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Cost-Based Analysis of Unmanned Aerial Vehicles/Unmanned Aerial Systems in Filling the Role of Logistical Support

15 December 2014

Maj Thomas Denevan, USMC

Thesis Advisors: Simona Tick, Lecturer
Douglas Brinkley, Senior Lecturer

Graduate School of Business & Public Policy

Naval Postgraduate School

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About the Author

Major Thomas Denevan enlisted in the United States Marine Corps in 1995. Following tours as a Correctional Specialist in Okinawa Japan and as Marine Embassy Guard in Abu Dhabi, U.A.E. and Santo Domingo, D.R. he was accepted to the Broaden Opportunity for Officer Selection and Training (BOOST) Program. Following completion, he was subsequently accepted to the Marine Enlisted Commissioning Education Program (MECEP) at the University of Idaho, where he received Bachelor of Science and Bachelor of Arts degrees. Major Denevan now serves as an Aviation Supply Marine. He has served in various billets at Marine Aviation Logistic Squadron 36, Okinawa Japan; Detachment OIC, 31 Marine Expeditionary Unit; Operations Officer, Multi-National Security and Transition Command, Baghdad Iraq; and as the Marine Detachment OIC, Space and Naval Warfare Systems Command, Norfolk Va. After graduating from the Naval Postgraduate School he will be reporting to Office of the Secretary of the Navy in the Office of the Commander Naval Operations, OPNAV n853J, Expeditionary Warfare.

Major Denevan married his wife Jennifer in January 2000, and they currently have 2 children, Seamus, 12, and Isabella, 10.

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ABSTRACT

This thesis conducts a comparative cost analysis for using unmanned aerial vehicles (UAVs)/unmanned aerial systems (UASs) for logistical resupply purposes as opposed to the traditional logistical resupply resources. First, the thesis examines the types of UAVs in the U.S. Department of Defense (DOD) inventory as well as the traditional aircraft currently used for logistical purposes. Then, using a cost-based analysis, the thesis identifies possible logistical uses for selected UAVs based on specific capabilities and scenarios where the use of these systems would be most advantageous compared to traditional logistic resources. As the DOD continues to develop the emerging technologies of UAVs, the findings of this thesis may point to some immediate adaptations in the logistical resupply process that could result in cost savings.

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LIST OF ACRONYMS AND ABBREVIATIONS

AFI	Air Force Instruction
AFO	Aircraft Flight Operations
AOM	Aircraft Operations Maintenance
AVDLR	Aviation Depot Level Repairable
BCA	Business Case Analysis
BOR	Budget OPTAR (Operational Target) Report
CBA	Cost–Benefit Analysis
CNAF	Commander Naval Air Forces
CUAV	Cargo Unmanned Aerial Vehicle
DAMIR	Defense Acquisition Management Information Retrieval
FAA	Federal Aviation Administration
FH	Flight Hour
FHP	Flight Hour Program
FMRA	FAA Moderation and Reform Act
FY	Fiscal Year
GPS	Global Positioning System
HALE	High Altitude, Long-Endurance
HMMWV	High Mobility Multipurpose Wheeled Vehicle
ISR	Intelligence, Surveillance, and Reconnaissance
LtGen	Lieutenant General
MAGTF	Marine Air and Ground Task Force
MALE	Medium Altitude, Long Endurance
MALS	Marine Aviation Logistics Squadron
MUAV	Micro Unmanned Aerial Vehicle
MDS	Mission Designed Series
MPH	Miles per Hour
MTVR	Medium Tactical Vehicle Replacement
MUAV	Mini Unmanned Aerial Vehicle
OEF	Operation Enduring Freedom
OFC	Operation Fund Code

O&MN	Operation and Maintenance, Navy
O&S	Operation and Support
POL	Petroleum, Oil, and Lubricant
POM	Program Objective Memorandum
RPV	Remotely Piloted Vehicle
SAR	Selected Acquisition Report
TAD	Temporary Assignment of Duty
TMS	Type Model Series
TUAV	Tactical Unmanned Aerial Vehicle
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
U.S. DOD	United States Department of Defense
VSTOL	Vertical/Short Takeoff and Landing
VTOL	Vertical Takeoff and Landing

ACKNOWLEDGMENTS

First and foremost, I would like to thank my family for allowing me to take the time and attention needed to fully commit myself to obtaining my master’s degree and the herculean task of completing this thesis. Specifically, thank you to my wonderful wife and life partner, Jen. Without your support I would not be where I am today. To my son, Seamus, and my daughter, Isabella. You have sacrificed so much for me and I am not sure I will ever be able to fully repay you. I cannot thank the three of you enough for the support you have so selflessly given me over the past 18 month and throughout my career. The sacrifices and the contributions you have made to my career and to this Country have not gone unnoticed and are as essential as my own service. Without you, I am incomplete. Thank you for all you do each and every day.

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I. INTRODUCTION

When Marine operational flying squadrons deploy, a Marine Aviation Logistics Squadron (MALS) augments the flying squadrons with personnel and support packages consisting of aircraft components and material necessary for essential repairs to the aircraft. The spectrum of deployments ranges from areas with very modern facilities and infrastructure to locations that are incredibly austere, where even the airfield is temporary. Despite having maintenance and supply personnel and material from the MALS, additional parts that are either not on hand or are in limited quantities are often required for essential repairs. Traditionally, to replenish or provide these critical components to forward deployed units, Marine Corps organic resources (aircraft that are currently in the Marine Corps force structure such as the CH-53 Super Stallion, the MV-22 Osprey, and the KC-130J Super Hercules) are employed to close this logistical gap in the supply chain. These aircraft, CH-53 Super Stallion, the MV-22 Osprey, and the KC-130J Super Hercules are referred to thought out this study as traditional or organic assets. This method is costly; both in terms of accumulated hours on the aircraft and the necessary maintenance and personnel required ensuring the readiness of these resources.

Commercial giants such as Amazon have started testing future applications of UAVs for logistical purposes, specifically using UAVs to deliver consumer goods (Amazon Inc., 2014). There are, however, many obstacles preventing Amazon from moving forward with this initiative. In particular, there are the Federal Aviation Administration (FAA) regulations regarding UAVs, and the fact that the regulators cannot develop new policies and procedures fast enough to keep up with this emerging technology.

The DOD is better able to take advantage of UAVs as an additional logistical capability, especially if the regulatory barriers faced by the private sector are not obstacles for the DOD. During deployments when critical aircraft components are not on hand, the U.S. Marine Corps relies heavily on its organic or traditional resources to deliver these materials. As discussed previously, using traditional resources for logistical replenishment and sustainment places an additional constraint on the CH-53, MV-22, and the KC-130J, and diverts them from their intended missions.

With the proliferation of UAVs and a downturn in operations in Iraq and Afghanistan, repurposing these systems to close the gap in logistical requirements within the supply chain may provide a cost savings to the U.S. Marine Corps (and other services) while preventing the over use and stain placed on tradition assets.

The goal of this thesis is to conduct a comparative analysis of the cost of using unmanned aerial vehicles (UAVs)/unmanned aerial systems (UASs)[1] for logistical resupply purposes relative to the traditional logistical resupply resources. This thesis examines the various types of UAVs in the U.S. Department of Defense (DOD) inventory as well as the traditional aircraft currently used for logistical purposes. This thesis identifies possible logistical uses for selected UAVs based on specific capabilities and scenarios where the use of these systems would be most advantageous compared to traditional logistic resources. As the DOD continues to develop the emerging technologies of UAVs, the findings of this thesis may point to some immediate adaptations in the logistical resupply process that could result in cost savings.

This thesis aims to address the following research questions:

1. Can the current inventory of UAVs within the Department of the Navy be used to provide logistical sustainment for deployed aviation units?

2. Is it less costly to use UAVs to provide logistical sustainment and replenishment for deployed aviation units than it is to use traditional sources to provide the same logistical sustainment and replenishment?

The approach used by this thesis is a cost-based or cost-effectiveness analysis, as a special-case of a cost–benefit analysis (CBA) model comparing costs of operating UAVs with the costs of operating traditional sources as an alternative resource to provide the sustainment and replenishment of critical aircraft components to deployed operational flying squadrons. The cost-based analysis developed here and the findings of this analysis can provide decision support to commanders, and thus bring value to the U.S. Marine

[1] The distinction between UAVs and UASs is discussed in Chapter II.

Corps by identifying opportunities to utilize new, cost-saving alternatives for logistical sustainment and resupply channels.

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II. BACKGROUND AND LITERATURE REVIEW

A. INTRODUCTION

This chapter presents relevant background information on UAVs, and reviews the main resources that are commonly used today to provide material for forward deployed Marine Corps flying squadrons. In addition, this chapter provides a review of studies that examine UAV systems that resupply or sustain forward deployed units within the DOD, and previous reports that conduct a similar, cost-based analysis that can provide useful insights for this study's analysis.

B. UAVS

According to Air Force Instruction (AFI) 16–401(I), *Designating and Naming Defense Military Aerospace Vehicles,* a UAV is defined as "a powered aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or is piloted remotely, can be expendable or recoverable, and carries a non-lethal payload. Ballistic or semi ballistic vehicles, cruise missiles, and artillery projectiles are not considered UAVs" (United States Air Force, 2005, p. 10).

With the proliferation of UAVs, several in-depth studies could be conducted on each variant of UAV in the DOD inventory alone. However, this chapter serves to refine the data and present specific UAVs to study based on current capabilities and characteristics. This analysis requires examining the different classes of UAVs, identifying the variations of UAVs that fall into specific classes, and carrying out an in-depth analysis of the characteristics of each variation.

This section summarizes information on current regulations provided by the government, specifically the FAA, as well as literature that has predicted future issues and concerns relating to the proliferation of UAVs.

The totality of these data provide context to answer the study's main question: Can UAVs be used to provide more effective and efficient means of providing necessary logistical support for a lower cost than traditional aviation resources?

To fully understand this research study, it is important to review the history, operation, and use of UAVs. Two works, in particular, offer a great deal of information on these topics: Fahlstrom and Gleason's (2012) *Introduction to UAV Systems* and Reg Austin's (2010) *Unmanned Aircraft Systems: UAVS Design, Development and Deployment.* The authors of both books begin with the history of UAVs and then describe basic characteristics and operational functions, as well as the very technical layers of UAV systems and their subsystems.

1. The History of the UAV

Although the technological advances in UAVs are considered an emerging technology and the use of UAVs has increased dramatically in recent years, these vehicles have been around, albeit crude in design and functionality, since the late 1800s. Fahlstrom and Gleason (2012) explain that, in 1887, Douglas Archibald attached cameras to a kite, creating the first reconnaissance UAV. William Eddy continued with the idea of using kites for intelligence gathering during the Spanish–American War, becoming one of the first to use aerial reconnaissance UAVs in combat (Fahlstrom & Gleason, 2012). According to Fahlstrom and Gleason (2012), UAVs were not officially recognized until their use in WWI when Charles Kettering developed the Kettering Bug, a biplane carrying high explosives that was guided to its target with preset controls; upon reaching the target, it plunged into it, exploding on impact. Fahlstrom and Gleason (2012) also write about Archibald Montgomery Low, who developed the data link systems used in UAVs today and, in 1924, successfully launched and controlled the first radio-controlled UAV. Low's creation spurred the radio-controlled capabilities of UAVs for years to come, most notably, the V-1 and V-2 rockets (which were actually UAVs) that were used by the German army in WWII, causing massive destruction (Fahlstrom & Gleason, 2012).

It was not until the Vietnam War that the use of UAVs for reconnaissance missions was fully realized (Fahlstrom & Gleason, 2012). The early UAVs were still crude in their flight capabilities: Fahlstrom and Gleason (2012) describe how these reconnaissance vehicles were "launched from C-130s and recovered by parachute" (p. 5).

