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Design optimization of a multi-mission helicopter configuration

Steven E. Halpern

To the Graduate Council:

I am submitting herewith a thesis written by Steven E. Halpern entitled "Design optimization of a multi-mission helicopter configuration." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Robert B. Richards, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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We have read this thesis and recommend its acceptance:

Dr. Alfonso Pujol

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Acceptance for the Council:

Vice Provost and Dean of Graduate Studies

DESIGN OPTIMIZATION OF A MULTI-MISSION HELICOPTER CONFIGURATION

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Steven E. Halpern

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Dedication

This thesis is dedicated to my father, Stanley Halpern, who impressed the importance of education and hard work in pursuit of excellence upon us. Through his actions, he showed the importance of strong ethics and family unity. I will be forever grateful for the sacrifices he made for us and indebted to him for my wonderful upbringing. Rest in peace.

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The completion of this degree spanned a period of 6 years, the birth of 2 children, 3 military moves, and countless other work-related 'crises'. I would like to thank my beautiful wife Shannon, and my impressive girls, Gavi, Eva, and Ahna. Although this work was completed in my off time, this time was actually your time and its completion is a result of your understanding and encouragement.

Abstract

The MH-60S helicopter program is currently in the development stages of incorporating provisions for the Airborne Mine Countermeasures (AMCM) Mission and the Armed Helicopter Mission. The integration of these mission provisions represents a departure from the initial design goals of the MH-60S as solely a combat support helicopter. This aircraft will ultimately be expected to execute in excess of 18 different missions in place of seven existing aircraft rather than just serving as a replacement for the H-46 helicopter.

Common to any aircraft program is the issue of weight growth. Weight growth has been cited as a major risk on this program in light of the fact that there will be provisions for both major mission areas in the final (FY 07) aircraft configuration. As a result of not anticipating specific design impacts associated with the requirement to perform a wide range of missions, the aircraft will not meet the requirements set forth in the Operational Requirements Document. The fact that a single aircraft will be taking the place of several aircraft that were implicitly designed for specific missions serves to further increase the gap between the requirements and the realized, as-designed performance.

The specific weight issue can be further clarified by a discussion of weight growth over time and a study of how each mission area will add weight. Incident to this discussion is a comparison of aircraft performance versus the requirements and the associated shortfalls in range, time on station, and combat radius. There are many areas where weight can be shed. Weight reduction and performance enhancements have

become unfunded program requirements, resulting in detailed analysis and considerations for postproduction changes to the aircraft. In this thesis, background and causal factors for the weight/performance issue will be analyzed. Candidates for weight reduction and performance enhancements that yield the greatest performance increase will be proposed.

Preface

The analyses, opinions, and conclusions expressed herein are those of the author and do not represent the official position of the Naval Air Systems Command or the Department of the Navy. Data presented in this thesis were obtained from various program office analyses and briefings in support of the MH-60S program. The integration of the Airborne Mine Countermeasures and Armed Helicopter missions into the MH-60S is still in the research and development phase. As the MH-60S Mission Systems Lead, the author is directly responsible for development of the multi-mission capability and in this capacity is working towards funding and scheduling implications of the weight and performance issues presented.

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List of Abbreviations

AGL	Above Ground Level
AH	Armed Helicopter
AMCM	Airborne Mine Countermeasures
AOA	Analysis of Alternatives
ARG	Amphibious Ready Group
ASuW	Anti-Surface Warfare
ASW	Anti-Submarine Warfare
BG or CVBG	Carrier Battle Group
BR	Best Range Airspeed
CLF	Combat Logistics Force
CNO	Chief of Naval Operations
CONOPS	Concept of Operations
CONUS	Continental United States
CRD	Capstone Requirements Document
CSAR	Combat Search and Rescue
CVBG	Carrier Battle Group
DOD	Department of Defense
FY	Fiscal Year
HMP	Helicopter Master Plan
HOGE	Hover Out of Ground Effect
IMD HUMS	Integrated Maintenance Diagnostic Health Usage Monitoring System
IOC	Initial Operating Capability
IRP	Instrument Rated Power
LIDAR	Light Detection and Ranging
MCM	Mine Countermeasures
MCP	Maximum Continuous Power
MIO	Maritime Intercept Operations
MSC	Military Sealift Command
MSL	Mean Sea Level
NEO	Noncombatant Evacuation Operation

NM	Nautical Miles
Nr	Main Rotor Speed expressed in percent
NSW	Naval Special Warfare
OAMCM	Organic Airborne Mine Countermeasures
OPEVAL	Operational Evaluation
ORD	Operational Requirements Document
PMA	Program Manager, Aviation
PMS-210	Program Manager, Airborne Mine Countermeasures
POM	Program Objective Memorandum
SAR	Search and Rescue
SWS	Special Warfare Support
TOGW	Takeoff Gross Weight
Vbe	Maximum Endurance Airspeed
Vbr	Best Range Airspeed
V99%BR	99% of Best Range Airspeed
VERTREP	Vertical Replenishment
VOD	Vertical Onboard Delivery
VROC	Vertical Rate of Climb
VTO	Vertical Takeoff

I. Introduction

Background

Following the Gulf War, the Armed Forces experienced a period of major downsizing. This downsizing was applicable to all areas and included but was not limited to manpower and equipment. Naval war fighting doctrine including *From the Sea* and the Joint Chiefs of Staff' *Joint Vision 2010/2020* operational concepts are the documents which describe the reshaping and restructuring of the Naval Forces for the 21st century.

A common thread throughout the doctrine is an increased emphasis on realigning force structure to be able to support sustained, conventional threats as well as addresses the unconventional/asymmetric threats that were highlighted September 11, 2001. The Naval Forces of the future must be able to fight in the littorals while maintaining the capability to conduct traditional 'blue-water' operations by leveraging and complementing the capabilities of other armed services. Ultimately, the collective doctrine describes a large degree of flexibility to the war fighter while highlighting the need to be a leader in technology.

A product of Naval Force restructuring is the CNO-approved Helicopter Master Plan (HMP) of 1998. The HMP was initiated in FY 1996 and represented the plan for helicopter aviation in response to the H-2 helicopter reaching the end of its service life. Ultimately, the HMP drives a reduction from seven type/model/series helicopters currently in use by the Navy to two; the MH-60S and the MH-60R.

The most obvious reason for this major change to force structure is to reduce acquisition as well as operations and support costs while supporting the concepts embodied in *Joint Vision 2010/2020.* The HMP acquisition strategy calls for a one for one airframe replacement with either an MH-60S or an MH-60R. It is interesting to note that the HMP is not based on war fighting analysis but only on life cycle cost reduction.

The HMP calls for retirement of the H-3, H-2, H-46D, H-60F, H-60B, H-1 and the H-60H. The MH-60S will take the role of the H-46 in its VERTREP role and the H-3 and H-1 in its utility role. H-60F and HH-60H aircraft will be retired as the MH-60S assumes their missions in the CVBG. The MH-60R will assume the H-60B and the H-2 missions. Figure 1 illustrates the migration of missions to an all H-60 helicopter community.

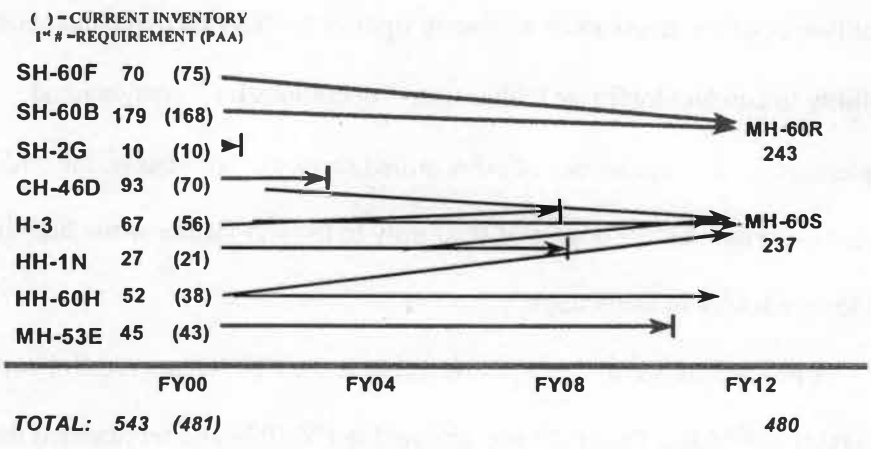

FIGURE 1: GRAPHICAL DEPICTION OF HELICOPTER MASTER PLAN

The MH-53E currently employed by the Navy for Airborne Mine Countermeasures (AMCM) and Vertical Onboard Delivery (VOD) begins to reach the end of its service life limit in FY 07. While the MH-53E was not specifically called out in the HMP, unofficial references to the future of the MH-53E tentatively trace its mission being transferred to the MH-60S. Furthermore, recent cost benefit analyses seem to favor eventual replacement of the MH-53E aircraft with the MH-60S. It is anticipated that a decision on whether to perform a service life extension program or retire the MH-53E will need to be addressed not later than the POM 06 process (fiscal year (FY) 2004).

The HMP transition to an all H-60 helicopter fleet is not a drastic change in capability except in the case of the MH-53E. In other words, the relative lift capabilities of all seven helicopters are fairly close to an H-60. Although the author will explore this area further, the transition from the MH-53E to an MH-60S possesses unique challenges in the AMCM and heavy lift missions.

Concept of Operations

Related to the HMP is the development of the helicopter concept of operations or CONOPS. Given an all H-60 helicopter fleet, the Navy must decide on a force structure that will provide the greatest war fighting capability. CONOPS is chartered to provide the correct numbers of helicopters combined with a streamlined command and control structure. The goal of CONOPS is completion of infrastructure realignment and the first MH-60R/S carrier deployment in FY 2008.

Based on the introduction of the MH-60S and MH-60R, combined with the retirement of the S-3, helicopter CONOPS has become a major driver in the realignment of the battle group. The overall purpose, of course, is victory in combat. This will occur by assigning the right number of helicopters to perform increased Anti-Submarine Warfare (ASW), Anti-Surface Warfare (ASuW), and AMCM coverage. The battle group (BG) commander will gain ultimate benefits as his situational awareness is improved and force protection is increased. The obvious difference from current force structure is that these benefits will be realized through the use of multi-mission capable, battle group-linked, H-60 helicopters.

Specifically, helicopter CONOPS brings four areas of force multiplication to the BG commander:

1. Mitigation of the ASuW coverage gap as a result of the S-3 retirement. The MH-60R and the MH-60S will operate synergistically in a sensor and shooter role respectively. Most importantly there will be three times the number of armed helicopters in the battle group that will provide a 24-hour coverage capability.
2. Provides the required ASW coverage to meet the littoral threat. CONOPS will also provide three times the number of dipping sonars available to the BG commander as well.
3. Substantial Combat Search and Rescue (CSAR), Maritime Interdiction Operations (MIO), Naval Special Warfare (NSW) capability resident in the

battle group. Five-fold increase in the number of assets available to conduct these types of missions.

4. Provides an organic AMCM capability to the BG commander. Currently, the only AMCM asset in the Navy is the MH-53E. The MH-53E, because of its size and the large logistics trail associated with current mine warfare sensors, is not deployed as part of the battle group. MH-53E assets are known as dedicated AMCM assets and can operate from either L-class ships or be land-based. These assets are known as dedicated AMCM assets because they are employed in a "911-response" nature. When the mine warfare risk increases either through intelligence or actual mining operations, AMCM operations are initiated. The fact that the AMCM assets are not resident in the BG can have serious implications as to where the BG can and cannot transit. Providing an organic AMCM capability to the BG commander through the MH-60S greatly increases his flexibility and ability to react quickly without having to rely upon a protracted MH-53E response time.

The previous discussion of CONOPS dealt with the benefits gained by the BG commander as a result of increased helicopter numbers resident on the carrier and the MH-60S taking on many missions. CONOPS also calls for replacement of the expeditionary structure. The two CH-46D helicopters currently deployed with the ARG for amphibious SAR will be replaced by up to four MH-60Ss. The same number of MH-60Rs will similarly replace the one or two SH-60B aircraft per ship deployed throughout the battle group in independent surface action groups. Capability for other missions including AMCM, heavy lift, Search and Rescue (SAR), Carrier Qualification (CQ) detachments, and Very Important Personnel (VIP) airlift will be maintained from shore based MH-60Ss and possibly MH-53Es. Although the MH-60R is a major part of the HMP and CONOPS, the author will focus primarily on the MH-60S in this thesis.

From a war fighting and certainly a fiscal standpoint, the transition to two helicopters that carry out all missions is a valid argument. The MH-60S must ultimately be able to carry out 18 different types of missions. Although the inherent nature of a helicopter is versatility, it follows that the degree of mission-specific optimization ultimately drives performance in a specific mission area. A derived requirement[1] of CONOPS and the HMP then is to develop the MH-60S in order to limit the degree of specific mission sub optimization. In other words, the MH-60S will have to do all of its missions well and cannot be designed for any one specific mission.

Operational Requirements

Leading up to the initial operating capability date (IOC) of the MH-60S (August 2000) the current HC helicopter, the H-46D, had been in service for 25 years and has exceeded its service life. The mission needs statement which drove the operational requirements document cited the urgency of replacing the HC helicopter.

