NPS-CE-13-096

ACQUISITION RESEARCH PROGRAM SPONSORED REPORT SERIES

Life-Cycle Cost Analysis for Small Unmanned Aircraft Systems Deployed Aboard Coast Guard Cutters

9 December 2013

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Prepared for the Naval Postgraduate School, Monterey, CA 93943.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE
09 DEC 2013

2. REPORT TYPE

3. DATES COVERED
00-00-2013 to 00-00-2013

4. TITLE AND SUBTITLE
Life-Cycle Cost Analysis for Small Unmanned Aircraft Systems Deployed Aboard Coast Guard Cutters

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School,Graduate School of Business & Public Policy,Monterey,CA,93943

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
As the Coast Guard endeavors to close the operational gaps created by the postponements in the National Security Cutter (NSC) delivery schedule, it is important to assess the cost implications of Small Unmanned Aerial Systems (sUASs) on the NSC with reasonable accuracy. The purpose of this research was to conduct a life-cycle cost (LCC) analysis of sUAS deployment on the Coast Guard?s National Security Cutters and Offshore Patrol Cutters to assist the program management team. Our research provides the program management team with an LCC analysis tool that incorporates the most current and accurate data available. We also provided research on current and emerging technologies in the sUAS field that could benefit the Coast Guard (e.g., swarm technology). Further, as the Coast Guard sUAS acquisition program requirements potentially change, our LCC analysis tool provides the program team with a custom tailored instrument that they can update themselves and use in providing accurate forecasting of LCC and program decision-making.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**75**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The research presented in this report was supported by the Acquisition Research Program of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

Abstract

As the Coast Guard endeavors to close the operational gaps created by the postponements in the National Security Cutter (NSC) delivery schedule, it is important to assess the cost implications of Small Unmanned Aerial Systems (sUASs) on the NSC with reasonable accuracy. The purpose of this research was to conduct a life-cycle cost (LCC) analysis of sUAS deployment on the Coast Guard's National Security Cutters and Offshore Patrol Cutters to assist the program management team. Our research provides the program management team with an LCC analysis tool that incorporates the most current and accurate data available. We also provided research on current and emerging technologies in the sUAS field that could benefit the Coast Guard (e.g., swarm technology). Further, as the Coast Guard sUAS acquisition program requirements potentially change, our LCC analysis tool provides the program team with a custom tailored instrument that they can update themselves and use in providing accurate forecasting of LCC and program decision-making.

Keywords: Unmanned Aircraft Systems, National Security Cutter, Offshore Patrol Cutter, Life-Cycle Cost, Swarm Technology

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LCDR Theodore Erdman graduated from the U.S. Coast Guard Academy in New London, CT, in 1997 with a degree in mechanical engineering. After graduation, he served onboard USCGC *Thetis* (WMEC-910) as the student engineer and damage control assistant. His second tour was in the Office of Buoytender Acquisition (G-AWL) as the assistant technical manager and configuration manager. During this tour, he attended the George Washington University and earned a Master of Science in mechanical engineering in 2002. He departed G-AWL to attend the George Washington University full time and earned a Master of Science in engineering management in 2006. His second afloat tour was aboard USCGC *Campbell* (WMEC-909) as the engineer officer. His following assignment was the Legacy Sustainment Support Unit in Baltimore, MD, as executive officer and chief production engineer. He married his wife, Amy, in May 1999, and they have two children, Mia and Cole. LCDR Erdman is active in the Naval Postgraduate School Cycling Club, serving as the equipment manager. He is an outdoor enthusiast and enjoys spending time hiking and exploring the surrounding area with his family. After graduation in December 2013, he will report to the In-Service Vessel Sustainment Project as assistant project manager at Coast Guard Headquarters in Washington, DC.