However, over 3,000 UAVs were launched during the Vietnam War and nearly all were recovered (Fahlstrom & Gleason, 2012).

Technological advances continued to add to the capabilities of these vehicles over the next few decades; however, due to funding constraints, major program acquisition of these vehicles failed (Fahlstrom & Gleason, 2012). In particular, the Aquila, which was the first UAV to become a system of systems, was part of a U.S. military program that expanded for decades and cost millions of dollars before finally being abandoned in 1985 due to a lack of performance (Fahlstrom & Gleason, 2012). While this was a costly endeavor, the Aquila program set the stage for the follow-on development of future UAVs and, more importantly, UASs (Fahlstrom & Gleason, 2012).

2. The UAV and Its Systems of Systems

Austin (2010) describes unmanned aircraft as "aircraft with its aircrew removed and replaced by a computer system or radio-link" (p. 1). Austin (2010) and Fahlstrom and Gleason (2012) define three specific types of such aircraft: UAVs, remotely-piloted vehicles (RPVs), and drones. Austin (2010) and Fahlstrom and Gleason (2012) further explain that, while the naming convention for these aircraft often leads to their names being used interchangeably, distinct differences characterize each system. Specifically, the authors indicate that drones are much simpler systems (despite the media referring to all unmanned air systems as drones) that lack sophisticated intelligence and are incapable of complex functions such as targeting, communication relays, and autonomous operability (Austin, 2010; Fahlstrom & Gleason, 2012). Moreover, not all unmanned systems are remotely piloted; some can be autonomous with preprogrammed coordinates and with the ability to use global positioning systems (GPSs; Fahlstrom & Gleason, 2012).

While this thesis study focuses on unmanned aerial vehicle capabilities and the term *UAV* is used throughout this study, it is important to look at UAVs with a more holistic approach. Authors (Austin, 2010; Fahlstrom & Gleason, 2012) emphasize that UAVs are a part of a much larger system and that a UAV should be seen as a system rather than as simply a vehicle. This system consists of the air vehicle itself, a control station, a navigation system, communication systems or data links, launch and recovery systems, and a payload.

a. The Air Vehicle

The air vehicle, as its name indicates, is the overall structure of the vehicle. Fahlstrom and Gleason (2012) describe the air vehicle as “the airborne part of the system that includes the airframe, propulsion unit, flight controls and electric power systems” (p. 8). Most of the other subsystems are specific to certain air vehicles; however, some subsystems such as payload can be used in various air vehicles as mission requirements dictate (Fahlstrom & Gleason, 2012). The specific mission requirements determine the size and functions of the air vehicle that is employed on a particular mission, including the use of a fixed-wing vehicle or a rotor-wing vehicle (Austin, 2010; Fahlstrom & Gleason, 2012).

b. The Navigation System

The navigation system allows the controller to be able to pinpoint the location of the UAV at any given time during the flight (Austin, 2010). This system also delivers the location of the vehicle back to the vehicle itself, providing non-piloted or autonomous vehicles’ location details (Austin, 2010). Improvements in technology, specifically advances in the sophistication of GPS units (much like a GPS unit in your car or on your smartphone), have drastically changed the engineering of navigational systems, allowing for smaller and lighter systems. These lighter GPS systems allow for an increase in payload and range in vehicle capabilities (Austin, 2010).

c. The Communication System

Austin (2010) and Fahlstrom and Gleason (2012) each argue that the communication system, also known as data links, is a crucial subsystem. This system allows for two-way communication between the vehicle and the operator. Within this communication network, there is an uplink, which is communication from the operator to the vehicle, and a downlink, which is communication from the vehicle back to the operator. Downlinks include location details, imagery data, and system status, whereas uplinks include flight and payload commands and mission updates (Austin, 2010; Fahlstrom & Gleason, 2012).

d. The Payload System

The payload system is what the vehicle is carrying based on its mission requirements. Payloads can range from imaging devices for surveillance and reconnaissance such as a video or still camera, to laser-guided smart munitions (Austin, 2010; Fahlstrom & Gleason, 2012). Fahlstrom and Gleason (2012) describe the payload as "the ultimate reason for having a UAV system" (p. 10).

e. The Launch and Recovery System

The launch and recovery system is the system that aids in launching the aircraft into the air and recovering the aircraft once it has returned from a mission (Austin, 2010; Fahlstrom & Gleason, 2012). These systems can range from complex catapults for launching the vehicle to simple systems such as netting used to recover the vehicles (Austin, 2010; Fahlstrom & Gleason, 2012).

f. The Control Station

The control station (CS), also described as the ground control station (GCS) by Fahlstrom and Gleason (2012), is where the UAV and its functionality are physically controlled (Austin, 2010). Typically, the CS is located on the ground where an operator controls and communicates with the vehicle (Austin, 2010). Improvements over the past decade allow the station's location to be more flexible, ranging from inside a backpack to a location on forward deployed ships (Austin, 2010; Fahlstrom & Gleason, 2012).

g. Supporting Systems

Additional supporting systems include ground support equipment used to help maintain the UAS and its systems as well as transportation systems used to deliver the system to the required deployment location (Austin, 2010; Fahlstrom & Gleason, 2012).

3. Rules and Regulations Surrounding the Use of UAVs

The FAA is in the process of updating rules and regulations regarding the operation of UAVs. The FAA has defined three separate categories of UAVs—civil, public, and model aircraft, and has established and published specific but limited guidelines for use under each category. Specifically, Section 333, Special Rules for Certain Unmanned Aircraft Systems of the FAA Moderation and Reform Act of 2012 (FMRA), will focus on the operation of UAVs, but it is still in a developmental stage.[2]

4. Possible UAV Issues and Concerns

Although the convenience and advantages of UAVs are easy to see, the issues and concerns surrounding such systems are often overlooked. In an article titled "Controlling Unmanned Air Vehicles: New Challenges," Dennis Gormley and Richard Speier (2003) detail how a lack of controls over UAVs in kinetic actions by militaries or military-like groups (non-state actors such as terrorist organizations), along with the growth and ease to make such aircraft, has made the world an increasingly dangerous place. Gormley and Speier (2003) specifically state, "These trends [the expansion of UAV availability], combined with the inherent capability of UAVs to deliver nuclear, biological or chemical payloads, set the stage for a new level of proliferation threat—one sharply at odds with a discriminating use of force" (p. 2). Gormley and Speier (2003) point out three main issues relevant to this discussion:

1. UAVs are fairly simple and inexpensive to produce.
2. The use of UAV technology is growing worldwide.
3. Regulations regarding UAVs are lacking.

These issues build on themselves, meaning that as the development and use of UAVs accelerate, their potential effect on society becomes increasingly more substantial. While newly adopted regulations from the FAA address some of these issues, this emerging technology is evolving more quickly than the regulators can act to efficiently or

[2] For a full and detailed list of the FAA's rules and regulations regarding the use of UAVs, see http://www.faa.gov/uas.

effectively manage regulations. Additionally, some issues may be beyond the scope of the FAA, including those that involve newly adopted regulations within the international community. As the ambiguity of who controls UAVs increases, the international community will struggle with who is ultimately responsible for them and what appropriate actions need to be taken when misuse occurs. The following are some examples of these dangers: midair collisions and the fallout of debris from such accidents, collisions with commercial aircraft, international sovereignty and flyover restriction violations, theft of the vehicle and/or its contents, and, finally, unintentional landings (crashes) caused by the disruption of the remote signal or incorrect coordinates from human input.

5. Classes of UAVs

UAVs are differentiated in a number of ways, including cost, size, range, and capability. A seemingly endless list of different classifications exists with a limited consensus for any naming conventions. Fahlstrom and Gleason (2012) discuss the different classes of UAVs based on their various sizes. The size classifications range from very small aircraft (the size of a large insect) to large UAVs that are the same size as traditional aircraft (Fahlstrom & Gleason, 2012). Austin (2010) describe UAVs specific to their roles—high altitude, long-endurance (HALE); medium altitude, long-endurance (MALE); tactical UAVs (TUAVs); close range UAVs —as well as by their size—Mini-UAVs (MUAVs) and Micro-UAVs (MAVs). The DOD uses specific naming conventions for its UAVs. According to AFI 16–401(I), this is known as the Mission Designed Series (MDS; U.S. Air Force, 2005). The first alphanumeric position of the naming convention is designated for the vehicle type; the second corresponds to the mission of the vehicle. The third position is not applicable. The fourth position is the design number of the vehicle followed, finally, by the series letter or variant of that vehicle. For example, MQ-1C would translate into vehicle type M (UAV), mission type Q (target drone), design number 1 (first design), and series C (third variant of this aircraft; U.S. Air Force, 2005). Additionally, the DOD classifies UAVs into tiers.

The Marine Corps in particular has four tiers into which UAVs are classified: Tier N/A, consists of Micro UAVs; Tier 1, consists of mini UAVs; Tier II, consists of short-range UAVs; and Tier III, consists of long-range UAVs (Fahlstrom & Gleason, 2012). Austin (2010) and Fahlstrom and Gleason (2012) recommend *The Unmanned Vehicles Handbook: The Concise Global Industry Guide* (Kemp, 2008) as an excellent reference that provides in-depth details of the various unmanned vehicles. For the purpose of this research, micro, mini, very small, and small UAVs are not considered due to their limited range and payload capabilities.

6. Groups of UAVs

According to the brief presented by Dyke Weatherington, deputy director, Unmanned Warfare, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics/Portfolio Systems Acquisition (OUSD[AT&L]/PSA), UAVs are categorized into five specific groups (see Figure 1; C., Seemayer, personal communication, October 12, 2014, p. 5). These groups are determined by the range, size and payload capacity of each vehicle.

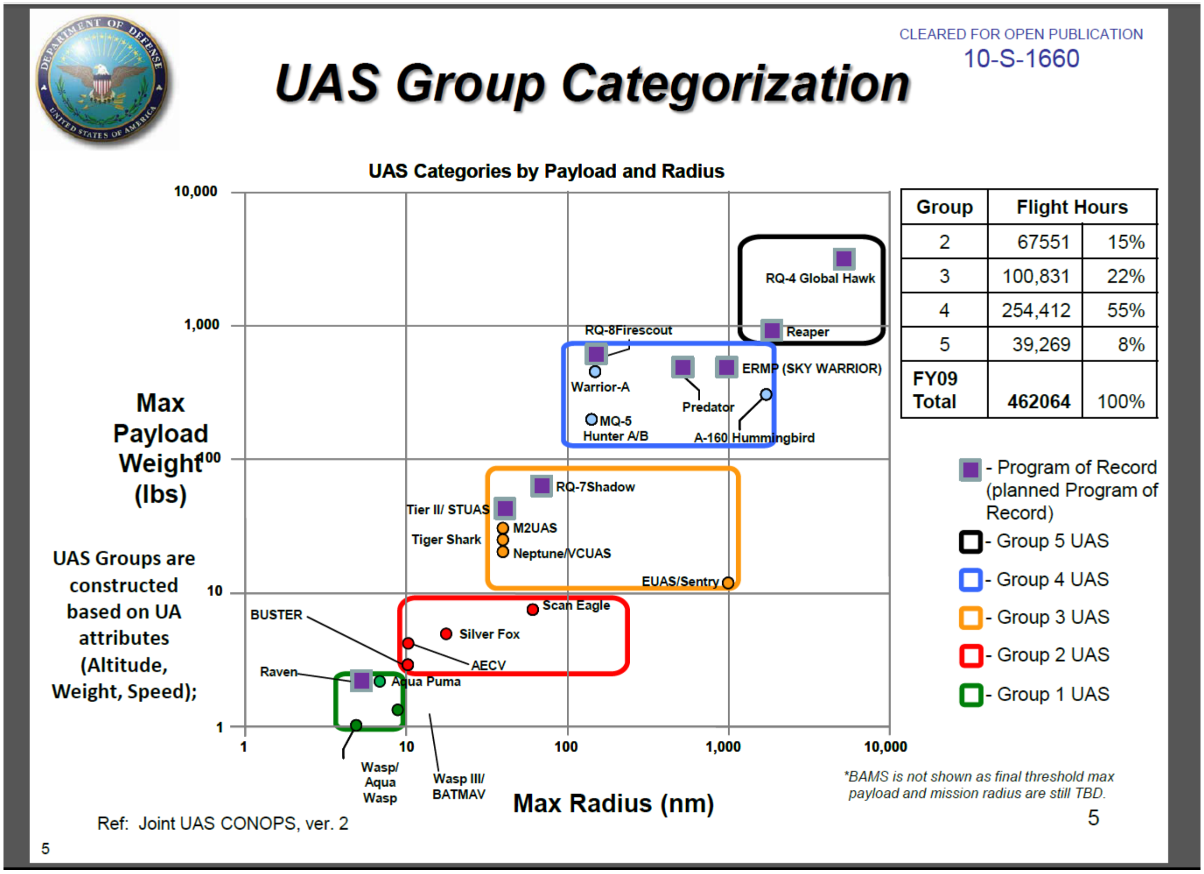


Figure 1. UAS Group Categorization Matrix (from C. Seemayer, personal communication, September 12, 2014, p. 5)