The primary mission of the HC helicopter is to provide rapid airborne delivery of personnel and material to Naval forces engaged in power projection. The secondary

[1]Derived requirements are requirements that are not specifically listed, but become necessary in order for the aircraft to successfully perform its anticipated mission(s).

mission is to provide support to the Amphibious Ready Group (ARG) by providing a SAR capability. These two missions historically comprised the main capabilities of an HC helicopter. In line with the HMP, however, the Operational Requirements Document (ORD) also mandated that the replacement HC helicopter would also be required to support the armed helicopter (AH) mission and the airborne mine countermeasures mission. In fact, the ORD is written in such a manner that the HC replacement helicopter is the base mission and that the AH and AMCM missions are additive to the base mission.

The typical operational requirements document outlines the requirements that the acquisition community must utilize in their procurement. Through the systems engineering process, the specification of the chosen product is trace-linked back to the ORD. In this manner, the acquisition community is guaranteed that the aircraft that is being procured meets the requirements of the war fighter. In the case of the multi-mission combat support ORD, the MH-60S is actually identified as the replacement. This represented a deviation from the majority of ORDs in that the aircraft to be procured was mandated. Paragraph 1.3 of the multi-mission combat support helicopter ORD refers to the Analysis of Alternatives (AOA) that was performed to analyze what aircraft would be best suited for this role.

> The AOA supports the procurement of a MH-60S (a modified in-production helicopter, which provides maximum commonality with the US Navy H-60s and US Army UH-60Ls currently in service and fully supported by the DOD logistics system) as the most cost effective approach to meeting mission requirements for the Vertical Replenishment (VERTREP) and Vertical Onboard Delivery (VOD) for Combat Logistics Force (CLF) and Military Sealift Command (MSC) ships and maritime Search and Rescue (SAR) support for L-class amphibious ships.

For clarity, it should be stressed that the MH-60S was categorized as a new production aircraft.

The major reason that the MH-60S was approved was the large amount of commonality it shared with the existing H-60 airframe and the resultant reduction in life cycle costs. Although not specifically stated, it is obvious that the HMP was a major driver of this solution. Furthermore, since the MH-60S would be based on a marinized version of the existing, in production UH-60 Black Hawk, it was intended to be a quick solution for an HC replacement aircraft.

Industry and the acquisition community certainly felt the pressure leading up to the IOC of the MH-60S in Aug 2002. The Class A mishap rate of the aging H-46 had increased drastically as a result of a rapid rise in the engine failure frequency rate. The urgency of the requirement most likely resulted in the fact that the basic MH-60S program turned out to be very successful as it was below cost and ahead of schedule. It must be kept in mind that the basic program and almost the majority of the effort, both technically and fiscally, was to field a replacement for the HC mission. Although the ORD clearly mandated the follow-on AH and AMCM mission integration, these missions were not the top priority for fielding a replacement for the H-46 helicopter.

Annexes A and B to the ORD delineated the requirements for Armed Helicopter and Organic Airborne Mine Countermeasures respectively. It was mentioned earlier in this section that the typical ORD does not identify the system or aircraft to be procured. The multi-mission combat support helicopter ORD not only mandated the aircraft to be procured but also went on to identify the type of acquisition strategy to follow. The

Block I aircraft would be the VERTREP aircraft, Block II would incorporate AMCM modifications, and Block III would incorporate armed helicopter provisions. The blocks would be added under the premise of an evolutionary acquisition strategy where increasing capability is fielded to the Fleet over the course of time.

The H-60 airframe was proven in the fleet and in the Army that it could successfully be employed for a majority of missions. The MH-60S, although described as a new aircraft, was still based on H-60 legacy design. Although multi-mission was planned as future growth to the MH-60S, the H-60 airframe remained the 'box' to design around. New missions, when added, would be based on reverse engineering. It is not surprising that the additive nature of the armed helicopter and AMCM missions have posed the greatest challenge to the program from a technical standpoint.

Statement of the Problem

The basis for design of the MH-60S was for utility missions (cargo and passengers) and assumption of the role of the aging H-46 helicopter. As the Navy's HMP and CONOPS evolved, the planned role of the MH-60S transitioned from an H-46 replacement helicopter to an aircraft that would be expected to execute in excess of 18 different missions. To compound the problem, the MH-60S would assume the mission capabilities of helicopters that were designed based on a specific mission. The implications to helicopter design as a result of the multi-mission requirement should have been considered in the early stages of the program. Ideally, this should be accomplished prior to production.

In the case of the MH-60S, the program was ultimately faced with the task of integrating additional mission capability into an existing helicopter design where aircraft performance was fixed. As a result of the planned aircraft provisions combined with a wide range of operational requirements, the as designed MH-60S performance capability quickly became inadequate. Design requirements for a multi-mission helicopter not addressed pre-design ultimately lead to the identification of unfunded, unplanned weight reduction and performance enhancement programs.

II. Organic Airborne Mine Countermeasures

History

Even prior to the Civil War, the use of sea mines had been identified as an effective form of naval warfare. Although, initially classified as an "unethical" form of naval warfare, the use of sea mines as a tactic became large-scale during the American Civil War. Throughout the course of history many lessons were learned as to the utility of mine warfare. The most vivid statement was made during the Korean War by the Admiral Sherman with regard to the importance of mine warfare: "When you can't go where you want to go, when you want to, you haven't got command of the sea. And command of the sea is a rock-bottom foundation for all of our war plan…" (U.S. Navy Mine Familiarizer, 1999). As technology developed so did the type and numbers of mines as evidenced by their use in Vietnam and the Gulf War.

The sea mine remains a cost effective, offensive and defensive weapon within any country's naval arsenal. The most evident use of mines was during the Gulf War where two ships, the USS Princeton (CG-59) and the USS Tripoli (LPH-10), both struck Iraqi sea mines in the Persian Gulf. The mines that had probably cost on the order of several thousand dollars caused damages far exceeding 20 million dollars to the two warships. This graphic example from our recent history displays the utility of sea mines especially to nations that have small navies. More important is the fact that our allies and adversaries alike realize that the sea mine is a relatively inexpensive weapon that works remarkably well in leveling the playing field between two unequal opponents.

The very threat of the presence of mines in the water will delay or deter the movement of naval forces until the threat can be validated or neutralized. In future conflicts, it is not unreasonable to surmise that mines pre-positioned either overtly or in a clandestine fashion could limit our battle space dominance. It follows that the Navy is committed to maintaining a viable mine warfare posture.

AMCM Defined

Currently, the primary mission of the AMCM force is to maintain the capability to rapidly deploy worldwide to conduct independent or integrated MCM operations. This is the current mission of the two HM squadrons that currently employ the MH-53E. The task of locating and, if necessary, neutralizing sea mines must be executed as quickly as possible in order to maintain battle group maneuverability. This must be accomplished through all available MCM assets resident in the CVBG or ARG and augmented, as necessary, by assets that are CONUS-based.

To adequately define the future requirements for AMCM, the CNO staff is writing a Capstone Requirements Document (CRD) for Mine Countermeasures. The CRD will provide broad requirements in all mine warfare scenarios including a mine clearance timeline in strategic chokepoints and Sea Line of Communication to support war fighting requirements. In order to meet the requirements, the CRD cites a family of MCM systems that will combat the threat. The family of systems includes minehunting sensors, minesweeping systems, and mine neutralization systems. These systems are planned to be primarily deployed from the forthcoming AMCM helicopter platform, the MH-60S.

Mine warfare doctrine can be divided into two broad categories: mine hunting and mine sweeping. The preferred method of locating and neutralizing sea mines is through mine hunting which is conducted using sonar systems towed from the helicopter or a pod mounted external to the helicopter. This method is preferred due to the ability to rapidly respond to a threat combined with the fact that many complicated fuzing mechanisms that include such features as ship counters and dormant periods. The mine hunting systems provide for detection of both bottom mine as well as mines moored in the water volume. These mine hunting systems are complemented by mine neutralization systems that are mounted on the helicopter to neutralize the previously located mine.

In geographic areas where mine hunting is not practical, areas that possess poor bottom characteristics, or where there is a large amount of clutter, mine hunting is not practical. Influence minesweeping involves towing an influence system behind the helicopter to cause mines to safely detonate. The influence system generates magnetic and acoustic signatures similar to the target ship.

Organic AMCM vs. Dedicated AMCM

The current approach to AMCM is through the use of dedicated MH-53E helicopters. The purpose of dedicated assets, now and in the future, is to provide an increased AMCM capability necessary to sustain long-term mine clearance operations or short-term intensive operations.

Future requirements, however, point to the use of organic assets. Organic assets are those assets that are resident in the CVBG or ARG vice assets that must be sent to the area of operations. The AMCM missions will be fulfilled through the use of MH-60S helicopters that are outfitted with removable AMCM mission kits, sensors, and weapons. The BG commander will possess the equipment to quickly identify, detect, neutralize, and avoid bottom, submerged and floating sea mines. A notional timeline of an organic employment of the MH-60S helicopter in a typical mine warfare scenario is provided below:

1. Battle group commander determines threat level.
2. Exploratory/Reconnaissance: Mine hunting sensors deployed from the MH-60S to determine presence/absence of mines.
3. Results of exploratory reconnaissance evaluated to determine whether BG can transit through or avoid suspected area.
4. If adequate operational maneuver area is not available to BG commander, mine clearance operations commence using AMCM MH-60S to deploy neutralization or influence sweep systems.

The notional timeline provided above would be similar to a dedicated mission with the exception that the MH-60S will actually be embarked on the aircraft carrier CV(N). Dedicated AMCM would still exist and would be available to augment the organic forces in the case of a major regional conflict. Ultimately, organic AMCM provides flexibility to the BG commander and most importantly decreases the mine countermeasures (MCM) timeline.

Annex B to the multi-mission combat support helicopter ORD states that the MH-60S "...shall employ permanently installed aircraft equipment fixtures and removable (roll-on/roll-off) AMCM mission configuration equipment kits that allow integration, deployment, and operation of the individual AMCM sensor or weapon on/from the helicopter." The ORD also states that aside from providing the CVBG and the ARG with an organic capability, it may also serve to replace the current Navy's force structure of MH-53Es. As such the MH-60S will also become the dedicated AMCM platform. In order to understand the intricacies involved with the MH-60S assuming the AMCM role it is beneficial to briefly examine the differences between the two aircraft with respect to size and performance as well as a brief look at the current AMCM mission.

Aircraft Description of MH-53E

The MH-53E is a three-engine helicopter produced by Sikorsky Aircraft. It has a maximum gross weight of 69,750 pounds and is capable of sustained towing operations of 25,000 pounds with surges up to 30,000 pounds.

There is a common misconception throughout the U.S. Navy that concept of operations for dedicated mine warfare is solely through the use of a 'sled' that is towed behind the MH-53E. Although the mission is deemed critical when threat levels increase, the mission is not widely understood. The AMCM mission practiced in the Navy of today includes a large amount of mission planning and post mission analysis based on the tactical employment of a variety of sensors. The MH-53E commonly employs the following systems in order to conduct the dedicated mission:

1. MK-103 – A moored minesweeping system that is used to sever mines from their moorings. The MK-103 contains mechanical sweep wires that contain explosive mechanical cutters as well as fixed non-explosive cutters. The sweep is towed behind the MH-53E utilizing tensions of up to 11,000 pounds and sweep lengths up to 2150 feet.
2. AN/AQS-24 – A side-looking sonar that is towed behind the MH-53E. The system is comprised of an actively controlled, towed underwater vehicle, an electromechanical tow cable and winch, and associated controls and monitors. The side-looking, multi-beam forming sonar provides the operator with the ability to search for bottom targets as well as targets which are in the water volume.
3. MK-105 – The MK-105 commonly known as 'the sled' is used to sweep against influence mines. The system includes a platform that is stabilized via hydrofoils when under tow behind the MH-53E. The MK-105 has the capability of providing 2000 amps that is used to produce a magnetic signature that mimics a ship. It should be noted that there are several ways in which to launch the MK-105 from the well deck of an L-class ship to a beach launch. All methods require a fair amount of manpower outside of the helicopter crew as well as three small boats for stabilizing and tending the MK-105 components during launch and recovery.

4. MK-104 – This system is used to sweep acoustic mines. As the MK-104 is towed through the water a cavitating venturi system utilizes the seawater to generate noise that would mimic the acoustic signature of a ship.
5. MK-106 – The MK-106 is essentially a MK-105 with a MK-104 attached to it. This system is used to sweep acoustic and influence mines.
6. AN/SPU-1W – This system is also known as the magnetic orange pipe or MOP. Although initially designed and employed to sweep against influence mines, the MOP is most commonly used for training.

Although a discussion of current AMCM tactics is beyond the scope of this thesis, current tactics revolve around the use of the AQS-24 for initial exploratory reconnaissance of an area that is suspected to have been mined or is essential for movement of the fleet. Once the threat is identified through reconnaissance it is either swept or avoided. As discussed previously, there are areas that cannot be effectively evaluated using the underwater sonar which drives the requirement for sweeping or avoidance of the area. Where the area cannot be avoided, sweeping is essential.