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List of Acronyms and Abbreviations

ADE	Acquisition Decision Event
AFB	Air Force Base
A_O	Operational Availability
ARSENL	Advanced Robotic Systems Engineering Laboratory
AVDET	Aviation Detachment
AVO	Air Vehicle Operator
C4ISR	Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance
CO	Commanding Officer
CONOPS	Concept of Operations
COTS	Commercial Off-the-Shelf
CRP	Communication Relay Package
CWO	Chief Warrant Officer
DAU	Defense Acquisition University
DHS	Department of Homeland Security
EO	Engineering Officer
FAA	Federal Aviation Association
FLIGHTCON	Flight Condition
FY	Fiscal Year
G2M	GPS Guided Munitions
GAO	Government Accountability Office
GCS	Ground Control Station
HA/DR	Humanitarian Aid/Disaster Response
HRCAT	Human Resources Cost Analysis Tool
ISR	Intelligence Surveillance Reconnaissance
LCC	Life-Cycle Cost
MAV	Micro Air Vehicle
MPO	Mission Payload Operator

MTBF	Mean Time Between Failure
NAWCAD	Naval Air Warfare Center, Aircraft Division
NAWCWD	Naval Air Warfare Center, Weapons Division
NBC	Nuclear, Biological, Chemical
NPS	Naval Postgraduate School
NRE	Non-Reoccurring Engineering
NSC	National Security Cutter
O&M	Operations and Maintenance
OINC	Officer in Charge
OPC	Offshore Patrol Cutter
OS	Operations Specialist
PM	Program Manager
RDT&E	Research, Development, Test & Evaluation
SEGM	ScanEagle Guided Munition
SRR	Short Range Recovery
sUAS	Small Unmanned Aerial System
sUAV	Small Unmanned Aerial Vehicle
SWO	Surface Warfare Officer
TOC	Total Ownership Cost
TTL	Tagging, Tracking, and Locating
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
USSOCOM	United States Special Operations Command
VUAV	Vertical Takeoff/Landing UAV
WHEC	Coast Guard High Endurance Cutter
WMS	Weapons Management Suite
WMS GEN2	Weapons Management Suite Generation Two

I. INTRODUCTION

A. GENERAL

Aparicio and Wagner (2012) completed an analysis of the logistics support for the small unmanned aerial system (sUAS) program aboard Coast Guard National Security Cutters (NSCs). This research was conducted in support of the Coast Guard Office of Aviation Acquisition to “conduct a life-cycle cost analysis and evaluate integrated logistics support needs of the sUAS program while comparing strategies of contractor or organic logistics support” (Aparicio & Wagner, 2012, p. v). The Coast Guard has continued work on the sUAS program, and many of the associated project documents and guidance have been updated to reflect decisions made on the direction and scope of the program. The sUAS program is a Coast Guard non-major acquisition and is approaching Acquisition Decision Event (ADE) 2 in the Department of Homeland Security (DHS) Acquisition Timeline, highlighted by the red box in Figure 1.

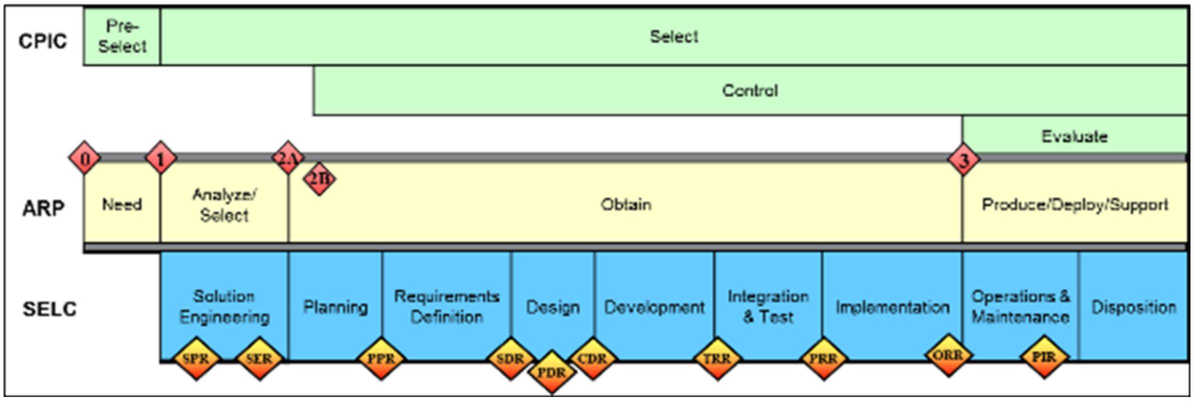

Figure 1. **Capital Planning and Investment Control and the Acquisition Management Framework Highlighting ADE 2**
(Department of Homeland Security [DHS], 2008)