a. Groups 1–3

Groups 1–3 include UAVs known as the Wasp III, the Silver Fox, the Scan Eagle, and the RQ-7 shadow. These aircraft are very small and have a payload capacity that does not exceed 400 lbs. Additionally, these aircraft have a limited range of less than 1000 nautical miles (nm) maximum radius. This group does not meet the minimum characteristics required for this research; therefore, we have not included them in this research.

b. Group 4

Group 4 UAVs, such as the Predator, are larger vehicles and have a payload capacity that exceeds 400 lbs., with a range of over 100 nm maximum radius. Due to their payload capacity, this group was included in our research model.

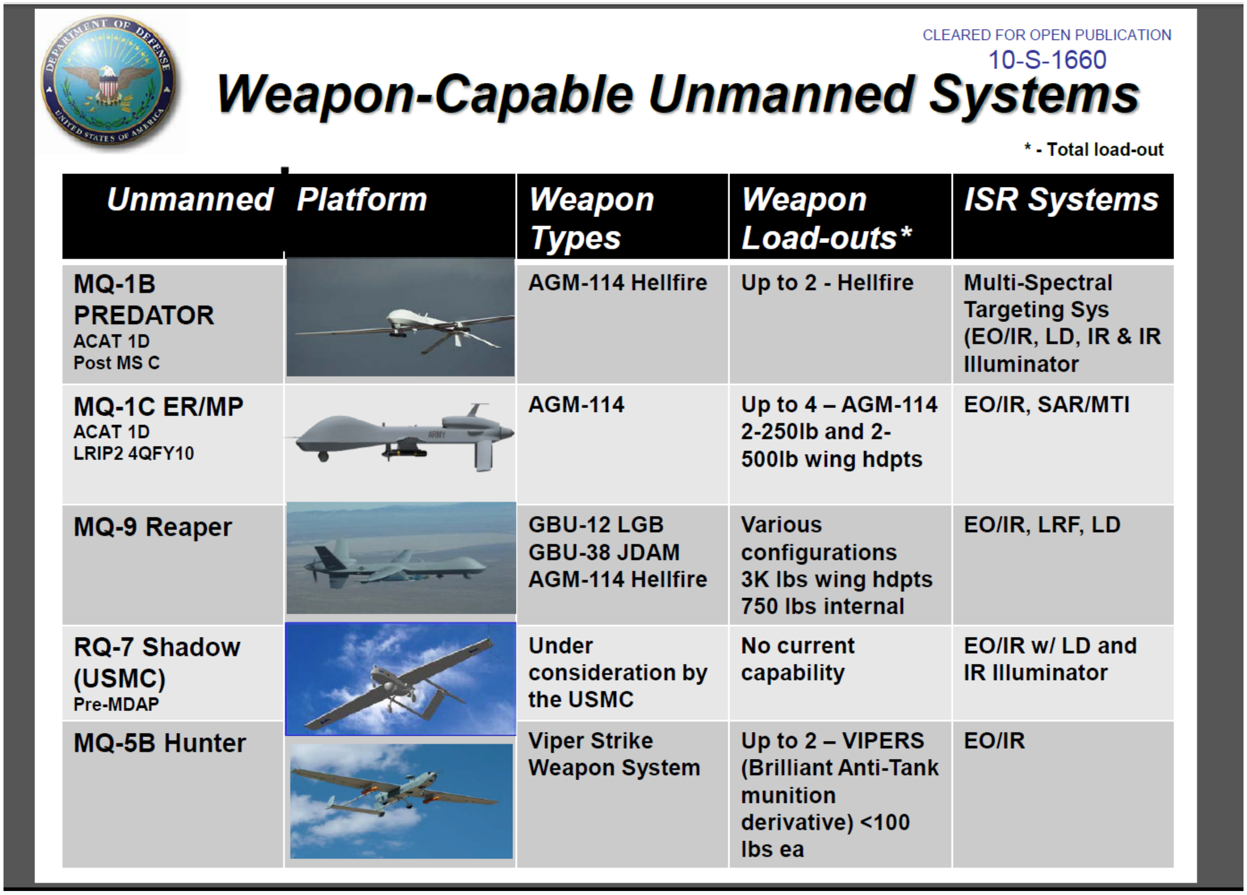
c. Group 5

Group 5 UAVs are the largest classification of vehicles with the largest payload capacities and maximum range. UAVs such as the Reaper and the Global Hawk are categorized as Group 5 UAVs and have a payload capacity of around 1,000 lbs. with a maximum range radius of 1,000 nm and up. Due to its payload capacity and range, this group of UAVs was included in our research model.

7. Variations of UAVs

While there are numerous variations of UAVs, this study is focused on the UAVs currently used in naval aviation. This study focuses on UAVs that have the ability to carry a payload greater than 300 lbs. The logic behind selecting UAVs capable of carrying a payload in this is study is that munitions can be swapped out for blivets (a missile-like container, which allows for the aerodynamics similar to a missile) and can be filled with critical materials. Figure 2 displays a list of UAVs that have a payload capable of carrying munitions.[3]

[3] See Tables 1 and 2 for additional details about all UAVs in this study.



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Weapon-Capable Unmanned Systems

* - Total load-out

Unmanned Platform		Weapon Types	Weapon Load-outs*	ISR Systems
MQ-1B PREDATOR ACAT 1D Post MS C		AGM-114 Hellfire	Up to 2 - Hellfire	Multi-Spectral Targeting Sys (EO/IR, LD, IR & IR Illuminator
MQ-1C ER/MP ACAT 1D LRIP2 4QFY10		AGM-114	Up to 4 – AGM-114 2-250lb and 2-500lb wing hdpts	EO/IR, SAR/MTI
MQ-9 Reaper		GBU-12 LGB GBU-38 JDAM AGM-114 Hellfire	Various configurations 3K lbs wing hdpts 750 lbs internal	EO/IR, LRF, LD
RQ-7 Shadow (USMC) Pre-MDAP		Under consideration by the USMC	No current capability	EO/IR w/ LD and IR Illuminator
MQ-5B Hunter		Viper Strike Weapon System	Up to 2 – VIPERS (Brilliant Anti-Tank munition derivative) <100 lbs ea	EO/IR

Figure 2. Payload Capabilities of UASs Used in this Study: Weapon-Capable Unmanned Systems (from C. Seemayer, personal communication, September 12, 2014, p. 22)

a. MQ-1C Gray Eagle

The DOD defines the mission of the MQ-1C Gray Eagle (see Figure 3) as

A dedicated, assured, multi-mission Unmanned Aircraft System. MQ-1C Gray Eagle provides reconnaissance, surveillance, and target Acquisition; command and control; communications relay; signals intelligence; electronic warfare; attack; detection of weapons of mass destruction; battle damage assessment; and manned-unmanned teaming capabilities. (DOD, 2013a, p. 5)

Figure 3. MQ-1C Gray Eagle (from DOD, 2013a)

b. MQ-4C Triton

The DOD defines the MQ-4C Triton (see Figure 4) mission and description as

> An integrated System of Systems and a force multiplier for the Joint Force and Fleet Commander, enhancing battlespace awareness and shortening the sensor-to-shooter kill chain. The system provides multiple-sensor, persistent maritime and littoral Intelligence, Surveillance and Reconnaissance data collection and dissemination as well as an airborne communications relay capability. The mission sensors installed on the MQ-4C Triton provide 360 degree radar and Electro-Optical/Infrared coverage. Additional functionality that optimizes the system for maritime search operations includes an Automatic Identification System and an Electronic Support Measures with Specific Emitter Identification. The MQ-4C Triton is a tactical, land-based, forward deployed platform. (DOD 2013b, p. 5)

Figure 4. MQ-4C Triton, Formerly Known as BAMS UAS (from Naval Air Systems Command, 2014d)

c. MQ-8

The MQ-8 UAV is a helicopter-style UAV (See Figures 5 and 6). Its mission is described as "a system designed to provide reconnaissance, situational awareness, and precision targeting support for ground, air and sea forces" (Naval Air Systems Command, 2014e). Figure 7 details the differences in these two UAVs.

Figure 5. MQ-8B Fire Scout (from Naval Air Systems Command, 2014e)

Figure 6. MQ-8C Fire Scout (from Naval Air Systems Command, 2014f)

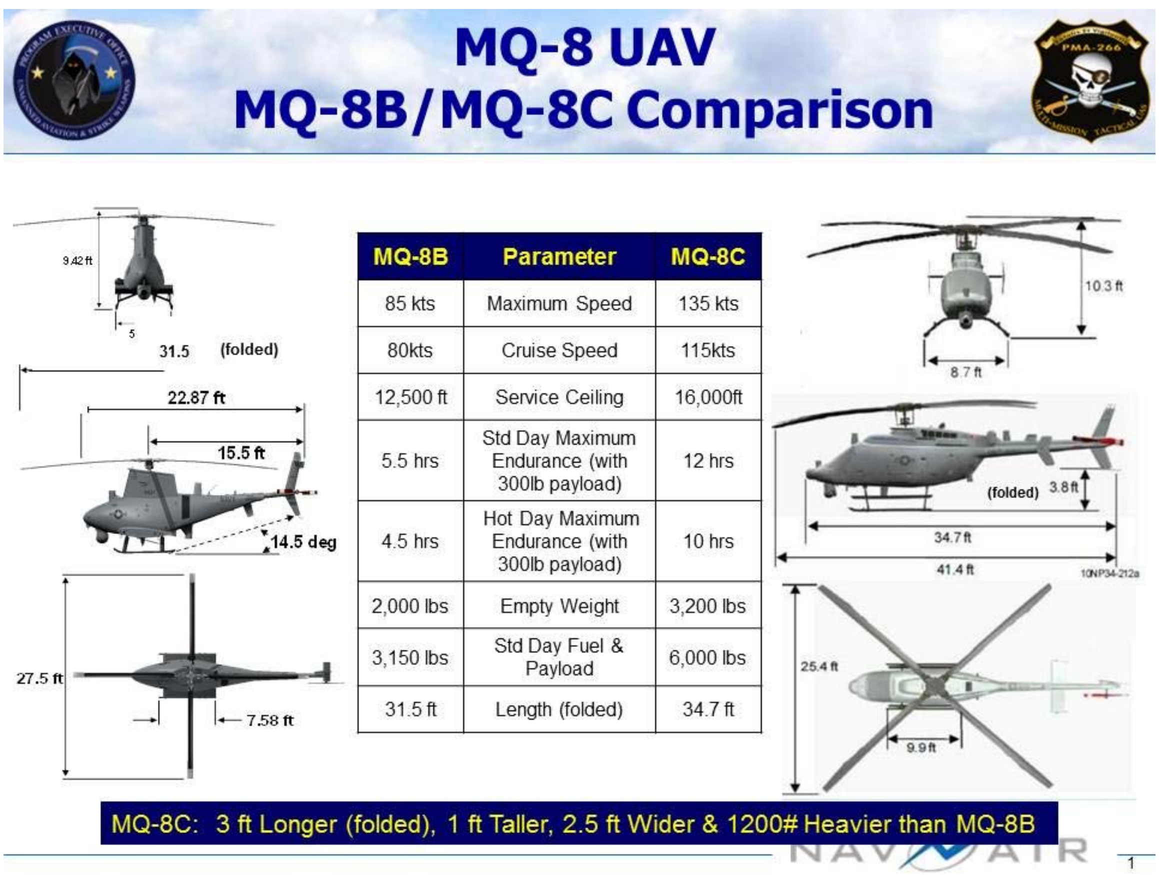

Figure 7. Side-by-Side Capabilities and Nomenclature Comparison between the MQ-8B and MQ-8C Fire Scout (from Naval Air Systems Command, 2014e)

d. MQ-9 Reaper

The DOD defines the MQ-9 Reaper's (see Figure 8) mission as follows:

> The MQ-9 Reaper Unmanned Aircraft System (MQ-9 Reaper) is a multi-mission Hunter-Killer and Intelligence, Surveillance and Reconnaissance (ISR) system, which provides a persistent capability to find, fix, track, target, engage and assess Time Sensitive Targets. The MQ-9 Reaper offers the commander a choice of weapons including the Hellfire Air-to-Ground Missile, Laser Guided Bombs and Joint Direct Attack Munitions. The MQ-9 Reaper's ability to fly for up to 14 hours at altitudes up to 25,000–30,000 feet while carrying up to 3,000 pounds on the wings. (DOD, 2014a p. 5)

Figure 8. MQ-9 Reaper (from DOD, 2014a)

e. RQ-4 Global Hawk

The DOD (2014c) defines the RQ-4 Global hawk mission and description as follows:

The RQ-4A/B Global Hawk Unmanned Aircraft System (RQ-4A/B Global Hawk) is a high altitude, long endurance Unmanned Aircraft System (UAS) with an integrated sensor suite and ground segment that provides Intelligence, Surveillance, and Reconnaissance (ISR) capabilities. The system provides high-resolution, high quality, digital Synthetic Aperture Radar (SAR) to include Ground Moving Target Indicator, plus Electro-Optical (EO), and medium wave Infrared (IR) imagery of targets and other critical areas of interest. (p. 5)

Figure 9. RQ-4A Global Hawk (from DOD, 2014c)

f. K-MAX

The Kaman-1200, or K-MAX (see Figure 10), is a cargo unmanned aerial vehicle (CUAV) developed by Kaman Aerospace Corporation in partnership with Lockheed Martin Corporation (Lockheed Martin, 2010). This vehicle was used in Operation Enduring Freedom as an alternative for resupplying Marine ground forces in Afghanistan and is capable of carrying a payload of 3,000 lbs. (Peterson & Staley, 2011). Lockheed Martin describes its missions as "battlefield cargo resupply for the military" (Lockheed Martin, 2010, p. 2).

Figure 10. K-MAX Cargo UAV (from Lockheed Martin, 2010)

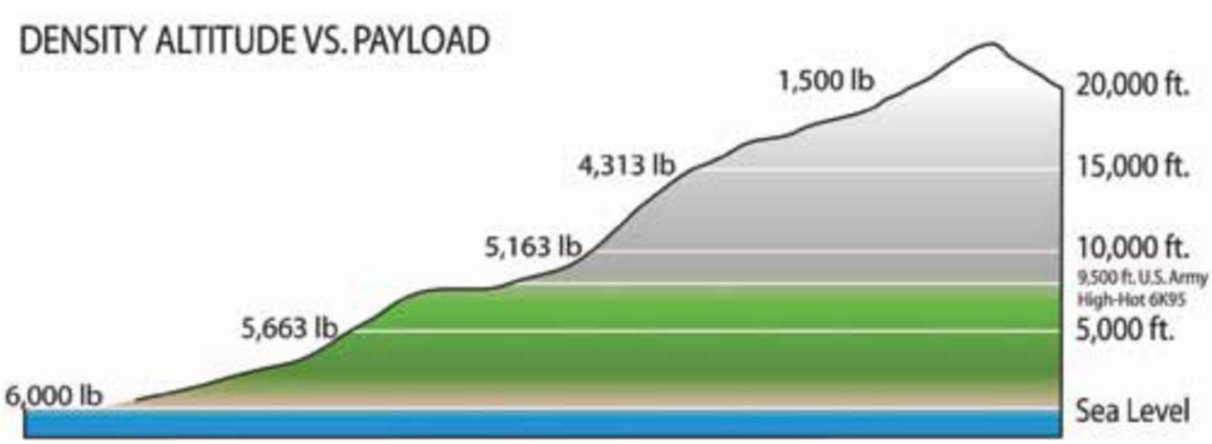

Figure 11. K-MAX Payload Capacity (from Lockheed Martin, 2010)

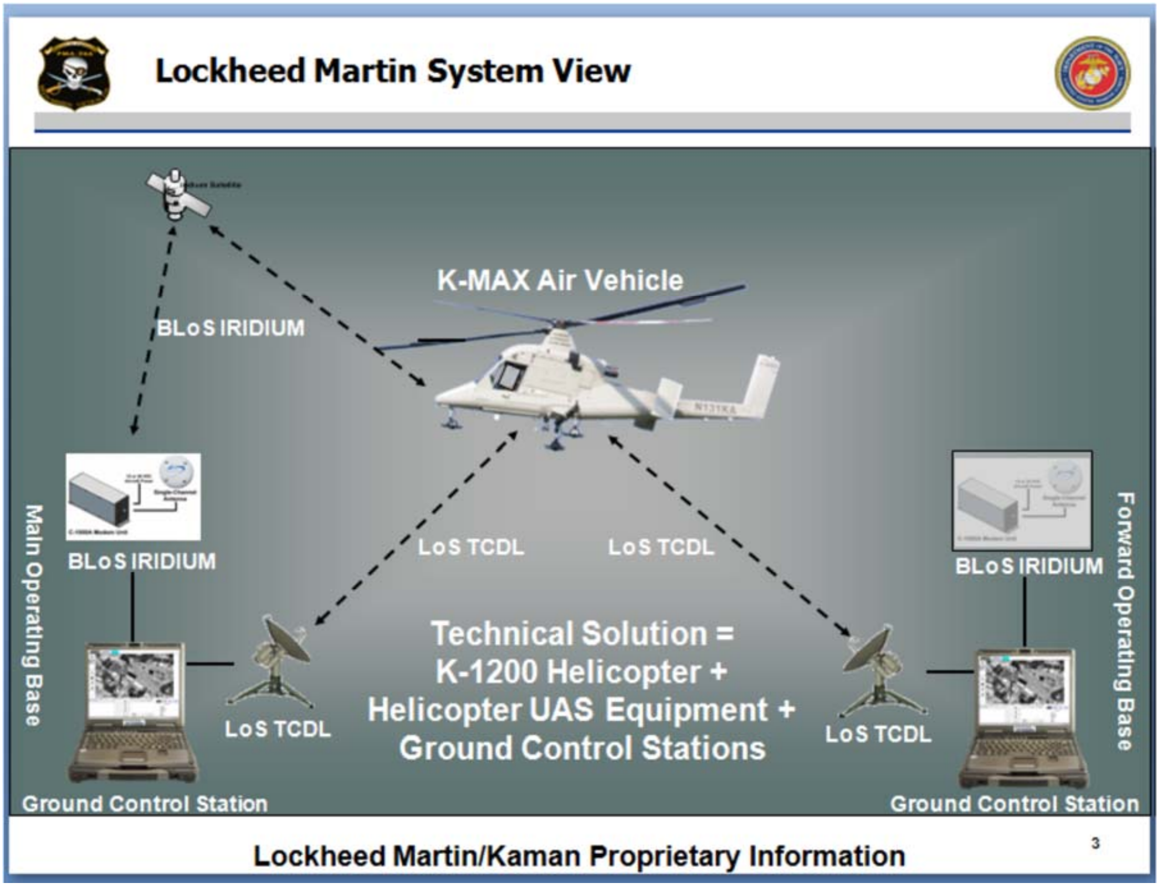

Figure 12. K-MAX Operational System View (from Peterson & Staley, 2011)

g. OTHER

Unmanned Combat Air Systems (UCAS) Aircraft Carrier Demonstration (UCAS-D; also known as the X-47B) is a UAV currently under development. Its roles and capabilities are still being defined; however, the Naval Air Systems Command currently states the mission as follows:

> The mission of the Navy Unmanned Combat Air System (UCAS) Aircraft Carrier Demonstration (UCAS-D) is to mature technologies for a carrier (CV) suitable unmanned air system (UAS), while reducing risk for UAS carrier integration and developing the critical data necessary to support potential follow-on acquisition programs. (Naval Air Systems Command, 2014g, p. 1)

Figure 13. Unmanned Combat Air System (UCAS) Aircraft Carrier Demonstration (from UCAS-D; from Naval Air Systems Command, 2014g)

C. TRADITIONAL RESOURCES

The Marine Corps traditionally uses three types of aircraft (known as type model series, or TMS) that are organic to the Marine Corps force structure in order to conduct the resupply of aircraft material. While other methods such as commercial vendors and ground support vehicles are also used, this cost analysis focuses on the KC-130J Super Hercules, the CH-53E Super Stallion, and the MV-22 Osprey. The basis of the cost analysis is derived from the Flight Hour Program developed from the Department of the Navy Comptroller's office. This program is covered more thoroughly in Chapter III, Methodology.[4]

[4] See Tables 1 and 2 for additional details about all traditional aircraft in this study.

1. KC-130J Super Hercules

The KC-130, developed by Lockheed Martin, is a Viet Nam-era aircraft dating back to 1962 and was designed for the U.S. Marine Corps to provide air-to-air refueling and to transport troops and equipment (Department of the Navy—Naval Historical Center, 2014a). Several variants have since been developed and the newest variant, the KC-130J Super Hercules, takes advantage of technological advances and replaces earlier F and R models of the aircraft (Department of the Navy—Naval Historical Center, 2014a). The KC-130J is a fixed-wing aircraft powered by four Rolls-Royce turbo propellers. Naval Air Systems Command (2012) describes the KC-130J as a "multi-role, medium sized tactical aircraft." The KC-130J continues to provide air-to-air refueling as well as transportation of personnel and material. Lockheed Martin Global Incorporated (2014) reports that the KC-130J has a maximum payload of 42,000 lbs. with a maximum range of 1,841 miles while carrying a payload of 35,000 lbs. Additionally, the KC-130J is capable of reaching maximum speeds of 417 miles per hour while consuming roughly 800 gallons of fuel per hour (Lockheed Martin Global Incorporated, 2014; Peterson & Staley, 2011). The KC-130J has a minimum crew of three: two pilots and a loadmaster (Naval Air Systems Command, 2012).

The mission of the KC-130J, as specified by Naval Air Systems Command (2012), is as a "multi-role, medium-sized fixed-wing tactical aircraft designed to replace the KC-130F/R/T aircraft providing logistic support, air-to-air refueling and close air support to fleet operating forces" (p. 1).