Aircraft Description of MH-60S

In stark comparison to the MH-53E, the MH-60S is a twin-engine helicopter also produced by Sikorsky Aircraft Corporation. It has a maximum gross weight of 23,500 pounds. Once modified the aircraft will have provisions for externally mounting AMCM systems as well as towing up to tensions of 6000 pounds.

Organic AMCM (OAMCM) Systems

PMS-210, the AMCM program office, owns the acquisition programs for the next generation AMCM systems that are intended to replace or augment the systems previously mentioned. A notional diagram of the employment of OAMCM systems is included in Figure B-1[2] and a brief description of the organic AMCM systems follow:

1. AN/AQS-20A – The Q-20A is essentially a follow on system to the legacy Q-24. In addition to multi-mode sonar, the Q20A will have an electro optic identification (EOID) feature that will provide for identification of mines in the water volume. In aggregate, the system will have forward looking sonar to avoid mines, side scan sonar to detect mines on the bottom and volume search sonar to detect volume mines. The Q-20 will be towed behind the MH-60S.
2. AN/AES-1 – The AES-1 or Airborne Laser Mine Detection System (ALMDS) will use Light Detection and Ranging technology (LIDAR) to detect, localize, and classify near-surface moored and floating sea mines. The ALMDS will provide organic self-protection, mine avoidance, and precursory reconnaissance in the combat escort role. The ALMDS is a 'pod' based system and will be employed by the MH-60S in a free flight (non-towed) regime at groundspeeds up to 80 knots.
3. Airborne Mine Neutralization System – The AMNS will be employed by the MH-60S to explosively neutralize unburied bottom and moored sea mines. This system is also non-towed.

4. AN/ALQ-220 – The Organic Airborne and Surface Influence Sweep System (OASIS) will provide an organic, high-speed, magnetic/acoustic influence minesweeping capability to be employed by the MH-60S or selected surface craft in support of the CVBG. An open-loop electrode design will provide the requisite influence output in a self-contained, transportable unit weighing less than 1000 pounds. OASIS is essentially a replacement for the MK-106 that will be towed from the MH-60S when influence/acoustic minesweeping is deemed necessary.
5. Rapid Airborne Mine Clearance System – RAMICS will be comprised of an integrated targeting, fire control, gun system, and supercavitating projectile technologies as a reacquisition and prosecution capability against near surface moored and floating mines. RAMICS will also be a non-towed system.

From the brief description of the systems above it is apparent that there is no one-for-one replacement of current system with next generation systems. In fact, the organic systems represent the elimination in the capability to perform mechanical minesweeping. The fact remains, however, that the Navy is determined to have an organic AMCM capability that utilizes an MH-60S. Furthermore, if these systems prove to be effective, the Navy is on track to retire the MH-53E forwarding the complete AMCM role to the MH-60S.

The Secretary of the Navy, Gordon England, continues to pledge support of the MCM forces. In a recent letter delivered to mine warfare proponents, Secretary England assures that he is committed to funding a potent mine warfare force while launching the organic force in 2005 (Inside the Navy, November 2002). This is consistent with the fact that in the DPG of FY 2002, the Navy was directed to achieve organic mine countermeasures capability in at least one CVBG by FY 05. In other words, not only is the Navy committed to this effort it is also 'under the gun' to deliver this capability by FY 2005.

The Navy has chosen this path for the future based on financial reasons despite limited war fighting analyses. Although the subject of continued as well as future analysis, it is postulated that the organic capability will be an acceptable replacement for the current capability and will bridge the loss of the MH-53E.

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[2]Figures B-1 through B-5 are included in Appendix B.

III. Armed Helicopter

Current Concept of Operations

Currently, the HS and the HCS communities employ the HH-60H in a variety of armed roles. The group of armed missions is covered under the broad term known as CSAR. Currently, the HS community employs carrier based HH-60H helicopters to perform the CSAR mission in addition to organic anti-surface warfare, Force Protection (FP), and expanded Special Warfare Support (SWS) capabilities. In the reserve component, HCS squadrons perform the same role with emphasis on CSAR also using the HH-60H.

As the current world situation has developed over the past several years, the use of armed helicopters for force protection as well as rescue of downed aviators in hostile regions has become vital. The situation has also driven an increased role of the Navy in special warfare missions both at sea and over land. The insertion and extraction of SEALs is a perfect example of the increased usage of naval H-60s.

Armed Helicopter

The MH-60S, or armed multi-mission helicopter, will assume the role of the current HH-60Hs in its armed configuration. The armed role, although equally as complex as the AMCM mission, is more easily understood and is well known throughout the fleet. Further, unlike in the AMCM mission, arming the MH-60S does not change the nature of the mission as it is performed today. For these reasons, a protracted discussion of the armed helicopter mission will not be made. Simply stated, the MH-60S will be modified so that it can also carry out the mission that is performed by the HH-60H of today. Annex A of the ORD states “The MH-60S shall be capable of accomplishing the CSAR, expanded SWS and SUW missions through the installation of mission kits containing CSAR/SWS/SUW peculiar equipment.” Just as in the case the AMCM capability, the ORD mandates that the armed helicopter mission be additive to the base combat helicopter support mission. “…The system characteristics listed herein are additive to those delineated in the base Multi-mission Combat Support Helicopter ORD.” (ORD, 2002)

IV. MH-60S Acquisition Strategy

Base Aircraft

As discussed previously, the baseline aircraft was a VERTREP replacement aircraft. In order to save money and time, the Navy essentially procured a marinized version of the Army UH-60 Black Hawk. Although the UH-60 was in production, the MH-60S differed enough from the UH-60 that it was handled as a new production aircraft with its own production line and contracting strategy.

The MH-60S contained the baseline Black Hawk configuration with Naval Hawk (SH-60) engines, rotor systems and dynamic components. It also included the Sea Hawk automatic rotor blade folding system, folding tail pylon, rotor brake, and automatic flight computer. Figure B-2 shows the relative make up of the MH-60S with respect to Black Hawk baseline, Sea Hawk baseline, and new development components.
From figure B-2 is apparent that the MH-60S is essentially a marinized version of the Black Hawk. The MH-60S production line at Sikorsky Aircraft Corporation is actually the same line as the Black Hawk line. The line splits at the point where Sea Hawk common components are installed. At the end of the production line, the MH-60S is completely built with the exception of the cockpit.

Common Cockpit/Avionics

In the increasing attempt to maximize commonality between the MH-60S and the MH-60R, a common cockpit was developed and procured from Lockheed Martin. The common cockpit consists of two flat panel displays per pilot; one for mission information and one for flight information. Each pilot also has a workstation that includes keysets and access to pointing devices. The common cockpit also includes communication and navigation subsystems, flight instruments, and manual operator input/output panels. Backup flight instruments are provided in the center of the instrument console and include airspeed, attitude, stabilator position, and clock. The cockpit is software driven through the Avionics Operating Program (AOP) which is hosted on 2 flight management computers.

Evolutionary Acquisition Strategy

The ORD clearly defined that future missions would be additive to the basic combat support helicopter. In other words, the basic combat support helicopter would be procured and future mission capability would be added. This is in contrast to developing a helicopter that can complete all of its intended missions from the time it is delivered. The sole purpose in a strategy such as this is to field an initial capability rapidly and provide follow on capability when it becomes available. The basic combat support helicopter would be fielded to answer an emergent requirement and AMCM and Armed Helicopter would be fielded at a later date.

The acquisition strategy for the MH-60S calls for the procurement of a total of 237 aircraft. All 237 aircraft will be capable of performing the basic VERTREP mission. Capability to perform AMCM and armed helicopter missions will be forward fit only. In other words, the capability will be introduced into the production line when it is available. It will not be retrofitted. This concept as well as the evolutionary acquisition plan is displayed graphically in figure B-3.

Block I aircraft are the VERTREP aircraft. Blocks II and III will be AMCM and armed helicopter respectively. From a production line standpoint, the AMCM modifications will be cut in the production line starting with aircraft 51 and the armed helicopter modifications will begin with aircraft 85. Aircraft 1 through 50 will not be AMCM capable and similarly aircraft 1 through 85 will not be armed helicopter capable. However, aircraft 85 and subsequent will have the provisions for all missions.

Figure B-4 is a graphical depiction of the MH-60S program. Block IIA will include initial AMCM capability to include Q-20A and ALMDS and is planned for IOC in calendar year 05. Block IIB will bring the remainder of AMCM capability and will include RAMICS, OASIS, and AMNS in FY 2007. Block IIA is sometimes referred to as the '05 configuration' and Block IIB is referred to as the 'final configuration'.

Block IIIA will provide an initial armed helicopter capability to the fleet in FY06. The remainder of this capability will be fielded in Block IIIB in FY07 with yet future growth in this mission area beyond FY 2007.

V. Mission Profiles

Definition

Included in the ORD are descriptions of the various types of missions that the combat support helicopter must be able to accomplish. The ORD is written in such a manner as to provide latitude with respect to the degree of meeting all of the requirements. The threshold requirement is the minimum acceptable capability. The objective requirement is the goal. Each mission area contains both threshold and objective values. The ORD complete with Annexes A and B calls for a sum total of 20 missions.

In each section of the ORD, mission profiles are described using a scenario. Unfortunately, the scenarios are open to interpretation with respect to aircraft configuration. The base ORD missions are: VERTREP, VOD, Amphibious SAR, Airhead Operations, NEO, SAR, SWS (OL). Verbatim descriptions of each mission scenario from the ORD, proceeded by the author's interpretation where applicable, follow in the paragraphs below:

Base ORD Missions:

VERTREP

ORD Definition:
Ship-to-Ship, 500-1000 yds separation. Vertical takeoff to Hover Out of Ground Effect (HOGE) for 15 seconds. Pick-up a maximum external payload of 5500 lb. (3000 lb. average), transition to forward flight and climb to 150 ft AGL. Transit 500-1000 yds. Descend to ship edge height, HOGE for 15 seconds and release payload.

Ship-to-Ship, Connected Replenishment (CONREP) Position. Vertical takeoff to HOGE for 15 seconds. Pick-up a maximum external payload of 5500 lb (3000 lb. average).

Transition to ship edge height, HOGE for 15 seconds and release payload."

Analysis: 1) Warm-up for 5 minutes at idle power

2) Vertical Take off (VTO)/Hover out of ground effect (HOGE) for 15 seconds at instrument rated power (IRP) at **Sea Level / 90 degrees F**, pick up external load of 5500 lb (3000 lb average)

3) Climb to 150 ft Mean Sea Level (MSL) at best climb speed

4) Transit 1000 yds with external load at 50 kts

5) Descend to Ship Edge Height (no fuel, time or distance)

6) HOGE for 15 sec, release payload

7) Climb to 150 ft MSL at best climb speed

8) Return without payload, traveling 1000 yds (Repeat cycles 2 through 8 up to endurance of aircraft)

9) Reserves: greater of 10% initial fuel or fuel for 20 minutes at maximum endurance airspeed (Vbe).

VOD

ORD Definition:
Vertical takeoff with a crew of 3 to HOGE with a maximum 5500 lb internal payload (3000 lb average). Transition to forward flight. Climb to 3500 ft MSL at best climb speed. Transit 100 nm at cruise airspeed. Descend to HOGE, land and discharge payload.

Analysis: 1) Warm-up for 5 minutes at idle power

2) VTO/ HOGE for 1 minute at IRP at **Sea Level / 90 degrees F**

3) Climb to 3500 ft MSL at best climb speed

4) Transit 100 nautical miles (NM) at 99% of best range airspeed (V99%BR)

5) Descend Sea Level (no time, fuel or distance)

6) HOGE, Land and Discharge Payload

7) Reserves: greater of 10% initial fuel or fuel for 20 minutes at Vbe

Amphibious SAR

ORD Definition:
Vertical takeoff and climb to 500 ft MSL. Transit 50 NM at maximum continuous power to search area datum. Search for 30 minutes. Descend to deploy SAR swimmer from either a HOGE or low altitude helocast (15 ft AGL/0 KIAS or 10 ft AGL/10 KIAS, respectively). Maintain HOGE for 5 minutes per person while loading up to 12 survivors as limited by endurance or aircraft capacity. Transition to forward flight. Climb to 500 ft MSL. Return to own ship at maximum speed and land.

Analysis: 1) Warm-up for 5 minutes at idle power

2) VTO/HOGE for 1 minute at IRP at **Sea Level / 90 degrees F**

3) Climb to 500 ft MSL at best climb speed

4) Transit 50 NM at maximum continuous power (MCP) to search area

5) Descend to 100 ft (no time, fuel or distance)

6) Search for 30 minutes at Vbe

7) Descend to sea level (no time, fuel, or distance)

8) HOGE while picking up rescuees at 5 minutes per rescuee

9) Climb to 500 ft MSL at best climb speed

10) Return 50 NM at MCP

11) Descend to ship deck height (no time, fuel or distance)

12) Reserves: Greater of 10% or 20 minutes at Vbe

Airhead Operations

ORD Definition:
Vertical takeoff to HOGE with a maximum payload of 5500 lb (3000 lb average) at 1000 ft MSL, 90 degrees F, in no wind conditions. Transition to forward flight climb to 1000 ft AGL and transit 12 NM offshore at cruise airspeed to ship. Descend to HOGE, land and discharge payload.

