be more cost beneficial. Per unit, the EH-101 would be \$18,249,369 less than the V-22.

B. MEASURES OF OVERALL EFFECTIVENESS

An overview of normalized sub-attribute values for the V-22 and EH-101 are provided in Table 8 below. As the table shows, the V-22 enjoys a Speed advantage over the EH-101, while the EH-101 has an advantage in Countermeasures and MC Rate, MMH/FH, and MTBF. There is no clear advantage for either aircraft in Range, Payload, Maneuverability, or Defensive Weaponry.

Table 8. Measures of Overall Effectiveness Overview Table (Authors, 2007).

Sub-Attribute	Advantage V-22	Advantage EH-101	No Clear Advantage
Speed	X		
Range			X
Payload			X
Maneuverability			X
Countermeasures		X	
Defensive Wpnry		X	
MC Rate		X	
MMH/FH		X	
MTBF		X	

Based purely on the information provided in Table 8, one might infer that the EH-101 has a significantly higher measure of overall effectiveness than the V-22, and that it is the best option for the Marine Corps' medium-lift mission. After inserting the normalized attribute values into the MOE equation, however, the V-22 actually has a higher MOE value (.8031) than the EH-101 (.725). Even though the Osprey only has an advantage over the EH-101 in a single area, Speed, this sub-attribute actually carries significant weight because it falls under the main attribute deemed to be most important, which is Mobility with a weight of 0.50. Furthermore, the EH-101's main advantages over the Osprey fall under the attribute Reliability, which carries the lowest weight (0.20) of the three main attributes.

The speed advantage of the Osprey is bolstered significantly by the higher weight placed on the Mobility attribute of the new weapon system. Likewise, the advantages enjoyed by the EH-101 in MC Rate, MMH/FH, and MTBF are watered down by the lower weight of the weapon system's Reliability attribute. Based solely on the results of the MOE analysis, the V-22 is the best option to fulfill the Marine Corps' medium-lift mission because it has a higher MOE value than the EH-101. But from a decision maker's perspective, the EH-101's advantages in the reliability sub-attributes cannot be ignored.

C. SIMULATION

Screenshots of the Arena simulation output are shown in Figures 17 and 18 below. The breakout between the two aircraft was very close to the values expected by the authors, with the V-22 averaging 19.31 sorties completed and the EH-101 averaging 24.73 sorties completed per month.

That gap of five sorties can be rapidly closed by the Osprey if the MTBF and mean repair time numbers improve, which is expected to happen as the system matures. In another version of the simulation, MTBF and repair time values for the V-22 were changed to 6.02 and 3.47 hours respectively, matching the attributes of the EH-101. The time required to complete the sortie was not changed, thus allowing the V-22 to exercise its speed advantage. Using the same 30 day timeframe, the V-22 averaged 30.53 sorties per month, a 58% increase in the completion rate.

During informal discussions with Marine Corps helicopter pilots, the authors determined that both aircraft are equally vulnerable to crashes, including those resulting from the Vortex Ring State phenomenon. Therefore, the assumption was made that both aircraft have similar survivability rates once airborne, so vulnerability to crashing was not factored into the Reliability attribute. As the V-22 matures and more data becomes available on catastrophic mechanical failures, this may be an area to study in more depth.