Figure 14. Marine Corps KC-130J Super Hercules (from Naval Air Systems Command, 2012)

2. CH-53E Super Stallion

The CH-53 is the heavy-lift transportation helicopter designed during the Viet Nam era to transport cargo both inside the aircraft (internally) as well as outside the structure of the aircraft (externally; Naval Air Systems Command, 2014a). A secondary role of the CH-53 is as an assault troops transport (Department of the Navy—Naval Historical Center, 2014b). The CH-53 has several different variants that are service and mission specific. The CH-53E Super Stallion was designed for the U.S. Marine Corps because it is a heavy-lift and assault troop transport helicopter, which is well suited to Marine Corps missions (Department of the Navy—Naval Historical Center, 2014b). The CH-53E, a three-engine helicopter, builds on advances from the CH-53D variant, adding power and a refueling capability (Sikorsky Incorporated, 2014).

The CH-53E Super Stallion has an external payload capacity of 17,000 lbs. and can consume fuel at a rate of 573 gallons per hour when traveling at 120 knots (Peterson

& Staley, 2011). In theory, with an ability to refuel in-flight, the CH-53E's range is only limited by the crew's ability to operate the helicopter for an extended period.

Figure 15. CH-53E Super Stallion (from Sikorsky Incorporated, 2014)

3. MV-22 Osprey

The MV-22 Osprey, the Marine variant of the V-22 Osprey, is one of the Marine Corps' newest and most unique aircraft. More details are required to fully understand its mission and capabilities than for the aircraft described previously in this report. According to Gertler (2011), the Osprey is a tilt-rotor aircraft that is capable of a vertical takeoff and landing (VTOL) with the ability to also fly like a traditional propeller plane. The V-22's two engines, known as nacelles, rotate upward 90 degrees, simulating the rotor head on a helicopter and thus allowing for the VTOL capability (Gertler, 2011). With the nacelles forward, simulating propellers on a plane, the engines provide the aircraft the speed, the lift, and the range of a modern two-propeller plane (Gertler, 2011).

The development of the V-22 Osprey stems from the joint forces' need for an aircraft with an increased payload and added range and speed. Additionally, the Marine Corps specifically needed to replace its aging fleet of CH-46 Sea Knight medium-lift helicopters from the Viet Nam War, and also needed to add capability to the Air Combat Element (ACE) of the Marine Corps' Marine Air and Ground Task Force (MAGTF). Lieutenant General (LtGen) Frederick McCorkle (2000), in his article "Transforming Marine Aviation," notes that the Marine Corps needed "increased synergy among the elements of the … MAGTF … if we are to remain the Nation's force of choice" (p. 24). The capabilities of this new tilt-rotor aircraft ensure this synergy while allowing the ACE to increase the Corps' "rapid response" and operational depth or "reach" while maintaining a "credible source [that] provides the flexibility to respond to unanticipated events and adds to the safety and security of the force" (pp. 24–25). LtGen McCorkle (2000) continues, stating that the Marine Corps variant of the V-22 Osprey—known as the MV-22—"will make the Osprey the aircraft that defines the commander's area of influence as it relates to placing Marines on the ground" (p. 25).

Naval Air Systems Command (2014b) describes the separate missions of the MV-22 and the CV-22 as follows: "The MV-22 Osprey's mission for the U.S. Marine Corps is the transportation of troops, equipment, and supplies from ships and land bases for combat assault and assault support."

The Osprey's two main requirements are that it is able to conduct vertical/short takeoffs and vertical landings (VSTOL) and produce an increase in the aircraft's range and speed (also known as aircraft flight envelope). With the nacelles forward, the flight envelope (see Table 13 in the Appendix) of such an aircraft is nearly double that of a traditional helicopter (Trask, 1996). Additionally, program requirements detailed in Selected Acquisition Report (SAR) RCS: DD-A&T (Q&A) 823–212 include the V-22's ability to fly 2,100 miles on a single tank of fuel, a refueling capability, and the ability to lift 15,000 lbs. externally (DOD, 2014b). (See Table 1 for additional characteristics of the MV-22.) The MV-22 has a minimum crew of three: two pilots and a loadmaster (Naval Air Systems Command, 2014b).

Figure 16. MV-22 Osprey (from Naval Air Systems Command, 2014b)

D. PREVIOUS STUDIES

There has been a considerable amount of research conducted on the proliferation of UAVs as an emerging technology. More work is being conducted, updated, and refined, and new innovations are waiting to come to fruition. The purpose of this section is to review the previous cost-based analyses that have been conducted on UAVs, as well as to review traditional aviation resources used to fill logistical gaps in the supply chain. Additionally, this thesis seeks to advance previous research by addressing areas that were not covered in the past. Using these analyses provides a greater understanding of current logistical resources and capabilities and also the DOD's potential to benefit from the use of UAVs to fill logistical gaps within the supply chain that are currently being filled by resources that are organic to Marine aviation.

1. Unmanned Aircraft in Support of Operation Enduring Freedom

Peterson and Staley (2011), in their MBA professional report *Business Case Analysis of Cargo Unmanned Aircraft System (UAS) Capability in Support of Forward Deployed Logistics in Operation Enduring Freedom (OEF)*, conducted an analysis very similar to the focus of this study. In their study, they focused on a specific UAV, the K-MAX, as an alternative to both ground convoys and Marine aviation assets using a cost–benefit methodology.

What differs in the Peterson and Staley (2011) study is that it wisely focused on one platform to analyze. Focusing on a single aircraft allowed the authors to provide a highly detailed background of the K-MAX from its acquisition phases to its deployment in OEF. Peterson and Staley's (2011) report provides a detailed description of the K-MAX.

As discussed earlier, Peterson and Staley's (2011) analysis of aviation assets producing a higher benefit than ground resources is an excellent resource for any researchers conducting studies that will compare air assets to ground assets. The modus operandi of terrorist groups in Iraq and Afghanistan to disrupt ground convoys with improvised explosive devices (IEDs) provides the basis for ground forces moving away from large movements of slow-moving, heavily armored ground vehicles and toward air assets providing equivalent support.

Peterson and Staley (2011) experienced similar issues to those of this study, particularly that CUAV technology is still very new and a lot of the data needed to conduct a thorough analysis is still in its infancy. However, they were able to masterfully detail operating and support costs and risk costs. Their analysis of risk of exposure was so detailed that it was used in this study as well.

Peterson and Staley (2011) determined that although ground conveys are capable of moving massive amounts of material, the costs of human life played a major factor in determining whether to use the K-MAX over ground resources (convoys). In fact, they determine that this cost had to be lower than $2 million per death for ground convoys to net a higher cost-benefit than the K-MAX (Peterson & Staley, 2011). Furthermore, Peterson and Staley (2011) conclude that the CH-53E and the KC-130J were both excellent resources to conduct logistical sustainment despite some of the operational restrictions placed on the aircraft in their scenarios. Finally, Peterson and Staley (2011) conclude that the use of K-MAX would not only significantly reduce the loss of life experienced using ground assets, but that it would also significantly reduce the cost of moving material. They support the continued development of the CUAVS program to include the K-MAX as an excellent alternative to other methods of logistics sustainment (Peterson & Staley, 2011).

III. METHODOLOGY

A. INTRODUCTION

The methodology that is used by this thesis to examine which logistic resupply process produces the highest value for the Marine Corps is a cost–based analysis. The purpose of this analysis is to compare the costs of traditional aviation resources—the KC-130J Super Hercules, the CH-53 Super Stallion, and the MV-22 Osprey—which are used to fill the logistical gaps within the supply chain, with that of selected UAVs. The costs are based on what is known as the cost per Flight Hour Program (FHP). Cost data is collected and then calculated by the Naval Air Systems Command and derived from the Department of the Navy, Naval Comptroller's office.

B. COST-BASED ANALYSIS

This study uses the methodological steps of a cost–benefit analysis. However, the benefit comparison between alternatives is negated since these benefits are the same and the goal of logistical resupply/sustainment is to provide end users with material in a cost-effective and timely manner. Therefore, study foregoes any estimation of benefit and focuses only on a cost differential. Within a cost–benefit analysis, this special case analysis is considered a cost-based analysis or a cost-effectiveness analysis. All steps and reasoning that apply to a cost–benefit analysis still apply to this cost-based analysis, except that perceived or actual benefit (already a subjective concept) is not monetized because it is treated equally across alternatives and therefore ignored in the analysis.

The cost–benefit analysis and its special case, the cost-based analysis, is a tool that decision-makers use in determining further procurement opportunities or advancements in like-resources (such as the procurement or replacement of similar aircraft, ground vehicles, or computer systems). In the textbook *Cost-Benefit Analysis: Concepts and Practice*, Boardman, Greenberg, Vining, and Weimer (2006) describe a CBA as "a systematic categorization of impacts as benefits (pros) and costs (cons), valuing in dollars (assigning weights) and the determining the net benefits of the proposal relative to the status quo (net benefit equals benefits minus costs)" (p. 2.). In the case of a cost-based analysis, net costs of alternatives are compared to make a final decision (the benefit here being the method which costs less—*ceteris paribus*). This tool provides the decision-maker with quantifiable outputs to aid in the justification of a key decision. While there are varying types of CBAs, this study is primarily an ex ante CBA, which is focused on the analysis of limited resources to produce public policy that provides the highest net benefit (Boardman et al., 2006). The DOD's 2011 guidebook on business case analysis, *DOD Product Support BCA Guidebook*, describes this process as "a structured methodology and document that aids decision making by identifying and comparing alternatives by examining the mission and business impacts (both financial and non-financial), risks and sensitivities" (Defense Acquisition University, 2011, p. 5). This guidebook goes on to state that the conclusion of a CBA is a "plan to achieve states' organizational objectives and desired outcomes" (Defense Acquisition University, 2011, p. 5). However, it is important to note that this recommendation is absent of any subjectivity on the part of the decision-maker. He or she must use individual judgment in making the final decision; the CBA is simply a tool to help rationalize and quantify costs, risks, and benefits. The guidebook notes, "The Product Support BCA does not replace the judgment of a decision-maker. Rather, it provides an analytic, standardized, and objective foundation upon which credible decisions can be made" (p. 5).

Boardman et al. (2006) delineate the nine stages of a CBA and how these stages provide the systematic analysis that decision-makers need to make well-informed decisions. The steps described by Boardman et al. (2006, p. 7) are as follows:

- Step 1: Decide whose costs count.

This is also known as *standing*. One has standing if his or her interests are impacted or influenced by the study. For this study, the Marine Corps has standing, as do taxpayers, because they provide the revenue for aviation assets (both traditional aircraft and UAVs).

- Step 2: Select the portfolio of alternative projects.

In Step 2, the researcher compares the status quo with an analogous product. In the case of this study, the status quo is traditional logistic sustainment resources. Peterson and Staley (2011) conducted a thorough analysis between ground and Marine aviation assets as a resource to resupply and concluded that the use of aviation assets net a higher benefit (a lower net cost in this case) than the use of ground assets such as the Medium Tactical Vehicle Replacement (MTVR) and the High Mobility Multipurpose Wheeled Vehicle (HMMWV). This analysis therefore forgoes any analysis on ground assets and focuses on the alternative of UAVs, using the same methodology. If traditional resources net a higher net benefit than UAVs, further studies could be conducted to determine the highest net benefit when comparing ground resources and UAVs. If traditional resources do not net a higher net benefit than UAVs, the additional work would be unnecessary.

Additionally, a thorough analysis for each alternative logistical resource must also include an analysis of the monetized value of life. Each time a pilot operates an aircraft; there is an inherent risk that the flight will end in either an accident (human error or mechanical error) or an intentional catastrophic disaster (being shot down purposely).

Finally, several scenarios are used for the comparisons and analysis of aviation resources to augment logistical supply chain shortages. These scenarios are based on the payload and distance required for the delivery of material; the scenarios include lightweight payload requirements for short distances, heavyweight payload requirements with long-distance requirements, and all cases in between. In addition to the nine mission types, additional examples are provided from real missions encountered during the career of this author. These scenarios are described in more detail in Chapter IV, Analysis.