Analysis: 1) Warm-up for 5 minutes at idle power

2) VTO/HOGE for 30 seconds at IRP with payload of 5,500 lb (3,000 lb avg) at **4,000 ft /90 degrees F**

3) Climb to 1000 ft above ground level (AGL)

4) Transit 12 NM offshore at cruise airspeed (V99% BR)

5) Descend to sea level

6) HOGE 1 minute and discharge payload

7) Reserves: greater of 10% initial fuel or 20 minutes at Vbe

NEO

ORD Definition:
Vertical takeoff at Sea Level, 90 degrees F, climb to 2000 ft AGL, transit at maximum speed 100 NM to landing area. Descend to landing at 4000 ft MSL, 90 degrees F. Load 12 evacuees (2400 lb). Vertical takeoff, climb to 2000 ft AGL (6000 ft MSL), and transit at maximum speed for return flight.

Analysis: 1) Warm-up for 5 minutes at idle power

2) VTO/HOGE for 1 minute at IRP at **4,000 ft / 90 degrees F**

3) Climb to 6000 ft at best climb speed

4) Cruise Out 100 NM at MCP speed

5) Descend to **4,000 ft / 90 degrees F**

6) HOGE 10 minutes, pickup evacuees

7) Climb to 6000 ft at best climb speed

8) Return 100 NM at MCP speed

9) Descend to landing at 4,000 ft / 90 degrees F

10) Reserves: Greater of 10% or 20 minutes at Vbe

MEDEVAC

ORD definition:
Vertical takeoff to HOGE with 4 SAR littered evacuees, 3 aircrewmen (2 pilots and 1 crew chief) and 1 corpsman. Transition to forward flight. Climb to 3500 ft MSL at best climb speed. Transit 100 NM at cruise airspeed. Descend to HOGE, land and discharge payload.

Analysis: 1) Warm-up for 5 minutes at idle power

2) VTO/HOGE for 1 minute at IRP at **Sea Level / 90 degrees F**

with 4 SAR littered evacuees + 1 corpsman

3) Climb to 3500 ft MSL at best climb speed

4) Transit 100 NM at V99%BR

5) Descend to seal level (no time, fuel or distance)

6) Reserves: Greater of 10 % or 20 minutes at Vbe

SWS (OW)

ORD Definition:
Vertical takeoff with 8 combat-equipped Naval Special Warfare (NSW) personnel and climb to 500 ft MSL at best climb speed. Transit 50 NM at maximum speed. Descend to deploy NSW Team from either a HOGE or low altitude helocast. Maintain HOGE for 10 minutes while NSW team is deployed. Transit to forward flight. Climb to 500 ft MSL at best climb speed. Return 50 NM at cruise speed and land.

Analysis: 1) Warm-up for 5 minutes at idle power

2) VTO/HOGE for 1 minute at IRP at **Sea Level / 90 degrees F**

3) Climb to 500 ft MSL at best climb speed

4) Cruise Out 50 NM at MCP speed

5) Descend to **Sea Level / 90 degrees F**

6) HOGE for 10 minutes, offload 8 naval special warfare (NSW) troops

7) Climb to 500 ft MSL at best climb speed

8) Return 50 NM at V99%BR

9) Land with greater of 10% or 20 minutes at Vbe

Annex A (Armed Helicopter Missions):

CSAR

ORD Definition:
Vertical takeoff with 5 aircrew, sea level, 90 degrees F. Transit at best range speed 200 NM at 500 ft MSL, 100 ft AGL over the last 20 NM. HOGE for 5 minutes per survivor, 3000 ft MSL, 90 degrees F (at mid mission weight). Pick up 4 survivors at 200 lb each. Transition to forward flight. Descend to 500 ft MSL. Return 200 NM at best range airspeed and land.

Analysis: 1) Warm-up for 5 minutes at idle power

2) VTO/ HOGE for 1 minute at IRP at **Sea Level / 90 degrees F**

3) Cruise Out 200 NM at 500 ft at V99%BR

4) Climb to **3,000 ft MSL / 90 degrees F** at best climb speed

5) HOGE for 5 minutes, while picking up 4 survivors

6) Descend to 500 ft MSL

7) Return 200 NM at V99% BR

8) Reserves: greater of 10% or 20 minutes at Vbe

SWS (overland)

ORD Definition:
Vertical takeoff with 5 aircrew and 8 combat equipped NSW personnel at sea level, 90 degrees F. Transit at best range speed 200 NM at 500 ft MSL, 100 ft AGL over the last 20 NM. Climb to 3000 ft MSL. HOGE for 5 minutes, 3000 ft MSL, 90 degrees F and drop off payload. Transition to forward flight. Descend to 500 ft MSL. Return 200 NM at best range airspeed and land.

Analysis: 1) Warm-up for 5 minutes at idle power

2) VTO/ HOGE for 1 minute at IRP at **Sea Level / 90 degrees F**

with 8 NSW troops

3) Transit at 500 ft MSL 200NM at V99%BR

4) Climb to **3,000 ft 90 degrees F** at best climb speed

5) HOGE for 5 minutes, offload troops

6) Descend to 500 ft MSL (no time, fuel or distance)

7) Cruise back 200 NM at V99%BR

8) Reserves: Greater of 10% or 20 minutes at Vbe

SUW

ORD Definition:
Detect and identify adversary missile patrol boats using a combination of the aircraft's Forward-Looking Infrared (FLIR) and cueing (e.g., radar vectors to the target) from naval ships and aircraft. Attack independently using a precision-guided air-to-ground missile or forward firing rockets/gun. In addition, the aircraft should provide air-to-surface targeting designation for other friendly aircraft.

CV Plane Guard SAR

ORD Definition:
Vertical takeoff and loiter for 30 minutes. Climb to 500 ft MSL. Transit out to 100 NM at maximum continuous power to search area datum. Search for 30 minutes. Descend to deploy SAR swimmer from either HOGE or low altitude helocast. Maintain HOGE for 5

minutes per person while loading 5 survivors (flight crew of E-2C). Transition to forward flight. Climb to 500 ft MSL. Transit 100 NM at maximum speed and land.

Analysis: 1) Warm-up for 5 minutes at idle power

2) VTO/HOGE for 1 minute at IRP at **Sea Level / 90 degrees F**

3) Loiter for 30 minutes

4) Climb to 500 ft MSL at best climb speed

5) Cruise out 100 NM at MCP

6) Search for 30 minutes at 500 ft at best endurance speed

7) Maintain HOGE for 5 minutes per survivor while loading 5 survivors

8) Climb to 500 ft MSL at best climb speed

9) Transit 100 NM at MCP speed and land

10) Reserves: Greater of 10 % or 20 minutes at Vbe

MIO

MIO is not listed in the ORD, but has been verbally added as a requirement.

1) Warm-up for 5 minutes at idle power

2) VTO/ HOGE for 1 minute at IRP at **Sea Level / 90 degrees F** with 8 NSW troops

3) Transit 50NM at MCP speed

4) HOGE 15 minutes over ship

5) Remain on station for 45 minutes

6) Return 50 NM

7) Reserves: Greater of 10 % or 20 minutes at Vbe

Additional Annex A Missions:

Although not explicitly stated in the ORD, it is possible to conduct the CSAR and the SWS (Overland) missions with the aid of inflight refueling. The missions are conducted in the same manner as described above; however, the operator has the option to plan a mission based on the availability/non availability of tanker assets. Receiving fuel from a tanker at an appropriate time in the mission permits the operator to manage own aircraft gross weight and time on station/range.

Annex B (AMCM Missions):

Unlike the basic missions and the Annex A missions, the AMCM missions are grouped based on flight regime. The ORD classifies AMCM missions as either free-flight, hover or tow. The ALMDS mission is considered a free flight mission. The AMNS and RAMICS missions are considered hover and the Q-20 and OASIS missions are classified as tow missions. The ORD further stipulates that all AMCM missions are assumed to be flown sea level, 90 degrees F, and no wind.

Free flight missions are defined in the ORD:

> Execute a vertical takeoff with up to four aircrew. Achieve AMCM mission radius (transit at maximum range speed 30 NM at 500 ft MSL). Perform AMCM mission search profile: maneuver at 60 knots ground speed for 120 minutes. Transition to maximum range speed at 500 ft MSL. Return 30 NM and land.

The basic requirement for the ALMDS mission is a 2-hour on station time with a combat radius of 30 NM. Hover missions are similarly defined in the ORD:

> Execute a vertical takeoff with up to four aircrew. Achieve AMCM mission radius (transit at maximum range speed 30 NM at 500 ft MSL). Perform an AMCM hover mission profile: stationary hover not to exceed 30 minutes at

optimum mission altitudes ranging between 25-1000 feet (depending on weapon system standoff requirement) followed by forward flight to acquire new target. Repeat this cycle for a total of 75 minutes. Transition to maximum range speed at 500 ft MSL. Return 30 NM and land.

The interpretation of the hover mission definition is that for the AMNS and RAMICS missions, the MH-60S is required to remain on station for a total of 75 minutes. During these 75 minutes, the aircraft would vary altitude and transition from hover to forward flight in order to prosecute as many mines as possible. Also included in this definition is the 30-mile combat radius.

The most demanding of the AMCM missions are the towed missions. The ORD definition of a towed mission is:

> Execute a vertical takeoff with up to 4 aircrew. Achieve AMCM mission radius (transit at maximum range speed 30 NM at 500 ft MSL). Perform AMCM equipment deployment from the helicopter (stationary hover at optimum deployment altitude for 15 minutes). Transition to AMCM tow operations at optimum altitude between 75 to 200 ft AGL. Perform an AMCM hunt/sweep mission profile (impart up to 6,000 lbs. tension) for 60 minutes. Perform AMCM equipment recovery on the helicopter (stationary hover at optimum recovery altitude for 15 minutes). Transition to maximum range speed at 500 ft MSL. Return 30 NM and land.

Further analysis yields the following profile/timeline:

1) Warm-up for 5 minutes at idle power

2) VTO/ HOGE for 1 minute at IRP at **Sea Level / 90 degrees F**.

3) Transit at 500 ft MSL 30NM at V99%BR

4) Descend to 75 ft AGL.

5) HOGE for 15 minutes, deploy AMCM gear

6) Climb to 125 ft AGL and tow at prescribed tension for 60 min

7) Descend to 75 ft AGL.

8) HOGE for 15 minutes, recover AMCM gear

9) Transit at 500 ft MSL 30NM at V99%BR

10) Reserves: Greater of 10% or 20 minutes at Vbe

The ORD places additional requirements with respect to the towed missions in the areas of temperature and wind limitations. For a hot (105 degree F) day, the tow requirement is reduced to 30 minutes with a combat radius of 10 NM. Every other parameter (as listed above) remains the same. The ORD also specifies that the aircraft have the capability to conduct tow operations with a 10 knot relative tailwind for up to 30 minutes. Additionally for each of the scenarios, the ORD specifies that the aircraft have the capability to impart up to 6,000 pounds of tension on the tow cable.

Summary

A summary of mission requirements is provided in Table A-1[3]. The aggregate of these missions define the ORD requirements for the multi-mission helicopter. Also listed are those missions which have been designated a key performance parameter (KPP). KPPs are a subset of missions deemed essential for success of the program.

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[3]Tables A-1 through A-6 are included in Appendix A.

VI. Basic Aircraft Weight Growth

Weight is probably the most critical design element of a new production helicopter. Simplistically, increase in air vehicle weight directly reduces performance and mission payload. Weight must be monitored closely from the initial design phases, throughout production, and once fielded following post-production modifications. The MH-60S, like any new production aircraft program, has experienced unplanned weight growth throughout design and production. The fact that this aircraft started out as a basic VERTREP aircraft replacement with planned mission growth to AMCM and armed helo made the control of basic weight growth critical to the success of the program. In other words, control of weight growth in the basic aircraft is important. The fact that this aircraft must "grow" to support other missions makes weight the critical design element in a multi-mission helicopter.

The weight growth of the MH-60S can basically be divided into three distinct categories. The first category is weight growth attributed to fielding the basic airframe including modifications that were either planned as post production modifications or modifications which became necessary to correct deficiencies noted during developmental and operational testing. The second source of weight growth is that weight which is attributed to incorporating the fixed aircraft provisions for the AMCM and armed helicopter missions (Blocks IIA and IIIA) for the FY 2005 configurations. The third source of weight growth is associated with the planned increase in capability for the Blocks IIB and Block IIIB, C or final configuration. The last two sources of weight growth are directly attributed to and result from the evolutionary strategy of introducing new capability to the fleet as soon as it is available.

It was mentioned previously that the MH-60S is essentially a Black Hawk that has been marinized. It follows that a large contributor of the MH-60S weight growth was through marinization. Another factor is manufacturing variation. Despite the closest process controls, variation in manufacturing is ultimately unavoidable. This variation has also caused a net increase in basic weight.

Marinization

Table1 is a comparison of the weight empty of three variants of the H-60. The MH-60S airframe is based upon the UH-60L 'Black Hawk' which is currently in production for the U.S. Army. Based on the differing types of projected operating environments, the MH-60S required marinization of the basic Black Hawk airframe. Specifically, increased structure to allow for more stringent crash loading and folding blades in order to provide shipboard compatibility. From Table 1, areas where major weight increase is observed is in the rotor group (387 pounds) which is attributed to blade fold provisions, the body group (317 pounds) for increased structure to handle crash loads, and the propulsion group (347 pounds) primarily for crash resistant fuel cells and installation of a rotor brake. Other areas where the most significant amount of weight increases occurred were in the electrical group, avionics group and cargo load handling group primarily for a rescue hoist and cargo rollers and rails. Overall, the marinization of the Black Hawk accounts for a weight delta of 2,116 pounds or a weight growth of 15%.