The Coast Guard has conducted and is in the process of continuing proof of concept demonstrations using sUAS air vehicles on NSCs. These demonstrations have been used to fine-tune requirements and operational profiles—information that is vital to accurately describe stakeholder requirements that will be used in the acquisition project. Based on this work in the Analyze/Select phase of the acquisition timeline, the Coast Guard is moving forward with an sUAS solution to meet an immediate need: filling a capabilities gap resulting from a lack of air surveillance capabilities, as reported by a 2009 Government Accountability Office (GAO) report:

> Delays in the delivery of the NSC and the support assets of unmanned aircraft and small boats have created operational gaps for the Coast

> Guard that include the projected loss of thousands of days in NSC availability for conducting missions until 2018. Enhancements to the NSC's capabilities following the 9/11 terrorist attacks and the effects of Hurricane Katrina were factors that contributed to these delays. Given the delivery delays, the Coast Guard must continue to rely on WHECs [high endurance cutters] that are becoming increasingly unreliable. Coast Guard officials said that the first NSC's capabilities will be greater than those of a WHEC; however, the Coast Guard cannot determine the extent to which the NSC's capabilities will exceed those of the WHECs until the NSC's support assets are operational, which will take several years. To mitigate these operational gaps, the Coast Guard plans to upgrade its WHECs and use existing aircraft and small boats until unmanned aircraft and new small boats are operational, but because the mitigation plans are not yet finalized, the costs are largely unknown. Also, the Coast Guard has not yet completed operational requirements for the unmanned aircraft or new small boats. As a result, the Coast Guard has not determined the cost of the WHEC upgrade plan or the operational gap created by the delay in fielding new support assets for the NSC. (Government Accountability Office [GAO], 2009)

The NSC was designed to have a large unmanned aerial system (UAS) onboard to enhance its capabilities, but the delays in the NSC procurement and the high cost of large UASs have prevented this capability from materializing. Therefore, the Coast Guard is pursuing the sUAS as an interim solution.

B. PURPOSE

The purpose of this project is to conduct a life-cycle cost (LCC) analysis for the deployment of sUASs on the Coast Guard's current and future NSCs and Offshore Patrol Cutters (OPCs). An LCC analysis is required prior to Milestone Decision Authority approval to move past ADE 2 and into the Obtain phase of the project. Aparicio and Wagner (2012) conducted an LCC analysis for NSC deployment with a focus on the logistics support structure and recommendations. Our analysis builds on their work, with the addition of the OPC class of cutters and incorporates project decisions made to date.

In support of the LCC analysis, we collected information pertaining to the current state of technology of sUASs to ensure that any relevant factors were considered when analyzing the LCC implications to the Coast Guard. These factors were incorporated into the life-cycle cost to the greatest extent possible, but some may represent technological advances with tactical implications that will require changes to the current Concept of Operations (CONOPS).

C. SUMMARY

In our research, we attempted to accurately forecast the life-cycle costs of sUAS aboard NSCs and OPCs. The Coast Guard is currently trapped in a vicious cycle of supporting aging assets that are costing more and more money to support, such as the high endurance cutters (WHECs). The funding used to support the aforementioned assets is competing with the need to procure and support the NSC fleet. The handicapping of NSCs caused by the lack of UAS capability greatly reduces the Coast Guard’s mission effectiveness and congressional funding support, furthering the need to keep the WHECs operational. This life-cycle cost is an important component in the process of procuring an sUAS as an interim solution to enhance NSC capabilities and break this vicious cycle.

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II. BACKGROUND, CURRENT STATUS OF TECHNOLOGY AND TACTICS, AND CONOPS CHANGES

A. PURPOSE

The purpose of this chapter is to analyze the current state of Coast Guard directives, sUAS technology, and future tactical implications. Our project is an extension of Aparicio and Wagner (2012). Since their work, there have been updates in directives that have affected the LCC of the project. Market research in sUAS technology provides the Coast Guard with information updates on how the Navy and other agencies are developing sUAS technology. The technology explained in the following sections has the potential to enhance the Coast Guard’s core mission capabilities.