- Step 3: Catalog potential impacts and select measured indicators.

Step 3 requires a thorough analysis of the cause and possible outcomes involved with the study—both positive and negative—and the selection of the indicators that the researcher is going to measure. In this study, money, specifically a cost per hour to operate traditional and UAV aircraft, is the indicator used to determine the method that nets the lowest cost today.

- Step 4: Predict quantitative impacts over the life of the project.

Cost estimation is the process used to identify the quantitative monetary life-cycle cost impacts of each system. For brevity, models consist of 10 years' worth of data.

- Step 5: Monetize all impacts.

Since money is the indicator being measured, there is not a need to monetize other values or convert other impacts into dollar values.

- Step 6: Discount for time to present value.

As part of a CBA, values must have the same meaning. Money in 1965 does not hold the same value as money in 2010 due to inflation. Similarly, Japanese yen and U.S. dollars are not equal. Therefore, a standard must be set so that reported values are all in an equivalent format. This is called *normalization*. In this study, values are normalized based on Operation and Maintenance Navy (O&MN) current fiscal year 2014 dollars (FY14$). The Joint Inflation Calculator, February 2014 edition, from the Naval Center for Cost Analysis is used for these calculations.

- Step 7: Sum—Add up the costs.

Once all indicators have been identified, cataloged, and normalized, a total value is produced and reported.

- Step 8: Perform sensitivity analysis.

To provide additional rigor to this study, sensitivity analysis is conducted. A sensitivity analysis measures changes in the outputs by changing one or more variables. For this study, the variables used to conduct a sensitivity analysis are human life and fuel prices.

- Step 9: Recommend the alternative with the largest cost savings.

This study looks specifically at the logistical support provided to Marine operational flying squadrons who are forward deployed and using traditional aviation resources to provide sustainment of material when logistical shortfalls within the supply chain occur. This study then compares the cost of these traditional resources to that of using UAVs in place of traditional resources. To answer the research questions noted previously, the resulting output in this study is the determination of whether or not UAVs can be used as an equal alternative to traditional resources in providing sustainment, but at a reduced cost.

C. COST DRIVERS

There are two primary cost drivers that determine the estimated costs within the cost-based analysis for the purpose of this study. These costs are the flight operations budget, known as Operational Plan 20 (OP-20), and the costs associated with the loss of human life. Because many of the aircraft in this study are considered emerging technology, life-cycle costs were ignored.

1. The OP-20 and the Flight Hour Program

Walter Glenn and Eric Otten (1995), in their MBA Professional Report *Commander Naval Air Forces (CNAF) Flight Hour Program: Budgeting and Execution Response to the Implementation of the Fleet Response Plan and OP-20 Pricing Model Changes,* focus on how the Navy can better manage the Flight Hour Program tool. They succinctly and successfully examined the FHP in clear and easy-to-understand terms and do a masterful job at presenting the various facets of data used to create the planning document for the FHP known as OP-20. The OP-20 planning document is comprised of several specific funding accounts at the Operation and Support (O&S) level of acquisition. Glenn and Otten (1995) examine this by breaking the funding into two main sections: Aircraft Flight Operations (AFO) and Aircraft Operations Maintenance (AOM).

a. Aircraft Flight Operations Funding

AFO funding (also known as Operation Fund Code [OFC]-01) is further broken down into two main codes of funding: 7B and 7F. Fuel and petroleum, oil and lubricants (POLs) are categorized as fund code 7B (Glenn & Otten, 1995). Flight equipment (flight suits, boots, and other special equipment used by the pilots and crew) are recorded in the 7F fund code (Glenn & Otten, 1995). These charges are reported to the Supply Accounting Division (SAD) of the MALS and then reported to the Wing comptroller on a monthly basis in the Budget Operational Target (OPTAR) Report (BORs). As a 2nd and 1st Lieutenant, the researcher of this study ran and operated the accounting division of the MALS for nearly two years.

b. Aircraft Operations Maintenance Funding

AOM funding (known as OFC-50) is composed of the other O&S costs for each aircraft. OFC-50 is broken down into four additional categories, including repairable material (9S), consumable material (7L), contract costs (FW), and other costs (F0; Glenn & Otten, 1995). Repairable material is referred to as aviation depot level repairable (AVDLR). These items consist of end item material that can be repaired within a MALS or, if beyond the capabilities of a MALS, can be repaired at depot level repairable facilities. An example of an AVDLR would be an aircraft battery, a rotor blade, or a component on the control panel of the flight controls. Items such as engines consist of many AVDLRs as well as many consumable items. Examples of consumable items are washers, bolts, and nuts. Along with these materials are contract costs such as corrosion control contracts that are used to remove and prevent corrosive effects on aircraft. The final component of OFC-50 funding is *other*, which acts as a catch-all for the other costs within the FHP. Examples of other costs would be simulator support, support of air traffic control costs, and funding for temporary assignment of duty (TAD; Glenn & Otten, 1995). Finally, for this research, a cost-of-life calculation is also used to more accurately determine the overall costs of each system in a holistic approach.

Using information from the background section, specific characteristics and capabilities are assessed and compared to determine which aircraft provides the highest net benefit in specific scenarios in which different amounts of supplies are required in various distances away from home bases.

This analysis can produce three separate tools that Marine Corps leadership can use to make informed decisions on the method of logistical resupply that best meets their needs for each scenario provided earlier. These three products are a cost–based analysis, a linear programming model, and a decision tree. A deeper understanding of the cost–benefit analysis and the results of this analysis are in Chapter IV of this thesis.

2. Risk Exposure Costs

Peterson and Staley (2011) conducted comprehensive research on loss of life costs as well as the specific statistical probability of instances resulting in the loss of a life. Peterson and Staley (2011) estimated the loss of a life at $6 million, and they multiplied this by the probability of a loss based on mishap rates, which they obtained from the Navy Safety Center (Peterson & Staley, 2011). Peterson and Staley (2011) established that there should be an additional $619.20 added to the total CH-53E and KC-130J flight hour cost (FY06$). This study also applies the same rate to the MV-22 Osprey as an analogous aircraft. Using Navy O&MN (composite) Operation & Maintenance, Navy cost elements from the Naval Center for Cost Analysis Joint Inflation Calculator, this equates to $738.80 in FY14$.

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IV. COST-BASED ANALYSIS OF UAVS AND TRADITIONAL LOGISTIC RESOURCES

A. INTRODUCTION

The purpose of this chapter is to first analyze the data, including cost drivers, vehicle capabilities, and known distances, by using the methodology described in chapter. III. Then, this chapter presents and discusses the cost-based analysis to determine the preferred method of resupply between traditional methods and UAVs.

B. COST-BASED ANALYSIS

As described in Chapter III, Methodology, this study uses a cost-based analysis in order to provide comparisons of alternatives and to make recommendations based on costs. The steps described by Boardman et al. (2006, p. 7) are presented again, this time with data provided:

- Step 1: Decide whose costs count. The Marine Corps and the American taxpayers are the two groups that have standing in this study—the Marine Corps for both operational and budgetary reasons, and the taxpayers for monetary reasons.

- Step 2: Select the portfolio of alternative projects. This study compared traditional resources—KC-130J, MV-22, and CH-53E—against various UAVs.

- Step 3: Catalog potential impacts and select measured indicators. The impacts for this study were vehicle capabilities and cost drivers. The main capabilities considered were range, speed, and payload. There are two different types of costing for flight hour programs within the DOD budget for aircraft. Chapter II contains a description of maintenance costs, that is, the cost to provide the required maintenance for each hour the aircraft is flown to include fuel costs. Another cost analysis used in this research is total O&S Flight Hour Program costs. These costs are calculated by summing the acquisition costs of a system and then dividing this number by the number of proposed hours of use.

- Step 4: Predict quantitative impacts over the life of the project. The life of the project was not predicted because FHP costs are annual.

- Step 5: Monetize all impacts. All costs are normalized in FY14$.

- Step 6: Discount for time to present value. All costs are normalized in FY14$.

- Step 7: Sum. Add up the costs: Tables 1–10 provide total costs based on distance traveled.

- Step 8: Perform sensitivity analysis. The K-MAX lacks traceable costs at this time via open sources. A high and low estimate was used as a sensitivity analysis.

- Step 9: Recommend the alternative with the lowest cost. Recommendations are provided in Chapter V.

C. DATA

The data provided in this section includes the vehicle capabilities (Table 1), Flight Hour Program (Table 2), and total costs using capabilities and costs for known distances (Tables 3–12).

1. Vehicle Capabilities

Vehicle capabilities were derived from various sources.[5] The key capabilities listed in Table 1 include range, endurance, speed, and payload. The range of the aircraft is a measurement of distance in miles. The endurance of each aircraft is a measurement of time the aircraft is capable of flying in hours. Aircraft speed is a measurement of distance (miles) over time (hours). Finally, payload is the measurement of weight in pounds that the aircraft is able to lift.

[5] See Table 13 for a complete listing of capabilities source data.

Table 1. Nomenclature of Aircraft Used in this Study

AIRCRAFT NOMENCLATURE							
MQ-4C Triton							
Length (ft)	Weight lbs	Airspeed (mph)	Range (miles)	Service Ceiling (ft)	Endurance (hrs)	Payload (lbs)	Contractor
48	32250 lbs.	381	11450	56000	24	6600	Northrop Grumman
MQ-8B Fire Scout							
Length (ft)	Weight lbs	Airspeed (mph)	Range (miles)	Service Ceiling (ft)	Endurance (hrs)	Payload (lbs)	Contractor
31	3150	132	537	20000	4.5	300	Northrop Grumman
MQ-8C Fire Scout							
Length (ft)	Weight lbs	Airspeed (mph)	Range (miles)	Service Ceiling (ft)	Endurance (hrs)	Payload (lbs)	Contractor
35	6000	161	1863	17000	10	700	Northrop Grumman
MQ-9 Reaper							
Length (ft)	Weight lbs	Airspeed (mph)	Range (miles)	Service Ceiling (ft)	Endurance (hrs)	Payload (lbs)	Contractor
36	4900	230	1151	50000	24	3750	General Atomics
K-MAX							
Length (ft)	Weight lbs	Airspeed (mph)	Range (miles)	Service Ceiling (ft)	Endurance (hrs)	Payload (lbs)	Contractor
	6866 lbs	92	246		12 +	6000	Lockheed Martin
RQ-4 Global Hawk							
Length (ft)	Weight lbs	Airspeed (mph)	Range (miles)	Service Ceiling (ft)	Endurance (hrs)	Payload (lbs)	Contractor
48	25250	357	14155	60000 ft.	32 +	3000	Northrop Grumman
Unmanned Combat Air System (UCAS) Aircraft Carrier Demonstration (UCAS-D)							
Length (ft)	Weight lbs	Airspeed (mph)	Range (miles)	Service Ceiling (ft)	Endurance (hrs)	Payload (lbs)	Contractor
38	44000	> 660	2416.638	40000		4500	Northrop Grumman
KC-130J Super Hercules							
Length (ft)	Weight lbs	Airspeed (mph)	Range (miles)	Service Ceiling (ft)	Endurance (hrs)	Payload (lbs)	Contractor
98	175000	311	4083	28000 ft.	N/A	44000 lbs.	Lockheed Martin
CH-53 Super Stallion							
Length (ft)	Weight lbs	Airspeed (mph)	Range (miles)	Service Ceiling (ft)	Endurance (hrs)	Payload (lbs)	Contractor
99	73500	173	621	10000 ft.	N/A	30000 lbs.	Sikorsky Aircraft
MV-22 Osprey							
Length (ft)	Weight lbs	Airspeed (mph)	Range (miles)	Service Ceiling (ft)	Endurance (hrs)	Payload (lbs)	Contractor
63	52600	322	990	25000 ft.	N/A	20000 lbs.	Bell-Boeing

Note. See Tables 13 and 14 in the Appendix for the sources used to collect data for this table.