TABLE 1: WEIGHT EMPTY COMPARISON (POUNDS)

Component	UH-60L 92-26408	HH-60H 165154 Pounds	MH-60S 165778
Rotor Group	1,504	1,919	1,891
Tail Group	424	454	461
Body Group	2,049	2,257	2,366
Alighting Gear Group	480	683	500
Engine Section or Nacelle Group	197	157	198
Air Induction Group	69	68	77
Propulsion Group	3,292	3,528	3,639
Flight Controls Group	991	1,068	1,039
Auxiliary Power Plant Group	182	180	183
Instruments Group	207	266	144
Hydraulic & Pneumatic Group	149	159	152
Electrical Group	410	479	582
Avionics Group	446	882	821
Armament Group	38	90	38
Furnishings & Equipment Group	1,045	956	1,110
Air Conditioning Group	57	138	141
Anti-Icing Group	94	108	114
Load & handling Group	53	183	345
WEIGHT EMPTY	**11,686**	**13,572**	**13,802**

Although this appears to be a fairly substantial increase in gross weight it does happen to be very close to the weight of the HH-60H. For comparison purposes, the HH-60H is often referred to as the baseline or "slick" version of the H-60 family. The result to the Navy is two fold: (1) a new aircraft (MH-60S) is procured which contains the derived benefits of being common with an in production aircraft (UH-60L) and (2) the MH-60S is close to the weight of the baseline version of the H-60 (HH-60H) thus providing a known performance capability (prior to any weight growth as a result of multi-mission).

Manufacturing Variation

Although it is the goal of any aircraft manufacturer to improve process control, the fact that there will be differences between the weights of production aircraft as they leave the line remain. Many parts of the MH-60S are made through high-speed machining and then built up by hand. The ultimate result is multiple tolerances and variation in basic weight.

The variation in basic weight for the MH-60S is addressed in the aircraft specification. Based on historical data, Sikorsky has seen variations in weights up to ½% of the average empty weight. In the case of the MH-60S, the specification contingency weight is 70 pounds. The weight between aircraft can vary as great as 70 pounds and still be acceptable. This total amount of weight must be included when doing performance calculations and throughout the course of planning for additional missions.

Integrated Maintenance Diagnostic/Health Usage Monitoring System (IMD/HUMS)

The IMD/HUMS system was a planned improvement to the MH-60S from the early design stages. It is completely unrelated to the weight growth experienced as a result of multi-mission. Once incorporated into the aircraft, this system will add a total of 73 pounds to the gross weight. It is anticipated that the IMD/HUMS modification once established in the production line will be a forward fit and a retrofit as depicted in figure B-3.

Vibrations

Throughout the developmental and operational flight test of an aircraft it is not uncommon to discover design deficiencies that require correction prior to fleet release. In the case of the MH-60S, a deficiency noted during flight test was the low/medium frequency vibrations at airspeeds typically flown during the VERTREP mission. This deficiency was listed as a Part I, which means that it had to be corrected immediately.

As the design of the aircraft continues to mature and more hours are flown it is anticipated that the vibratory nature of the VERTREP flight regime may result in airframe changes and future weigh growth. The initial repair to the vibrations is to modify a vibration absorber on the main rotor head with an ultimate weight growth of twelve pounds.

VII. Multi-Mission Weight Growth

It was mentioned that basic airframe weight growth as a result of making the aircraft capable of more missions is the key design constraint to the multi-mission helicopter. Prior to evaluating the specific amount of weight anticipated as a result of increased mission capability it would be beneficial to understand how air systems are introduced into a helicopter. It is fairly common, especially in aircraft that have more than one mission, to develop a mission kit. This is the approach that was used in the design of the MH-60S. The kit contains items that are not in the basic aircraft configuration which permit the aircraft to perform other missions.

A mission kit is typically comprised of two parts: an A-kit and a B-kit. The A-kit is defined as fixed aircraft provisions. As the name implies, A-kit items are fixed and become a part of the basic aircraft. An example of an A-kit item would be structural modifications to allow the structure to withstand increased fatigue loads. The B-kit parts are removable items that are installed prior to the specific mission and removed upon completion. An example of a B-kit item would be the common console for AMCM that is installed prior to AMCM missions and then removed.

It follows that in the design of a multi-mission helicopter there is an optimal balance between A-kit and B-kit items. If the shift favors a large number of A-kit items then the aircraft must carry this extra weight regardless of mission. If the shift favors a large amount of B-kit items then there is a commensurate increase in logistics support requirements and the time it takes for aircraft reconfiguration between missions.

Armed Helicopter Weight

Based on a review of the ORD missions and multiple meetings with the requirements officer, a list of assumptions for armed helicopter were generated. These assumptions ultimately drove the makeup of the A-kit for armed helicopter. The A-kits and corresponding weight that are required for the armed helicopter are summarized in Table 2. In aggregate, the weight increase to the basic gross weight due to armed helicopter A-kit items is 391 pounds. This represents an increase of 3% to the empty weight of the MH-60S as it was originally designed.

AMCM Weight Growth

AMCM, because it involves towing a device in the water, brings with it a requirement for a large amount of structural modifications to the base aircraft. In order to tow a Q-20A and the OASIS, a "tow point" must be added to the aircraft with its corresponding structural support. The "bath tub", portrayed in figure B-5, represents the major structural member of the aft transition section of the MH-60S. This area required modifications for the tow point as well as the incorporation of fittings that would in turn accept floor tie downs for AMCM equipment including a winch and a CSTRS (Common Stream Tow Recovery System). Specific modification of this area included the addition of beams and widening of structural members. Additionally, it is planned that the RAMICS system will cause structural modifications as a result of the relatively large amount of recoil associated with this gun system. In addition to structural modifications, AMCM capability requires the addition of a fourth hydraulic system in order to power

TABLE 2: ARMED HELICOPTER WEIGHT GROWTH (A-KITS)

Item	Weight (lbs)
Auxiliary fuel tank provisions	36
Refueling probe provisions	68
Link 16	12
CSAR/Integrated self defense items Avionics rack provisions GAU-16/19 structural provisions EFS fixed forward fire provisions Signal data conditioner (SDC) provisions PIU provisions HUD provisions Mission computer provisions FLIR hand control unit (HCU) AN/APR-39 provisions	275
Total Armed Helicopter A-kit	391

a winch, as well as power distribution provisions. The total weight of the A-kit for AMCM is 333 pounds or a 2% weight growth.

Associated with AMCM (and most likely the AH mission) is the requirement for a tactical data link. The plan is also to make this a "kitable" item with a resultant A-kit weight of 57 pounds.

The resultant increase in aircraft gross weight as a result of the multi-mission requirement is summarized in Table A-2. If we combine this weight growth with the weight associated with marinization (Table 1), the weight associated with pre planned improvements (IMD HUMS), and the weight associated with resolution of discrepancies identified in testing (to date), the overall impact to the basic aircraft as a result of designing a multi-mission helicopter is derived in Table B-3. Table B-3 shows the realized impact of modifying a helicopter that was originally designed to perform only VERTREP to a helicopter that has the provisions to perform multiple types of missions. An increase of approximately 1000 pounds to the empty gross weight was an unplanned result of adding these provisions. Further, the significance of an unplanned event implies little to no funds or schedule available to make changes.

It should be noted that the Navy was able to make small, initial adjustments to the design to allow for the increased gross weight. These adjustments included removal of a row of crew seats, the use of lighter fuel tanks, and lighter pilot seats. Regardless, the initial attempt at weight savings was only 140 pounds.

Mission Kits

The real significance of the 1000-pound increase in aircraft empty gross weight is graphically displayed as aircrew, fuel, and mission kits (B-kits) are added. Table 3 lists the projected operating gross weights for each mission planned for the MH-60S for the FY 2007 or final configuration.

TABLE 3: OPERATING GROSS WEIGHT

Mission	Gross Weight, Pounds
VERTREP	21000
VOD	22330
Amphibious SAR	18053
Airhead	22,660
NEO	18228
Medevac	18808
SWS (OW)	20662
CSAR	22596
CV Plane Guard	22000
SWS (OL)	22914
SWS (OL) w/ inflight re fueling	23221
Q-20A	22764
ALMDS	22664
OASIS	21324
RAMICS	22770
AMNS	22300

VIII. Limiting Aircraft Performance Factors

The previous discussion of the unplanned weight increase as a result of the spiral acquisition strategy would not be a problem if the MH-60S had unlimited performance capabilities. This is obviously not the case. In fact, the MH-60S ORD requirements were based on the current performance of the HH-60H. As the weight empty of the MH-60S is projected to be approximately 1000 pounds heavier than the HH-60H and both aircraft share a common drive train and rotor head, it follows that the MH-60S will be incapable of completing its ORD missions without a combination of a weight reduction program or performance enhancements.

The definition of limiting performance factors as applied to this thesis is the causes for the difference between the planned multi-mission helicopter performance based on the HH-60H capabilities and the realized performance of the MH-60S. Throughout the development of the MH-60S these limiting factors ranged from limits of the basic aircraft due to gross weight to performance limitations as a result of ORD interpretation. An example of a limiting performance factor as a result of ORD interpretation is invoking of a requirement for a power margin or the existence of excess torque to provide a safety margin in certain situations.

In a helicopter designed for a specific type of mission, the range of operating environments is bound. For example, a helicopter which is designed to perform VERTREP and other fleet support missions would be expected to perform its mission carrying cargo either ship to ship or ship to shore. In the case of the MH-60S, the requirement for multiple missions means that the helicopter will operate in a wide range of operating regimes. These regimes range from overland while conducting the SWS (OL) mission to high altitude while conducting the airhead mission to low over water while towing a Q-20 in the AMCM role. This operating range essentially covers every possible regime that a helicopter could be expected to operate in. The unplanned increase in weight empty combined with the requirement to include extra safety margin serve further to reduce future capability of the MH-60S

Gross Weight

Regardless of the mission, helicopters have a given amount of power available limited either by engine or transmission performance. The MH-60S NATOPS lists the maximum gross weight as 23,500 lbs. This is the maximum structural limitation of the aircraft. NATOPS currently lists the maximum internal weight as 22,500 lbs. Based on Table 3, the maximum gross weight is not a factor in the final MH-60S configuration. The maximum internal gross weight on some missions, however, does now become a limiting factor resulting in a reduction in the amount of fuel that can be carried with a resultant decrease in range/endurance.

Issues occur in helicopter design when the maximum gross weight must be set lower than the maximum structural gross weight. This is usually a result of developmental testing where a specific flying quality results in a reduced maximum gross weight. This also happens to be the case in the MH-60S. During dynamic interface testing conducted as a part of MH-60S developmental testing it was noted that at gross weights in excess of 22,000 pounds unacceptable pilot workload was required in the approach to landing regime on combatant ships (destroyers and frigates). As a result of these adverse handling qualities a recommendation out of developmental test was to limit the maximum takeoff gross weight of the MH-60S to 22000 pounds when operating from small decks. This requirement would not apply when operating from larger decks such as L-Class ships (LPD, LHD, LHA) and aircraft carriers. Since the ORD requires the MH-60S to operate from combatants, the 22000 maximum gross weight further limits aircraft performance.

Hover Out of Ground Effect (HOGE) Limits

Another aircraft limitation is the maximum weight at which the helicopter can hover out of ground effect. This weight applies to shipboard takeoffs where in most cases the aircraft will be in an out of ground effect hover as soon as it clears the deck edge. The maximum weight an aircraft can hover out of ground effect is a function of power available which is a function of ambient conditions.

Most of the ORD missions are based on sea level/ 90 degrees F or 3000 ft/90 degrees F. Utilizing the hover charts in the MH-60S NATOPS, the aircraft can HOGE at 22,650 lbs sea level/90 degrees F and 20,200 lbs 3000 ft/90 degrees F. Referring to the mission profiles chapter in this thesis, the requirement to HOGE applies to any mission which starts out from the ship as well as the missions which have a specific mid-mission HOGE requirement such as SWS (OL). Once again, comparing these weights to the operating weights in Table 3, the increased gross weight as a result of multi-mission provisions has a negative affect on aircraft performance.

Takeoff Criteria

Takeoff criterion, or the amount of power available for a safety margin, has been a subject of discussion for many years. Helicopter performance is based on shaft horsepower produced by the engines (power available) and shaft horsepower required by the main and tail rotors, drive system and accessories (power required). In a flight test quality, still air hover, power available equals power required and the helicopter neither climbs nor descends. For this to happen the pilot determines for a given pressure altitude and environmental condition the engine power available and the gross weight requiring that power available. For the heaviest gross weight there is no power margin.

The expression power margin and torque margin are sometimes used interchangeably. Because pilots fly based on a torque setting, shaft horsepower is converted mathematically to a torque value. The pilot flies based on a torque setting where 100% correspond to a reference amount of power (2828 shaft horsepower for the H-60) at 100% main rotor revolutions per minute (RPM). Furthermore, pilots calculate mission parameters based on torque available and torque required. The ability to hover with a 10% torque margin is calculated utilizing the NATOPS performance charts artificially reducing the engine power available by 10%.