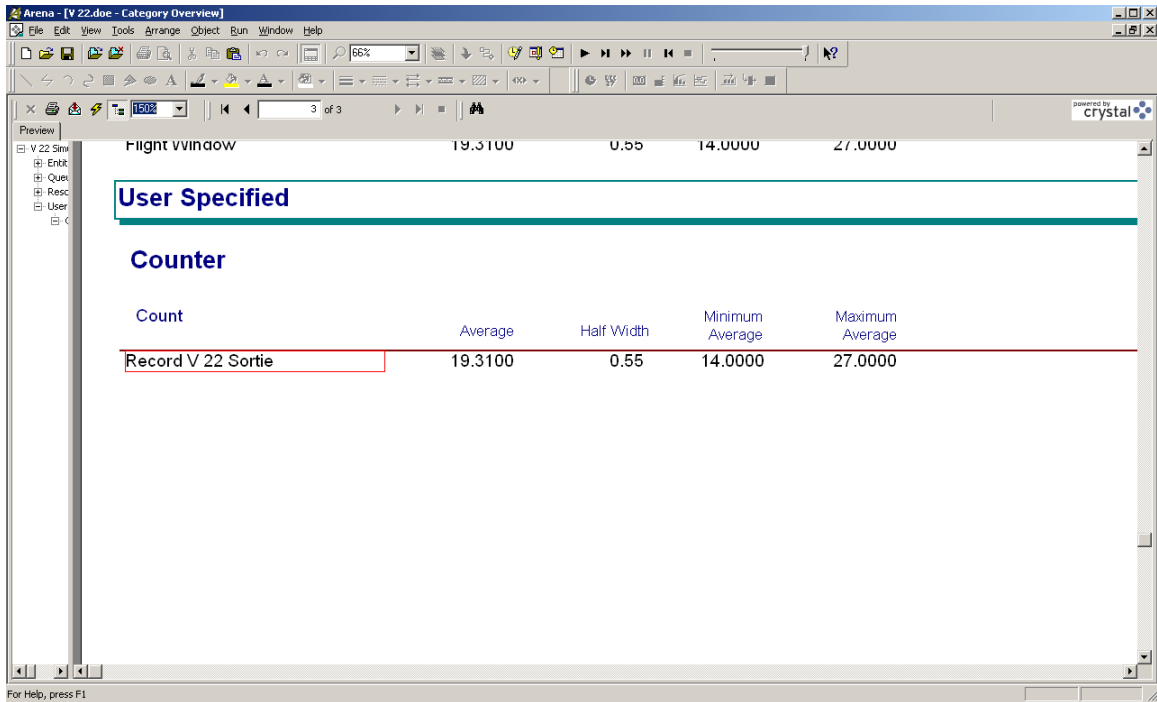


Figure 17. V-22 Simulation Output (Authors, 2007).

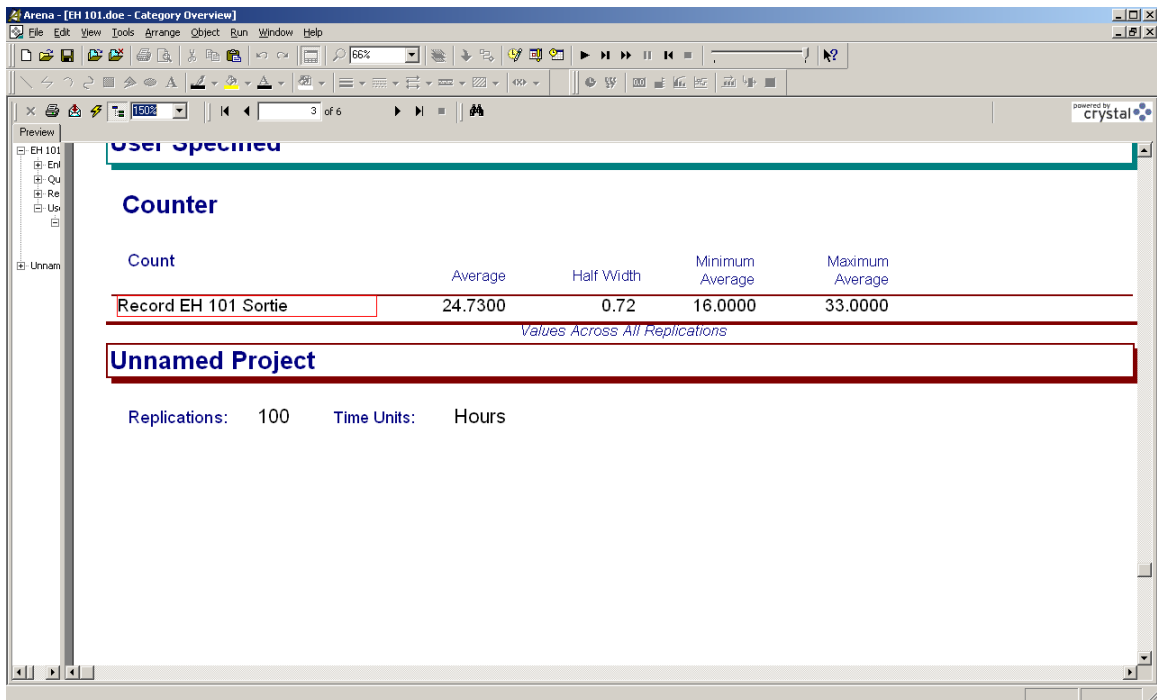


Figure 18. EH-101 Simulation Output (Authors, 2007).