2. Flight Hour Program

Flight Hour Program costs on each vehicle was estimated based on in-depth research of various open sources, DOD sources, and personal communications.[6] Flight hour costs do not include a full year's worth of data, and estimates were used in cases where data was limited or unavailable.[7,8] MQ-8C costs are estimated by taking the ratio between the MQ-8B and MQ-8C based on the Program Objective Memorandum (POM) FY17 FHP Baseline estimate and using current flight hour cost for RQ-8B (537 hours). Maintenance costs for AVDLR and consumables are approximately 7% higher for the MQ-8C over the MQ-8B ($1803 / $1943). Also, fuel is ~29% higher due to consumption (25 gallons consumed per hour for the MQ-8B vs 35gallons of fuel consumed per hour for the MQ-8C (L. Nabasny, personal communication, October 29, 2014). The Global Hawk also has limited cost data available; the estimate in Table 2 is derived from total O&S costs, where

Costs per flight hour = total procurement costs of each aircraft divided by projected hours to be flown

(C. Carlin personal communication, October 20, 2014).

The loss of life calculation was taken from Peterson & Staley (2011) and is estimated in FY14$ as shown in Table 2.

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[6] See Table 14 for data sources.

[7] Costs are based on data current as of August 2014. This only includes 11 months' worth of data, and only March–August FY14 for the MQ-8B Fire Scout. Additionally, these costs only include AVDLR, AFM, and Fuel costs.

[8] MQ-8B figures are based on RQ-8B actuals from March–August FY14. Global Hawk costs are total O&S costs, not maintenance costs. Limited data is available for the K-MAX. Estimated FHP costs were based on a high and low estimate from Larkin, Heffern, & Swan (2013).

Table 2. Cost per Flight Hour for Each Vehicle Used in this Study

Costs per Flight Hour					
TMS	7B Fuel	9S FA/DLR	7L AFM	Loss of Life Calculations	Total Cost Per FH
KC-130J	$2,971.54	$477.87	$470.17	$738.80	$4,658.39
MV-22	$1,844.23	$4,326.04	$2,225.61	$738.80	$9,134.68
CH53E	$1,551.80	$7,321.43	$2,269.19	$738.80	$11,881.22
K-MAX (1)	N/A	N/A	N/A	$0.00	$3,000.00
K-MAX (2)	N/A	N/A	N/A	$0.00	$9,000.00
RQ-4 Global Hawk	N/A	N/A	N/A	$0.00	$24,123.00
MQ-9 Reaper	N/A	N/A	N/A	$0.00	$2,617.00
MQ-8B Fire Scout	$90.96	$1,651.91	$823.62	$0.00	$2,566.49
MQ-8C Fire Scout	$116.95	$1,770.94	$882.96	$0.00	$2,770.85
MQ-4C Triton	N/A	N/A	N/A	$0.00	$6,319.81

Note. See Table 14 in the Appendix for the sources used to collect data for this table.

3. Cost-Based Analysis

By using Flight Hour Program data in conjunction with vehicle capabilities assessments and various known distances, the following tables (Tables 3–12) show the cost to fly each TMS by distance.[9] Since flight time plays a significant factor in determined cost per hour, speed played a vital role in the total cost to fly each TMS by its respected known distance.

As shown in Table 3, for known distances of 25 miles, with its max speed of 230 mph and a flight hour cost of $2,617 (FY14$), the MQ-9 Reaper was the least costly aircraft followed by the KC-130J which has a speed of 311 mph at a cost of $4658.39 (FY14$) per flight hour.

Table 3. Cost-Based Analysis for Known Distance of 25 Miles

25 Miles					
TMS	Total Costs Per Hour	Flying Time (hrs)	Max payload capacity (lbs)	Max Range (miles)	Cost (FY14$)
MQ-9 Reaper	$2,617.00	0.11	1151	3750	$284.26
KC-130J	$4,658.39	0.08	44000	4083	$374.82
MQ-4C Triton	$6,319.81	0.07	6600	11450	$414.79
MQ-8C Fire Scout	$2,770.85	0.16	1863	700	$429.96
MQ-8B Fire Scout	$2,566.49	0.19	537	300	$484.83
MV-22	$9,134.68	0.08	20000	990	$708.73
K-MAX (1)	$3,000.00	0.27	246	6000	$814.66
RQ-4 Global Hawk	$24,123.00	0.07	3000	14155	$1,690.51
CH53E	$11,881.22	0.14	621	30000	$1,720.75
K-MAX (2)	$9,000.00	0.27	246	6000	$2,443.99

[9] Distances that are outside the capable range of that particular system would require re-fuel and possible crew change. Additional costs were not considered.

As shown in Table 4, for known distances of 50 miles, with its max speed of 230 mph and a flight hour cost of $2,617 (FY14$), the MQ-9 Reaper was the least costly aircraft followed by the KC-130J which has a speed of 311 mph at a cost of $4658.39 (FY14$) per flight hour.

Table 4. Cost-Based Analysis for Known Distance of 50 Miles

50 Miles					
TMS	Total Costs Per Hour	Flying Time (hrs)	Max payload capacity (lbs)	Max Range (miles)	Cost (FY14$)
MQ-9 Reaper	$2,617.00	0.22	1151	3750	$568.53
KC-130J	$4,658.39	0.16	44000	4083	$749.63
MQ-4C Triton	$6,319.81	0.13	6600	11450	$829.57
MQ-8C Fire Scout	$2,770.85	0.31	1863	700	$859.93
MQ-8B Fire Scout	$2,566.49	0.38	537	300	$969.66
MV-22	$9,134.68	0.16	20000	990	$1,417.47
K-MAX (1)	$3,000.00	0.54	246	6000	$1,629.33
RQ-4 Global Hawk	$24,123.00	0.14	3000	14155	$3,381.02
CH53E	$11,881.22	0.29	621	30000	$3,441.50
K-MAX (2)	$9,000.00	0.54	246	6000	$4,887.99

As shown in Table 5, for known distances of 100 miles, with its max speed of 230 mph and a flight hour cost of $2,617 (FY14$), the MQ-9 Reaper was the least costly aircraft followed by the KC-130J which has a speed of 311 mph at a cost of $4658.39 (FY14$) per flight hour.

Table 5. Cost-Based Analysis for Known Distance of 100 Miles

100 Miles					
TMS	Total Costs Per Hour	Flying Time (hrs)	Max payload capacity (lbs)	Max Range (miles)	Cost (FY14$)
MQ-9 Reaper	$2,617.00	0.43	1151	3750	$1,137.05
KC-130J	$4,658.39	0.32	44000	4083	$1,499.27
MQ-4C Triton	$6,319.81	0.26	6600	11450	$1,659.14
MQ-8C Fire Scout	$2,770.85	0.62	1863	700	$1,719.86
MQ-8B Fire Scout	$2,566.49	0.76	537	300	$1,939.32
MV-22	$9,134.68	0.31	20000	990	$2,834.94
K-MAX (1)	$3,000.00	1.09	246	6000	$3,258.66
RQ-4 Global Hawk	$24,123.00	0.28	3000	14155	$6,762.03
CH53E	$11,881.22	0.58	621	30000	$6,883.00
K-MAX (2)	$9,000.00	1.09	246	6000	$9,775.98

As shown in Table 6, for known distances of 250 miles, with its max speed of 230 mph and a flight hour cost of $2,617 (FY14$), the MQ-9 Reaper was the least costly aircraft followed by the KC-130J which has a speed of 311 mph at a cost of $4658.39 (FY14$) per flight hour.

Table 6. Cost-Based Analysis for Known Distance of 250 Miles

250 Miles					
TMS	Total Costs Per Hour	Flying Time (hrs)	Max payload capacity (lbs)	Max Range (miles)	Cost (FY14$)
MQ-9 Reaper	$2,617.00	1.09	1151	3750	$2,842.64
KC-130J	$4,658.39	0.80	44000	4083	$3,748.17
MQ-4C Triton	$6,319.81	0.66	6600	11450	$4,147.86
MQ-8C Fire Scout	$2,770.85	1.55	1863	700	$4,299.64
MQ-8B Fire Scout	$2,566.49	1.89	537	300	$4,848.30
MV-22	$9,134.68	0.78	20000	990	$7,087.34
K-MAX (1)	$3,000.00	2.72	246	6000	$8,146.65
RQ-4 Global Hawk	$24,123.00	0.70	3000	14155	$16,905.08
CH53E	$11,881.22	1.45	621	30000	$17,207.49
K-MAX (2)	$9,000.00	2.72	246	6000	$24,439.95

As shown in Table 7, for known distances of 500 miles, with its max speed of 230 mph and a flight hour cost of $2,617 (FY14$), the MQ-9 Reaper was the least costly aircraft followed by the KC-130J which has a speed of 311 mph at a cost of $4658.39 (FY14$) per flight hour.

Table 7. Cost-Based Analysis for Known Distance of 500 Miles

500 Miles					
TMS	Total Costs Per Hour	Flying Time (hrs)	Max payload capacity (lbs)	Max Range (miles)	Cost (FY14$)
MQ-9 Reaper	$2,617.00	2.17	1151	3750	$5,685.27
KC-130J	$4,658.39	1.61	44000	4083	$7,496.35
MQ-4C Triton	$6,319.81	1.31	6600	11450	$8,295.71
MQ-8C Fire Scout	$2,770.85	3.10	1863	700	$8,599.29
MQ-8B Fire Scout	$2,566.49	3.78	537	300	$9,696.60
MV-22	$9,134.68	1.55	20000	990	$14,174.68
K-MAX (1)	$3,000.00	5.43	246	6000	$16,293.30
RQ-4 Global Hawk	$24,123.00	1.40	3000	14155	$33,810.17
CH53E	$11,881.22	2.90	621	30000	$34,414.98
K-MAX (2)	$9,000.00	5.43	246	6000	$48,879.89

As shown in Table 8, for known distances of 1,000 miles, with its max speed of 230 mph and a flight hour cost of $2,617 (FY14$), the MQ-9 Reaper was the least costly aircraft followed by the KC-130J which has a speed of 311 mph at a cost of $4658.39 (FY14$) per flight hour.

Table 8. Cost-Based Analysis for Known Distance of 1,000 Miles

1000 Miles					
TMS	Total Costs Per Hour	Flying Time (hrs)	Max payload capacity (lbs)	Max Range (miles)	Cost (FY14$)
MQ-9 Reaper	$2,617.00	4.34	1151	3750	$11,370.55
KC-130J	$4,658.39	3.22	44000	4083	$14,992.69
MQ-4C Triton	$6,319.81	2.63	6600	11450	$16,591.42
MQ-8C Fire Scout	$2,770.85	6.21	1863	700	$17,198.58
MQ-8B Fire Scout	$2,566.49	7.56	537	300	$19,393.20
MV-22	$9,134.68	3.10	20000	990	$28,349.35
K-MAX (1)	$3,000.00	10.86	246	6000	$32,586.59
RQ-4 Global Hawk	$24,123.00	2.80	3000	14155	$67,620.33
CH53E	$11,881.22	5.79	621	30000	$68,829.96
K-MAX (2)	$9,000.00	10.86	246	6000	$97,759.78

As shown in Table 9, for known distances of 2,500 miles, with its max speed of 230 mph and a flight hour cost of $2,617 (FY14$), the MQ-9 Reaper was the least costly aircraft followed by the KC-130J which has a speed of 311 mph at a cost of $4658.39 (FY14$) per flight hour.