The specific torque margin discussions, however are typically held in an ad hoc manner as part of pilot training, ready room discussions, NATOPS manuals, and unit level operating procedures. The inclusion of this safety margin has never been included in the design phase of a helicopter because historically missions were not planned to utilize 100% of the power available for takeoff and hover. As the basic operating weight of the MH-60S increases, many missions will in fact require 100% of the power available (prior to any future weight reduction program). Naturally, the definition of power margin in the case of the MH-60S cannot be left to the post-design audience and now must be addressed at the Systems Command level prior to IOC. Further, the varying opinions on this subject make it very difficult to formalize.

In the case of the multi-mission helicopter, the ORD specifies mission takeoff gross weight. For example, in the CSAR mission the direction is "...vertical takeoff to HOGE with 5 aircrew, sea level, 90 degrees F...." The operational evaluation (OPEVAL) pilots will be applying a 10% torque margin to power available to determine takeoff gross weight (TOGW), based on common fleet procedures. Since the mission will have allocated 100% of the power available for takeoff, the addition of the 10% will exceed the power available and not permit conduct of the mission.

Currently, the requirement for a torque margin capability varies by aircraft and by service. For example, many of the wind envelopes that list wind limits for takeoff and landing from ships prescribe a specific torque margin. The HH-60H NATOPS prescribes a 10% torque margin for takeoffs from the aircraft carrier, Spruance class destroyers, and oilers.

Vertical Rate of Climb (VROC)

The same discussion for torque margin in a HOGE also applies to VROC. Specifically, the "practice" of applying additional margin which ensures that the pilot will have excess power to climb in a given situation. As in the previous discussion, the concept of a VROC margin is discussed because the aircraft is required to do all missions. Obviously torque margin and VROC are related. If there is a torque margin then there is the ability for the aircraft to climb. In the case of the H-60, a 5-6% torque margin yields a 500 foot per minute (fpm) VROC. VROC is typically planned when dealing with maneuvering flight such as in the AH and some of the combat support missions such as NEO. The CSAR maneuver guide, for example, requires that during mission planning a percent torque margin for all maneuvers be established which ultimately indicates the level of risk. A margin of greater than 10% is indicative of low risk whereas a torque margin of less than 5% would indicate a high-risk flight. Similarly, the H-60F/H NATOPS states that power equal to HOGE plus 5% may be required during the waveoff or landing abort from a confined area landing site.

Other sources of comparison on this issue include the Army ORD for the Black Hawk and ADS-33 Flying Qualities Specification. For the Army ORD, the design requirement is 4000 ft/95 degrees F, using 95% takeoff power and 500 foot per minute VROC. This satisfies the real world requirement to hover OGE at 6000 ft/95 degrees F. The number 500 fpm VROC is also mentioned in ADS-33 as a steady state requirement for level I (the best) handling qualities.

The question that is unclear is how much margin or VROC capability is required for each situation. The answer to whether which should be the metric a 10% torque margin or a 500 fpm VROC is subject to debate. The bottom line is that some ability to establish a vertical rate of climb is necessary. The 500 fpm VROC, however, is not a rigorously defendable or traceable value. Currently, the answer is very subjective with the answers all over the scale from a 0% requirement to at least 10%. Regardless of the answer, the fact remains that there are different requirements driving the MH-60S design. The ORD allows for zero margin because 100% of the performance is utilized for the mission yet the test community and the fleet will expect a torque margin of some degree. The addition of the airframe provisions for all of the missions makes a torque margin unachievable without weight reduction or performance enhancements.

Engine Degradation

Another damaging performance assumption is the calculation of aircraft performance with perfect or specification-level engines. The measurement for the relative health of an engine is the Average Torque Factor or ATF. A 1.0 engine is an engine that produces 100% of the specified power or 2828 shaft horsepower (SHP) at 100% main rotor speed. Since the missions mandated by the ORD require 100% of the power available once the final configuration weight is added, there was no allowance for degraded engines. Adding to the problem is the fact that the average engine in the fleet today is less than 1 .0 and is usually closer to a 0.93 or 7% degraded.

In a sense, there are three end users of the MH-60S, the requirements officers who author the ORD, the operational testers who verify ORD compliance, and ultimately the fleet. The ORD remains silent on the ATF and the VROC values. In order to maximize the performance in light of the increased weight for multi-mission provisions, it is necessary to plan on the availability of 100% of the power available. For this reason, performance calculations based on the ORD used the least conservative values of 1.0 ATF and 0 VROC. This serves to understate the weight and performance issues for both the acquisition and requirements community. VX-1, the operational test squadron, will perform the operational testing with MH-60S aircraft that are projected to have approximately 200 flight hours on them. It is not unreasonable to expect that the engines will have degraded to less than a 1.0 ATF. Furthermore, it is not clear what torque margin will be utilized for mission planning but it is not unreasonable to assume that it will be greater than 0%. Last and possibly most important is the fleet projection for the MH-60S. Based on current employment of the H-60 in the fleet, the average engine will have an ATF of 0.93 and a VROC of 500 fpm will be used as a planning metric.

The excessive weight growth as a result of multi-mission is a large enough problem in itself. The problem is compounded by unclear and perhaps more stringent than planned performance requirements. Weight growth is a fairly easy problem to understand. As aircraft provisions are added in order to make the aircraft multi-mission capable, aircraft empty gross weight subsequently increases. The performance related issues are somewhat less easy to understand and even harder to foresee as a result of the multi-mission requirement. The performance limiting factors are an intangible problem associated with an aircraft that must perform many missions. An example would be an attack helicopter that must have excess power available in order to perform evasive or offensive maneuvers. The same amount of excess power may not be required in a transport helicopter that may only have a torque margin requirement to allow a safety buffer when landing and taking off from the ship. Since the MH-60S must conduct both of these mission in addition to many others, there is no one answer which will drive the multi-mission design.

IX. Mission Shortfalls

A simple analysis of the projected gross weight combined with the performance degradation demonstrates the fact that the MH-60S will be unable to meet all of the ORD missions in the FY 07 configuration. Tables A-4 and A-5, developed by the NAVAIR Performance Branch, show projected mission performance in each mission profile. In cases where capability is limited, the limiting factor is also listed.

For Tables A-4 and A-5, the white color indicates that the aircraft can meet the mission without weight reduction or performance enhancement. The light gray indicates that the aircraft is limited as a result of a HOGE limit or gross weight limit, but could meet the mission if the requirements were reduced by a minimum amount. Dark gray is a take off gross weight excursion. In many cases, the aircraft does not meet the mission using the ORD assumptions (1.0 ATF/0 FPM VROC). When realistic parameters are applied (0.93 ATF/500 FPM VROC), the performance deficit is made greater. Furthermore, as the weight empty increases, the MH-60S is unable to perform the base missions

The large number of missions and associated variables that must be analyzed becomes a cumbersome task. The analysis can be simplified by comparing limiting factors (gross weight and engine performance) to the various VROC and ATF combinations. This analysis, presented in Table A-6, when performed for each mission clearly summarizes MH-60S mission performance.

In Table A-6, the first number is the number of missions that the aircraft is able to perform. The number following the slash is the number of missions that are limited by either gross weight or a performance limit. For example, for the seven basic ORD missions, the aircraft can meet six of the requirements based on a 1.0 ATF and 0 VROC requirement. As 0.93 ATF and a 500 FPM VROC is added the aircraft can only complete four of the seven missions.

It is apparent from the previous analyses that in the final configuration of the MH-60S, a combination of weight and reduction and performance enhancements will be required. Rather than analyzing each mission, the most restrictive missions should be analyzed. Specifically, mitigation paths need to be developed for the CSAR unrefueled, SWS(OL), MIO, and the Q-20A (tropical and hot day) missions. Resolution to the shortfalls to these design critical missions will obviously optimize the overall aircraft capabilities.

X. Weight Savings Options

Obviously, the most efficient method to reduce weight in an aircraft is in the design phase prior to 'bending of metal'. Since the requirement to reduce weight in the MH-60S was not clearly identified until the post-production phase, the impact of a weight reduction program will be significant. The task of identifying the easiest ways to eliminate weight will be difficult. The difficulty of this task is compounded by the fact that the aircraft is already in production and any changes may have to be retrofitted to aircraft already delivered. The options to save weight can be compared utilizing many factors such as cost, time to implement, ease of implementation, factory or field modifications, and technological difficulty. For purposes of this thesis, options will be categorized by ease of implementation.

Low Technology Insertion

Weight reduction options classified as low technology insertion utilize already in production components which are 'form, fit, and function' components, but obviously lighter than the current MH-60S component. One example of this is replacement of the current pilot seats with a lighter version. This lighter version of the pilot seat has the same function as the existing armored seats in the MH-60S and currently under development for the Army UH-60M aircraft. Once development is complete, it is expected that these seats will be 30 pounds lighter than the existing seats for a total weight reduction of 60 pounds.

Other examples of low technology insertion include lightweight fuel cells and the addition of a kitable HIRSS (Helicopter Infrared Suppression System). Like, the lightweight pilot seats, weight savings technology employed in the UH-60M can be transferred to the MH-60S. In addition, new, lighter materials could be utilized to fabricate the fuel tank. The tank used in the UH-60M is approximately 25 pounds lighter. The UH-60M tanks in conjunction with a lighter material could save as much as 75 pounds in the MH-60S.

The HIRSS as currently installed on the MH-60S is a permanent change to the engine exhaust. The HIRSS is only required for missions where the risk of exposure to enemy IR missiles is high. For the AMCM and many of the basic missions the HIRSS is extra weight that also happens to decrease the performance of the engine. There currently exist two different designs that permit the HIRSS to be removed and reinstalled when dictated by mission. Weight savings associated with removal of the HIRSS is 175 pounds. The associated increase in engine performance is approximately equal to 125 pounds in a hover (2% increase in SHP). Although, this provision will not help the armed helicopter missions it does represent a sizeable weight reduction for AMCM.

Other relatively simple changes include the use of lighter materials such as titanium instead of steel hydraulic lines and fasteners or the increased use of composites. Although these changes are relatively simple from a technology standpoint they do represent changes that are costly and more difficult to implement.

Medium Technology Insertion

As the technological level of the proposed change to the aircraft becomes increasingly difficult, the level of analysis required also increases. An example of a medium technology insertion weight reduction option is the replacement of the aluminum horizontal stabilator with a composite stabilator. This design is currently planned for the UH-60M so the U.S. Navy would be in a position where they would either have to accept the U.S. Army testing or conduct their own test program. The replacement of this component, because it is safety critical, would require an extensive test program and structural analysis.

The fourth hydraulic system installed as part of the AMCM aircraft provisions can also be evaluated as a potential area of weight savings. Although it is planned that the actual pump will be removed from the gearbox for all non-AMCM missions, the weight of the plumbing and the reservoir will be a weight penalty for all missions. An alternative to the fourth hydraulic pump is the design and fabrication of an electric motor for the AMCM winch. The motor would be installed as part of the AMCM B-kit. Impact to the aircraft is obviously an analysis of the electrical loads and the actual design modifications to the current winch and associated control system. Potential savings for an electric winch are anticipated to be approximately 82 pounds.

Another example of the medium technology insertion weight reduction is the elimination of the fourth aircrewman for the AMCM mission. The weight that is planned per crewman is 250 pounds. The design plan for the AMCM mission was a minimal level of integration. In other words, the mission is planned to be executed by the 2 crewmen in the rear of the aircraft. The pilots would of course be responsible for minefield navigation and overall conduct of the mission. An example of the minimal level of integration is that during the stream process of a Q-20, the pilots are unable to monitor the status of the device. The plan is that one crewman would actually be operating the winch while the other crewman would be controlling/monitoring the device from the console. Once under tow, the fourth crewman would not have much to do until the recovery process. Increasing the level of integration so that such stream and recovery tasks could be conducted by the crewman sitting at the console with monitoring being performed up front by the pilots. A simple analysis indicates that the majority of this integration would be related to increasing the amount of information on the data bus and subsequently making it available to the pilots. In other words, there would be little weight penalty associated with the removal of the fourth crewman and the associated seat. Further analysis, both in the human factors, crew systems and avionics arenas are obviously required.

High Technology Insertion

High technology insertion items are those items that either represent the latest in helicopter design or require a large amount of analysis and test. It follows that this category would drive the largest impact to the design of the MH-60S and most likely take the longest amount of time. Examples of high technology items include fly by wire technology, wide chord main rotor blades, and active vibration control. There are also opportunities for insertion of technology for the purpose of weight decrease in AMCM in the area of lighter tow cables and a weight reduction study for the AMCM sensors.

Cost

Throughout this section there was no mention of the cost of each of the options. Similar to the design phase for an aircraft, cost per pound of weight lost can be calculated. The previous discussion covered the wide range of changes that can be made in order to lose weight. Because this part of the MH-60S was never initially planned, the correct choice will obviously be based on fiscal constraints and how to get the largest weight reduction for the lowest price with the least impact to the schedule.