VI. CONCLUSIONS

The history of the V-22 Osprey is one of much controversy. The aircraft has survived cost and schedule overruns, numerous deadly crashes, and a scandal over falsified maintenance records. Even as the Osprey transitions from developmental to operational use, the aircraft is still a source of heated debate between those who say the program is transforming military aviation and those who say it should be cancelled.

As the V-22 Osprey began its first operational deployment to a hostile environment in September 2007, supporters of the program enthusiastically celebrated this major milestone. But critics are quick to point out that the aircraft is already being sheltered from potentially risky situations. For example, rather than taking advantage of the V-22's long-range self-deployment capability, VMM-263 chose to ferry them over on the USS WASP (LHD-1) to avoid dangerous icing conditions. During previous trans-Atlantic flights, the aircraft's de-icing system was shown to be inadequate, resulting in an emergency landing in Iceland due to an engine compressor stall (Whittle, 2007). The purpose of this research project was to provide an evaluation of whether or not the V-22 is the "best" option to meet the Marine Corps' medium-lift aviation needs.

Results from our analysis put the EH-101 on top in both the net present value and computer simulation models, while the V-22 was superior in measures of overall effectiveness. Based on these results, the authors' evaluation is that the V-22 Osprey is not the "best" option to meet the Marine Corps' medium-lift aviation needs. Analysis is based on the most current data made available to the authors which, in some cases, dates back to 2005. As the V-22 matures, performance data are expected to improve. However, even in scenarios where the V-22 was assigned values exceeding those expected to be achieved at maturity, the gain in performance was only marginally better than that of traditional helicopters.

The authors conclude that the Marine Corps continue V-22 procurement plans through 2011, while transitioning to procurement of EH-101 helicopters beginning in 2009. Even though the Osprey does offer unique capabilities in speed, the benefit over

traditional helicopters is marginal. In addition, our computer simulation model shows that the V-22's advantage in speed is counterbalanced by the reliability and maintainability advantages of the EH-101. The difference in cost realized by procuring a mixed-fleet is \$18,249,369 per EH-101. Although cost is an important consideration in selection of weapons system to be procured, it is not necessarily the *most* important. The system's ability to meet key performance parameters as defined by the end user is ultimately the most important factor. The mixed fleet option has the potential to offer the best of both worlds for the Marine Corps. Under this plan, the Osprey would still be procured in sufficient numbers to allow the Marines to exploit the aircraft's unique capabilities in speed and self-deployability. At the same time, substituting half of the medium-lift fleet with EH-101s would preserve precious procurement dollars without sacrificing readiness.

The EH-101 is a viable replacement option for the V-22 because it has similar troop and cargo carrying capacities. The aircraft is also a good choice because it is already flown by military organizations around the world, including the Canadians, Italians, and Britain's Royal Air Force. The airframe has already been selected to fulfill the Presidential Support mission as "Marine One", so existing contracts, manufacturing capability, and personnel training requirements can be leveraged to save costs. Perhaps most significantly, since the aircraft is already a proven commodity, RDT&E costs incurred by replacing the V-22 with the EH-101 would be negligible.

Potential downfalls to instituting a mixed aircraft fleet include a loss of economies of scale and the need for a larger logistics footprint to support both aircraft. Having a single airframe to meet all mission requirements is advantageous because it would allow consolidation of the supply chain, resulting in lower costs for spare parts inventories. A single airframe also allows the Marines to have a standardized set of tools and equipment to support the entire fleet. Commonalities between the V-22 and EH-101 would be extremely limited. However, since the airframe has already been selected for the Presidential Support mission, the opportunity still exists to implement supply chain consolidation initiatives. Future research may be able to answer the question of whether the cost incurred by operating a mixed fleet exceeds the cost of an all V-22 fleet.

Due to limited availability of time and EH-101 information, the NPV analysis in this study was based solely on procurement cost of each aircraft type. Future researchers may be able to conduct a more accurate NPV analysis by calculating total system life cycle cost for each aircraft. When all cost factors are taken into consideration, the conclusion on whether or not system cost is justified by the benefits gained may be different.

Finally, due to the narrow focus of our study, the computer simulation model in was kept very basic. Future researchers may choose to develop a more robust model that factors in the level of hostility in the operational environment, logistics footprint required for shipboard operations, and more current data on mobility, survivability, and reliability.

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