Table 9. Cost-Based Analysis for Known Distance of 2,500 Miles

2500 Miles					
TMS	Total Costs Per Hour	Flying Time (hrs)	Max payload capacity (lbs)	Max Range (miles)	Cost (FY14$)
MQ-9 Reaper	$2,617.00	10.86	1151	3750	$28,426.37
KC-130J	$4,658.39	8.05	44000	4083	$37,481.73
MQ-4C Triton	$6,319.81	6.56	6600	11450	$41,478.55
MQ-8C Fire Scout	$2,770.85	15.52	1863	700	$42,996.45
MQ-8B Fire Scout	$2,566.49	18.89	537	300	$48,482.99
MV-22	$9,134.68	7.76	20000	990	$70,873.38
K-MAX (1)	$3,000.00	27.16	246	6000	$81,466.48
RQ-4 Global Hawk	$24,123.00	7.01	3000	14155	$169,050.84
CH53E	$11,881.22	14.48	621	30000	$172,074.90
K-MAX (2)	$9,000.00	27.16	246	6000	$244,399.45

As shown in Table 10, for known distances of 5,000 miles, with its max speed of 230 mph and a flight hour cost of $2,617 (FY14$), the MQ-9 Reaper was the least costly aircraft followed by the KC-130J which has a speed of 311 mph at a cost of $4658.39 (FY14$) per flight hour.

Table 10. Cost-Based Analysis for Known Distance of 5,000 Miles

5000 Miles					
TMS	Total Costs Per Hour	Flying Time (hrs)	Max payload capacity (lbs)	Max Range (miles)	Cost (FY14$)
MQ-9 Reaper	$2,617.00	21.72	1151	3750	$56,852.74
KC-130J	$4,658.39	16.09	44000	4083	$74,963.47
MQ-4C Triton	$6,319.81	13.13	6600	11450	$82,957.11
MQ-8C Fire Scout	$2,770.85	31.03	1863	700	$85,992.89
MQ-8B Fire Scout	$2,566.49	37.78	537	300	$96,965.99
MV-22	$9,134.68	15.52	20000	990	$141,746.75
K-MAX (1)	$3,000.00	54.31	246	6000	$162,932.97
RQ-4 Global Hawk	$24,123.00	14.02	3000	14155	$338,101.67
CH53E	$11,881.22	28.97	621	30000	$344,149.80
K-MAX (2)	$9,000.00	54.31	246	6000	$488,798.90

As shown in Table 11, for known distances of 10,000 miles, with its max speed of 230 mph and a flight hour cost of $2,617 (FY14$), the MQ-9 Reaper was the least costly aircraft followed by the KC-130J which has a speed of 311 mph at a cost of $4658.39 (FY14$) per flight hour.

Table 11. Cost-Based Analysis for Known Distance of 10,000 Miles

10000 Miles					
TMS	Total Costs Per Hour	Flying Time (hrs)	Max payload capacity (lbs)	Max Range (miles)	Cost (FY14$)
MQ-9 Reaper	$2,617.00	43.45	1151	3750	$113,705.49
KC-130J	$4,658.39	32.18	44000	4083	$149,926.93
MQ-4C Triton	$6,319.81	26.25	6600	11450	$165,914.22
MQ-8C Fire Scout	$2,770.85	62.07	1863	700	$171,985.79
MQ-8B Fire Scout	$2,566.49	75.56	537	300	$193,931.98
MV-22	$9,134.68	31.03	20000	990	$283,493.50
K-MAX (1)	$3,000.00	108.62	246	6000	$325,865.93
RQ-4 Global Hawk	$24,123.00	28.03	3000	14155	$676,203.35
CH53E	$11,881.22	57.93	621	30000	$688,299.61
K-MAX (2)	$9,000.00	108.62	246	6000	$977,597.80

As shown in Table 12, for known distances of 15,000 miles, with its max speed of 230 mph and a flight hour cost of $2,617 (FY14$), the MQ-9 Reaper was the least costly aircraft followed by the KC-130J which has a speed of 311 mph at a cost of $4658.39 (FY14$) per flight hour.

Table 12. Cost-Based Analysis for Known Distance of 15,000 Miles

15000 Miles					
TMS	Total Costs Per Hour	Flying Time (hrs)	Max payload capacity (lbs)	Max Range (miles)	Cost (FY14$)
MQ-9 Reaper	$2,617.00	65.17	1151	3750	$170,558.23
KC-130J	$4,658.39	48.28	44000	4083	$224,890.40
MQ-4C Triton	$6,319.81	39.38	6600	11450	$248,871.32
MQ-8C Fire Scout	$2,770.85	93.10	1863	700	$257,978.68
MQ-8B Fire Scout	$2,566.49	113.34	537	300	$290,897.97
MV-22	$9,134.68	46.55	20000	990	$425,240.25
K-MAX (1)	$3,000.00	162.93	246	6000	$488,798.90
RQ-4 Global Hawk	$24,123.00	42.05	3000	14155	$1,014,305.02
CH53E	$11,881.22	86.90	621	30000	$1,032,449.41
K-MAX (2)	$9,000.00	162.93	246	6000	$1,466,396.70

Tables 3–12 provide a snapshot of estimated cost for known distances. While there are limitations to these estimates such as the availability of more accurate actual costs as well as the limited ability of each aircraft to fly the known distances without re-fueling or crew changes, this thesis provides commanders with a tool for the decision making processes concerning the use of UAVS for logistical purposes.

V. CONCLUSION

A. INTRODUCTION

This study conducted a cost-based analysis of logistical resupply resources (UAVs, UASs and traditional logistical resupply resources) in order to provide commanders with decision support for making thorough and well informed policy decisions regarding cost saving strategies in logistical resources.

This thesis aims to address the following research questions: This thesis provided an in-depth and comprehensive analysis of the various aviation resources available to the Marine Corps which can be used to provide the critical material for the sustainment and resupply of forward deployed operational flying squadrons. The aviation resources analyzed in this thesis included both traditional assets, such as the KC-130J Super Hercules, the CH-53E Super Stallion, and the MV-22 Osprey, as well as, various unmanned aerial vehicles.

The research questions addressed in this thesis are stated below:

1. Can the current inventory of UAVs within the Department of the Navy be used to provide logistical sustainment for deployed aviation units?

2. Is it less costly to use UAVs to provide logistical sustainment and replenishment for deployed aviation units than it is to use traditional sources to provide the same logistical sustainment and replenishment?

To address these questions, the thesis performed a cost–based analysis of the available UAVs, UASs, and traditional logistical resupply resources by using regression analysis of commonly used cost data, known as the flight hour program, along with aircraft capabilities in order to produce ideal aircraft to use for logistical operations.

B. SUMMARY OF FINDINGS

Based on the data, information and analysis of this study, there are considerable costs saving provided in the use of UAVs. The K-MAX, with its lower cost estimate, provides a significant saving over the MV-22 and the CH-53E option if the K-MAX's max speed can be increased thus reducing its flight time. There are other possible UAV options such as the Fire Scout and the Reaper but they both lack the payload capability over the K-MAX. The KC-130J is the cheapest option of the three traditional assets. This fact along with its max speed, range and payload capability make the KC-130J an ideal aircraft for large payloads.

C. RECOMMENDATIONS

The environment that existed at the time this study began is very different than the environment we find ourselves in today. By the end of 2013, the United States had ended the war in Iraq and was scheduled to begin to withdraw forces from Afghanistan. There was no publically known kinetic engagement against the Islamic State (ISIL), and the Russian government was not publically engaged with Ukraine. At the time, it seemed that the need for ISR assets (one of the main uses of the UAVs discussed in this study) was decreasing. As the environment described previously began to emerge, it was obvious that the ISR requirements would continue to be critical resources, once again straining the limited resources of the UAV community. Re-tasking UAVs conducting ISR roles to deliver aviation material no longer seems logical. Conducting such logistics roles would only be feasible if an abundance of UAV resources were available, and not desperately needed to conduct ISR or targeting roles. However, the data presented in this report shows that UAVs can provide cost savings to the DOD and that pilot programs should be established and monitored in order to determine future decisions for cargo UAVs. Similar to the Petersen and Staley (2011) study, the K-MAX and other CUAVs seem to provide a significant advantage to using ground assets and heavily tasked traditional Marine aviation assets.

D. AREAS FOR FURTHER RESEARCH

UAVs are still an emerging technology despite their proliferation. Because of this, much of the data that was needed to produce a more definitive analysis was simply not available. The Marine Corps has just now started capturing cost data for UAVs and the Marine Corps analysis on these costs are still in its infancy. Once the Marine Corps has more established cost data for UAVs, much like it does for the traditional aircraft, another study should be conducted.

In additional to a lack of cost data, the DOD (and the world) has yet to see the full potential of UAVs. Again, this is an emerging technology and it is advancing more quickly than individuals are able to react. As advances in these systems continue to come to fruition, research should be conducted on the newest advances and their impacts.

At this time, regulations are also limited because technology moves faster than regulators can establish rules and regulations. Any future research should consider both these advances and the rules regulating the use of UAVs.

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APPENDIX. DATA SOURCES

Table 13. Vehicle Capabilities Data Sources

Vehicle	Data Source
MQ-4C Triton	Northrop Grumman Systems Corporation, 2014a, Triton; Naval Air Systems Command, 2014d, MQ-4C Triton; Department of Defense (DOD), 2013b, MQ-4C Triton
MQ-8B Fire Scout	Northrop Grumman Systems Corporation, n.d., MQ-8B Firescout; Naval Air Systems Command, 2014e, MQ-8B Fire Scout
MQ-8C Fire Scout	Northrop Grumman Systems Corporation, n.d., MQ-8C Firescout; Naval Air Systems Command, 2014f, MQ-8C Fire Scout.
MQ-9 Reaper	United States Air Force, 2010, MQ-9 Reaper; Department of Defense (DOD), 2014a, MQ-9 UAS Reaper
K-MAX	Lockheed Martin 2010 K-MAX; Petersen & Staley, 2011
RQ-4 Global Hawk	Northrop Grumman Systems Corporation, 2014b, RQ-4 Global Hawk; Department of Defense (DOD), 2014c, RQ-4A Global Hawk
UCAS-D	Naval Air Systems Command, 2014g, UCAS-D
KC-130J Super Hercules	Lockheed Martin Global Incorporated, 2014 C-130; Naval Air Systems Command, 2012, C/KC-130 Hercules/Super Hercules; Department of the Navy—Naval Historical Center, 2014a, C-130J Super Hercules
CH-53 Super Stallion	Sikorsky Incorporated, 2014, CH-53E; Naval Air Systems Command, 2014a, H-53E Helicopters; Department of the Navy—Naval Historical Center, 2014b, CH-53E Super Stallion
MV-22 Osprey	Naval Air Systems Command, 2013/2014; Naval Air Systems Command, 2014b, V-22 Osprey; Trask, 1996; Department of Defense (DOD), 2014e, MV-22 Osprey

Table 14. Vehicle Flight Hour Program Cost Data Sources

Vehicle	Data Source
MQ-4C Triton	Department of Defense (DOD), 2013b
MQ-8B Fire Scout	from: L. Nabasny personal communication, October 29, 2014
MQ-8C Fire Scout	from: L. Nabasny personal communication, October 29, 2014
MQ-9 Reaper	Department of Defense (DOD), 2014a.
K-MAX	from: Larkin, T., Heffern, T., Swan, D., (2013).
RQ-4 Global Hawk	from: C. Carlin personal communication, 20 October 2014
KC-130J Super Hercules	from: K. Chapman and K. Doyle, personal communication, October 03, 2014
CH-53 Super Stallion	from: K. Chapman and K. Doyle, personal communication, October 03, 2014
MV-22 Osprey	from: K. Chapman and K. Doyle, personal communication, October 03, 2014

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