XI. Performance Improvements

In addition to an aggressive weight reduction program, the growth of the MH-60S has resulted in a requirement to improve helicopter performance. The most compelling reason is the need to increase takeoff gross weight and hover performance in the SWS, CSAR and AMCM missions. Increased TOGW will permit the aircraft to leave the flight deck with the requisite amount of fuel and mission equipment in order to meet the combat radii mandated in the ORD mission profiles. As in the weight reduction program, however, any performance enhancement decision must be based on impact to the aircraft. This section is not intended to be inclusive; rather it is intended to demonstrate the problems associated with even the simplest methods of increasing helicopter performance in a postproduction environment.

There are many ways to increase the performance capabilities of a helicopter. An obvious example would be through the use of wide chord main rotor blades mentioned in the previous section. Another tactic is to evaluate the drive train and engines. A simplistic explanation of this area is that the aircraft performance is limited by the amount of power the engines can produce or limited by the amount of torque that the main gearbox can accept. As an example, the main gearbox of the MH-60S is limited to 120% torque at airspeeds less than 80 knots. The only way to increase the ability to accept increased shaft horsepower from the engines is to replace the gearbox. This is an example of a performance enhancing change which would be cost and schedule prohibitive since it would involve a completely new design not currently installed in any

H-60 variant. There are cases, however, where the MH-60S is limited by the engine power available and not gearbox input torque.

Engines

The engines currently installed in the aircraft are designated T700–401C engines. For normal operating conditions, pilots operate this engine within their maximum continuous turbine temperature specified in the NATOPS manual. When additional power is required, the MH-60S NATOPS provides for an Instrument Rated Power (IRP) setting for up to 30 minutes. Although not approved for use in the Navy variants of the H-60, the U.S. Army also uses the T700, but has an additional 10-minute rating which permits a time limited availability of increased shaft horsepower. This directly increases the ability to hover in warm weather where the aircraft is engine limited.

Although implementing a 10 minute limit on the –401C engine seems like an 'easy' method to increase hot day hover performance, there is a large amount of analysis which must be performed. With this increased demand on the engine is the commensurate decrease in engine service life. Further analysis to determine exact life penalty for this requirement. At the very least, an increase in engine asset availability would be required throughout the fleet.

The U.S. Army is currently testing a new version of the T700 engine, the T-700-701D, for use in the UH-60M. This engine, if approved for use in the MH-60S would provide for up to 4% increase in shaft horsepower that equates to several hundred pounds of increased lift capability. Like the previous example, however, a large amount of analysis and testing would be required prior to implementation.

Increased Nr

Another example of increasing takeoff and hover performance is by increasing main rotor RPM. Increasing Nr would have two effects on performance. The first effect would be in handling qualities where the main rotor would provide increased control power at higher speeds. This would allow pilots to set a higher RPM when taking off and landing at high gross weight from the ship. The second area where increased RPM increases performance is at sea level conditions where the aircraft would be main gearbox torque limited if the –401D engine were installed.

Currently, the MH-60S is designed to operate at 100% Nr. In helicopter design, the main rotor RPM impacts may areas. Prior to approving operations at any increased rotor speed, effects to the engines, vibratory signature, electrical power, and dynamic components would have to be evaluated. An additional impact is that in the current design there is no method to set an Nr at any value over 101.5%. The control system would have to be modified to allow the pilot to set Nr at 103 or 105%.

Engine Health

In Chapter VIII, the fact that the ORD considered that the engines were operating at 1.0 ATF or were producing specification power is challenging In actuality, the average engine in the fleet is degraded as much as 7% thereby decreasing power available. Given an unlimited supply of engines and manpower, an engine would be removed and replaced as soon as its health decreased below 100%. Reality has driven the removal criteria to 0.93. Anything that can be done from an engine logistics and reliability/maintainability standpoint would serve to indirectly increase MH-60S performance. An example of this might be robust compressor blades that are less susceptible to erosion from salt spray and sand. By affecting the overall health of the engines in the fleet so that the average engine becomes a 0.95 ATF, performance gains would be realized without directly changing anything on the aircraft.

Similar to the weight reduction discussion, the correct performance enhancement solution will be a combination of various items. A prime example would be the incorporation of the –701D engines with increased main rotor RPM for takeoffs and landings. The goal, of course, must be to increase the performance abilities of the aircraft so that the maximum takeoff gross weight specified in the NATOPS of 23,500 pounds could be realized.

XII. Recommendations

The on-going and planned multi-mission modifications to the MH-60S pose many unprecedented challenges for the Naval Aviation Systems Command and contractor teams. In theory, its intended mission should drive the design of a helicopter. The most stringent missions should play a major role in the design characteristics. In the case of the MH-60S, however, the challenge becomes weight reduction and performance enhancements in a production helicopter. In order to compensate for the impacts of the multi-mission capability, the following should be investigated:

1. Requirements Definition: The requirements were written utilizing current mission needs that were in turn based on a dedicated platform for each mission. No regard was given for the potential degradation in performance resulting from one aircraft performing many diverse missions. The fact that the MH-60S will be organic to the battle group and able to be used for many missions at the discretion of the Battle Group Commander is an enhancing characteristic that is not currently taken into account by the requirements generation process. The current requirements need to be re-evaluated based on the actual requirements and not based on the capability of the legacy aircraft. Additionally, the derived benefit of having this asset readily available should be factored in.

2. Spiral performance 'buy back': Weight reduction studies and performance enhancements should be evaluated based on cost and benefits. Once decided upon, "performance" should be "bought back" along the same schedule as the spiral acquisition path. An example of such a performance buy back plan follows:

•Block 2A – FY03

–Kitable HIRSS
–New pilot seats (from the UH-60M)
–Fuel tank (from the UH-60M)

•Block 3A – FY05

–Utilize refueling probe
–Reduce unrefueled range requirement in ORD
–Reduce number of SWS(OL) crew in ORD

•Block 3B – FY06

–401D Engine upgrade
–Develop active vibration controls to allow increased Nr operations
–Composite stabilator

•Block 2B – FY07

–Tow cable or removal of fourth AMCM crewman
–4th stage hydraulic pump removal

As new capability is added a commensurate amount of performance should be substituted through a combination of weight reduction, performance enhancements, and requirements analysis. A plan of this type should be added to the acquisition strategy and incorporated as part of the production line for each block.

3. Mission Analysis: Rather than analyzing 20 different missions, the requirements should be based on a subset containing the most stringent missions. The task of analyzing many different missions and all possible variations is difficult as shown in Chapter V. The task could be simplified by only defining/mandating requirements for the most stringent base mission, the most stringent armed helicopter mission and the most

stringent AMCM mission. These mission profiles would drive future weight reduction/performance enhancements. It follows that if the most difficult missions were considered, overall performance of the air vehicle would be optimized.

XIII. Conclusion

Even the brief analyses presented in this thesis demonstrate the intricacies involved in the conduct of the AMCM and armed helicopter missions. The weight growth associated with increasing the MH-60S capabilities was not planned. The mission profiles are reminiscent of the way that the missions are currently conducted with platforms dedicated to that specific mission; specifically, the MH-53E for the AMCM mission and the HH-60H for the armed helicopter mission. Inevitably some mission profiles will have to be reduced as there is no compensation planned for the synergies gained by conducting all missions in one aircraft.

Design requirements for a helicopter can be thought of as a chair with four legs. Each leg can be symbolized by the following design attributes: weight, performance, engines, and requirements. The first three are not easily changed once the aircraft is in production. The fourth is relatively easy to change.

If the MH-60S were a new aircraft it would have a specification that detailed engine ratings, transmission limits, rotor disk area, tip speed, solidity, and mission performance calculations with clearly stated ground rules. Additionally, design work would be performed taking the necessity of additional margin into account. This would be required to allow for weight growth and performance degradation over the life cycle.

The decision to transition to one type of helicopter for the U.S. Navy has been the subject of many studies. This strategy, officially adopted as part of the HMP, will change the way the Navy of the future operates both tactically and fiscally.

The multi-mission concept will have many tangible and intangible effects. The tangible effects will be the cost associated with a weight reduction and performance enhancement upgrades to the MH-60S. Intangible and unknown impacts will be the potential sub optimization of each mission the MH-60S will be required to perform.

It is not possible for an aircraft to do all missions perfectly. Nor is it possible for the MH-60S to perform to the same level as an aircraft that was optimized for a particular mission. The resultant situation is that the Navy will be forced to purchase an aircraft that can do all missions to an acceptable level. The acceptable level will have to be arrived at based on revision of the way the Navy currently operates.

It is surmised that this acceptable level will someday, once again based on weight reduction and performance enhancements, be within the limits of the MH-60S. If the MH-60S cannot perform all missions at this acceptable level then there are one of three outcomes. The first and least desirable is that the Navy accepts the fact that it will not meet war fighting requirements. The second is that the Navy aborts the one type aircraft plan. The third is that the Navy operates a 'split' fleet of MH-60S aircraft where some aircraft are designated VERTREP only, some are AMCM only and some are armed helicopter only.

Of course, the above postulation over simplifies the situation and does not take into account advancement in tactics and war fighting technology associated with integrating the latest, state of the art sensors and weapons into the MH-60S. It does serve however to demonstrate the magnitude of the decision to transition to the MH-60S for all missions. It also highlights the difficulty of designing for many missions let alone making post production changes to account for multi-mission related airframe changes.

The plan to utilize one helicopter for many missions is clearly highly pragmatic. The cost and final capability once all modifications are complete is yet to be seen. The only way the program will succeed is through continued analysis and careful planning to counter the effects of adding multi-mission weight over time.

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Appendices

Appendix A: Tables

TABLE A-1: SUMMARY OF REQUIREMENTS

VERTREP

MISSION	KPP	PAYLOAD	ENDURANCE (hrs)	RANGE(nm)
VERTREP	YES	5500 lbs	1.7 hrs	--
VOD	YES	5500 lbs	--	100 nm
AMPHIB SAR	YES	Up to 12	--	50 nm
Airhead	--	5500 lbs	--	12 nm
NEO	--	12 pax	--	100 nm
MEDEVAC	--	4 pax	--	100 nm
SWS(OW)	--	8 troops	--	50 nm

AMCM

MISSION	KPP	TOS (min)	ROA (nm)
AQS-20X /OASIS Trop Day	YES	60 min	30 nm
AQS-20X/OASIS Hot Day	YES	30 min	10 nm
ALMDS	YES	120 min	30 nm
AMNS (Tethered)	YES	75 min	30 nm
RAMICS	YES	75 min	30 nm

ARMED HELO

MISSION	KPP	PAYLOAD	RANGE (nm)
CSAR	YES	4 Pax	200 nm
SWS(OL)	YES	8 Troops	200 nm
MIO	YES	8 Troops	50 nm
ASUW	--	--	--
CV PLN GD		5 Pax	100 nm

(Source: PMA Brief)

TABLE A-2: MULTI-MISSION GROSS WEIGHT IMPACT

Item	Weight (lbs)
Armed Helicopter A-Kit	391
AMCM A-Kit	333
TCDL	57
Total	781

TABLE A-3: H-60 WEIGHT GROWTH

Item	Weight (lbs)
MH-60S weight empty (UH-60L plus marinization weight)	13,802
IMD/HUMS	73
Manufacturing Variation	70
Discrepancy resolution (Vibration absorbers)	12
A-Kits	781
Total	14,738

TABLE A-4: MISSION PROFILE SUMMARY (BASIC AND AH)

KPP	Mission	Requirement	ATF = 1.0, VROC = 0	ATF = 0.93, VROC = 500	Limit
X	VERTREP	5500max/3,000avg 1.75 hrs	6587/5714 lbs 1.74 hrs	4816/3943 lbs 1.84 hrs	
X	VOD	4,500max/3000avg 100 NM	208.6 nm	138.8 nm	
X	Amphibious SAR	Up to + 12 PAX 50 NM	4.6 pax 50 nm	4.6 pax 50 nm	
	AIRHEAD	5,500max 12 NM	5500 lbs 131.4 nm	5500 lbs 0 nm	1K/90 deg HOGE (Performance Limit)
	NEO	12 Pax 100 NM	12 pax 94.2 nm	12 pax 0 nm	4K/90 deg HOGE (Performance Limit)
	MEDEVAC	4 Pax 100 NM	4 Pax 230 NM	4 Pax 230 NM	
	SWS (OW)	8 SEALs 50 NM	89.3 nm	89.3 nm	
X	CSAR (unrefueled)	2 survivors 200 NM	157 NM	60 NM	Mid-Mission HOGE (3K / 90F) (Perf. Limit)
	CSAR (refueled)	2 survivors 200 NM	440 NM	0 NM	Mid-Mission HOGE
X	SWSOL (unfueled)	8 SEALs 200 NM	116 NM	58 NM	TOGW & Mid-Mission HOGE (Performance Limit)
	SWSOL (refueled)	8 SEALs 200 NM	365 NM	226 NM (329 w/10 min)	Mid-Mission HOGE (Performance Limit)
X	CV PLN GD	5 survivors 100 NM	150 NM	[redacted]	2 Aux Tanks req'd. TOGW limit.
	MIO	8 SEALs 80 NM	[redacted]	[redacted]	TOGW

TABLE A-5: AMCM MISSION PROFILE SUMMARY

KPP	Mission	Requirement	ATF = 1.0, VROC = 0	ATF = 0.93, VROC = 500	
X	AQS-20X Towing Trop	60 Min 30 NM	50 min (289 lb over)	0 min (1210 lb)	Gross Weight Limit
X	AQS-20X Towing Hot	30 Min 10 NM	30 min (265lb)	0 min (1387lb)	Gross Weight Limit
X	OASIS Towing Trop	60 Min 30 NM	52 min (178 lb over)	2 min (1100lb)	Gross Weight Limit
X	OASIS Towing Hot	30 Min 10 NM	30 min (155 lb)	0 min (1277lb)	Gross Weight Limit
X	ALMDS Trop	120 Min 30 NM	165 min	144 min	
X	RAMICS Trop	75 Min 30 NM	69 min (150 lb)	28 min (1200 lb)	1500 ft HOGE (Perf. Limit)
X	AMNS (Tethered) Trop	75 Min 30 NM	103 min	15/64 min (TBD+235lb)	(IRP wt+perf wt) (Perf. Limit)
X	AMNS (Untethered) Trop	120 Min 30 NM	148 min	124 min	
			Upwind / Downwind Minutes	Upwind / Downwind Minutes	Upwind / Downwind Minutes
	AQS-20X Towing Trop Downwind	30 up / 30 down 30 NM	25 up / 30 down (103 lb over)	21 up / 30 down (189 lb over)	11 up / 30 down ([illegible] lb over) (Gross Wt Limit)
	OASIS Towing Trop Downwind	30 up / 30 down 30 NM	30 up / 30 down	27 up / 30 down (87 lb	16 up / 30 down ([illegible] lb over) (Gross Wt

TABLE A-6: SUMMARY OF MH-60S MISSION PERFORMANCE

	ATF=1.0	ATF=0.93
	VROC=0	VROC=500
Basic ORD		
7 Total	6/1	4/3
3 KPP	3/0	2/1
Armed Helo		
6 Total	3/3	0/6
3 KPP	1 / 2	0/3
AMCM		
10 Total	3/7	2/8
8 KPP	3/5	2/8

(Source: PMA Brief)

Appendix B: Figures

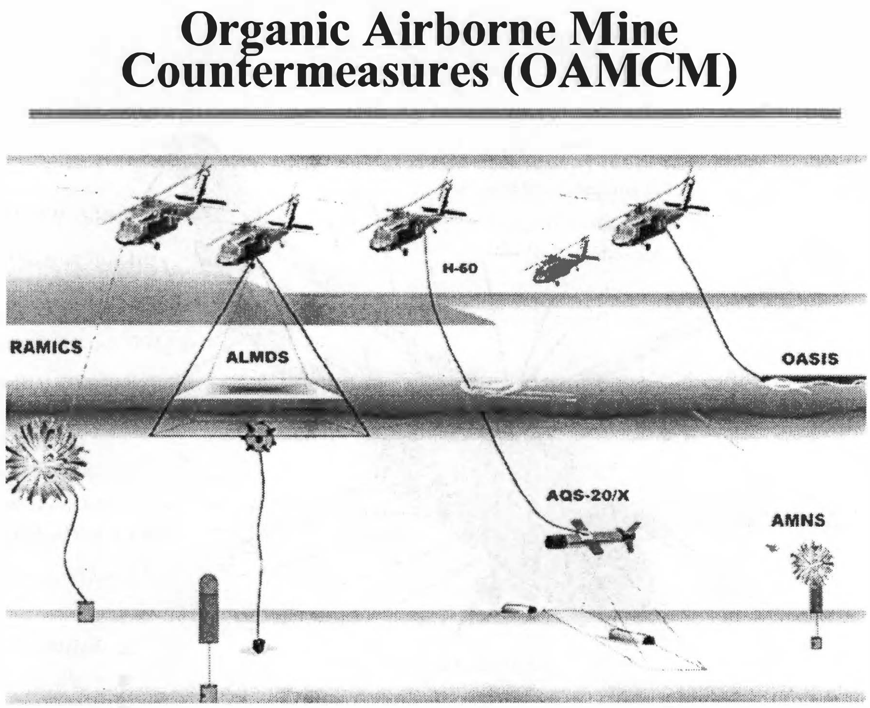


FIGURE B-1: OAMCM SYSTEM EMPLOYMENT

(Source: PMA Briefing Slide)

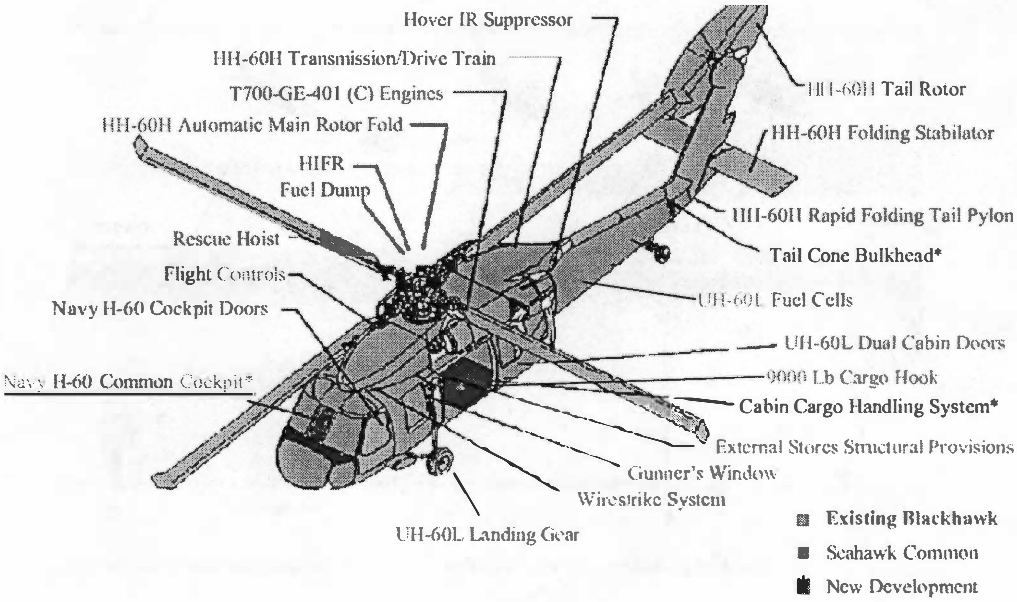
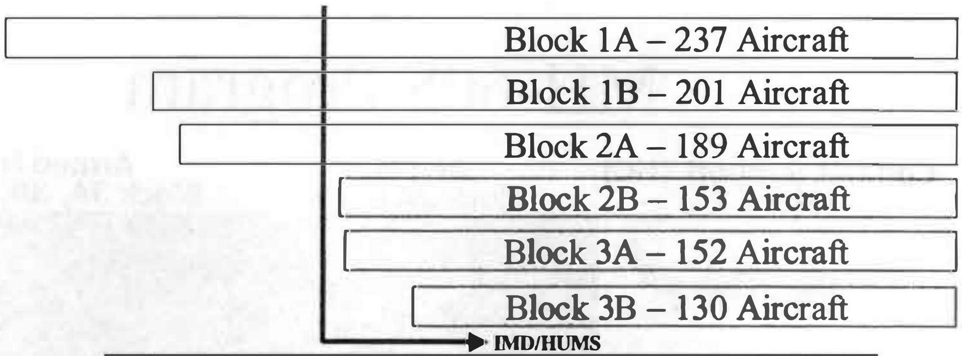


FIGURE B-2: MH-60S COMPONENTS

(Source: Ibid)

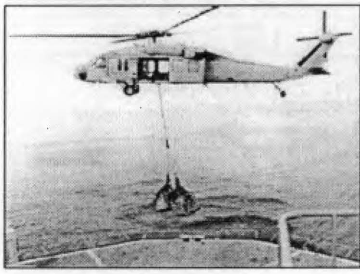


1A	Basic Vert Rep, Amphibious SAR
1B	1 + Internal Aux Tank Capable
2A	1B + Console, CSTRS, ASQ-20X, ALMDS, AMNS
2B	2A + TCDL, OASIS, RAMICS
3A	2B + Side Suppression Weapon, FLIR (MTS), Mission Computer, Second Aux Tank
3B	3A + Precision guided Munition, Forward Firing Weapon, Link-16, Integrated Self Defense, Digital Moving Map, Helmet Mounted Display, Improved FLIR Mount

FIGURE B-3: AIRCRAFT CONFIGURATION

(Source: Ibid)

MH-60S Program

Combat Support (HC) Block 1	AMCM Block 2A & 2B	Armed Helo Block 3A, 3B, and 3C
		

Combat Support: IOC FY02

- Replaces the Aging H-46D, HH-60H, HH-1N, and H-3 with a Newly Manufactured H-60 Airframe
- Supports Helo CONOPS Through Reduction of Type/Model/Series from 7 to 3
- New Production of 237 A/C
- 5000 + LBS Internal/External Cargo
- Fully Integrated Glass Cockpit and Mission Sensor Suite
- Cockpit Common with MH-60R

BLOCK 2A: IOC CY 05

- Carriage, Stream, Tow and Recovery System (CSTRS)
- Common Console
- Auxiliary Fuel Tank
- AN/AQS-20A Sonar Mine Detection Set[1]
- AN/AES-1 Airborne Laser Mine Detection System (ALMDS)[1]

BLOCK 2B: IOC FY07

- Sensor Link
- Airborne Mine Neutralization System (AMNS)[1]
- Organic Airborne & Surface Influence Sweep (OASIS)[1]
- Rapid Airborne Mine Clearance System (RAMICS)[1]

[1] PMS-210 Development Items

BLOCK 3A: IOC FY06

- Forward Looking Infra Red (FLIR)
- Crew Served Guns
- Additional Aux Tank
- Mission Computer
- External Weapons Mount System
- Integrated Self Defense (ISD) System
- Precision Guided Munition Air to Ground
- Fuel Probe

BLOCK 3B: IOC FY07

- Link 16

BLOCK 3C: (Planned; IOC TBD)

- Digital Moving Map
- Helmet Mounted Display
- Improved FLIR Mount
- Forward Firing Weapon

FIGURE B-4: MH-60S SPIRAL ACQUISITION STRATEGY

(Source: Ibid)

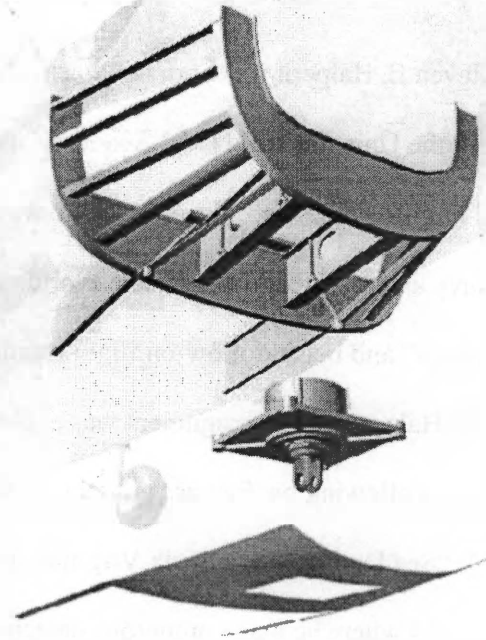


FIGURE B-5: AMCM STRUCTURAL MODIFICATIONS

(Source: Ibid)

Vita

Commander Steven E. Halpern was born in Queens, New York on 13 May 1965. In July 1983, he entered the United States Naval Academy and graduated in May 1987 with a B.S. in General Engineering. Upon graduation, he was commissioned an Ensign in the United States Navy and reported to Pensacola, Florida for flight training. In May 1989, he earned his "wings" and began follow-on flight training in the SH-3 Sea King helicopter. Commander Halpern's first assignment was at NAS Patuxent River, MD as a Search and Rescue pilot. Following his first assignment, he was selected for transition training to the MH-53E "Sea Dragon" in Norfolk Virginia. In 1991, Commander Halpern reported to HM-14 where he made numerous detachments in support of the Airborne Mine Countermeasures mission. In 1995, Commander Halpern was selected for Naval Test Pilot School (USNTPS). Following graduation from USNTPS, Commander Halpern reported to the Naval Rotary Wing Aircraft Test Squadron as the MH-53E platform coordinator and Dynamic Interface Department Head. In this capacity, he was in charge of several H-53E dynamic interface detachments and was a project officer for both Navy and USMC test programs. In 1999, Commander Halpern reported to HM-15 in Corpus Christi, Texas for his Department Head tour. While at HM-15, Commander Halpern held the billets of Admin Officer and then Maintenance Officer as well as detachment Officer in Charge. In recognition of superior performance while assigned as HM-15 Maintenance Officer, Commander Halpern was recognized as the NHA Maintenance Officer of the Year 2002.

In November 2001, Commander Halpern reported to Naval Air Systems Command and held the Aviation Training Lead and his current assignment, Mission Systems IPT Lead on the MH-60S program.

Commander Halpern has completed Joint Professional Military Education at Air Command and Staff, Air University and is a graduate of the Advanced Program Management Course, Defense Systems Management College, Defense Acquisition University.

Commander Halpern has been selected for aviation command and will report to Norfolk, Virginia in May 2003. In the Fall 2003, Commander Halpern will become the Commanding Officer, Airborne Mine Countermeasures Weapons Systems Training School.