B. SUAS UTILIZATION IN NAVAL OPERATIONS

In addition to the standard use of sUASs for intelligence surveillance and reconnaissance missions, the Navy utilizes sUASs to fulfill several other mission requirements: surveying and collecting samples from nuclear, biological, and chemical (NBC) sites; locating snipers; tracking submarines; aerial relay communication; search and rescue; suppression of enemy air defense; and aerial raid decoys. The following is a brief summary of different mission sets and the sUAS packages that have the potential to be of use to the Coast Guard.

1. Nuclear, Biological, and Chemical sUAS Detection Systems

Boeing has developed a biological collection and detection unmanned aerial vehicle (UAV), called ScanEagle, as a component in its Biological Combat Assessment System. Its intelligence surveillance reconnaissance (ISR) sensors are utilized to observe NBC sites and send the data back to the control station to assist in forecasting an NBC dispersal model. The sUAS is also outfitted with special sensors consisting of “five modular cartridges and four “pass through” particle collectors, enabling multiple measurements” (“InSitu, Boeing,” 2009). It is controlled by satellite and has the capability of travelling 250 nautical miles and then loitering over the area for an hour (“InSitu, Boeing,” 2009, p. 2).

2. Meteorological Data and Research

sUASs are replacing many of the functions previously fulfilled by weather balloons. sUASs with the sensors to collect atmospheric data help the Navy to better understand how the weather and other natural anomalies affect the Navy’s radar and communications platforms. Also, sUASs can assist the Navy by providing better meteorological data, which allows for more accurate naval gunfire capabilities, as suggested in the following quotation:

> “In the old days, we launched weather balloons to give us the best data on the real environment, but that only happened in one place and at one time of day,” said Cmdr. Rob Witzleb, head of capabilities and requirements on the staff of the Oceanographer of the Navy. “Many miles and hours later, we were often left looking for answers when weapon systems didn’t perform the way we thought they would. Using UAVs is a giant leap forward in that they can give us near-continuous data, across multiple parameters where the atmosphere is the most unpredictable. (Beidel, 2013)

3. Aerial Relay Communication Drones

The Navy has begun researching the development of sUASs with communication relay packages (CRPs) “to extend the range of terrestrial communication—primarily radios” (Cheney-Peters, 2013). This technology has three practical applications. First, an sUAS with a CRP can extend line-of-sight communications and act as an additional medium to transmit and enhance data exchange rates. Secondly, during operations, it can act as a secondary means of communication architecture in the event that the primary means is “degraded, denied, or compromised” (Cheney-Peters, 2013). Lastly, in humanitarian aid/disaster response (HA/DR), the CRP can be utilized to fill the gaps in the communications grid when cellphone towers are damaged, or to enhance existing “communications past its normal quality, range, or security” (Cheney-Peters, 2013).

4. Search and Rescue

The Navy’s research in swarm technology, which we cover in more depth later in this chapter, significantly improves the success rate in search and rescue operations. As time increases, the search area increases exponentially in maritime search operations. Swarm technology allows multiple sUASs to work in tandem to cover larger areas and communicate back to a single ground control station. Not only does this utilization of sUASs improve search and rescue outcomes, but it also has cost-savings implications.

5. Tracking Submarines

The Naval Air Warfare Center Aircraft Division (NAWCAD) is working with Boeing to modify the ScanEagle to assist in identifying and tracking submarines. The UAS diesel engine is converted so that it can operate in a “magnetically silent” mode in order to allow it to effectively utilize its “magnetic anomaly detection systems tracking submarines underwater” (“InSitu, Boeing,” 2009, p. 2). The ScanEagle is air inserted by parachute from a P-8A utilizing the MagEagle Compressed Carriage.

When the parachute decelerates to a specified altitude and speed, the sUAS will separate from the parachute and “deploy its wings and start the engine to begin the mission” (“InSitu, Boeing,” 2009, p. 2), all the while remaining magnetically silent. This capability will facilitate the Navy in conducting simultaneous low- and high-altitude “anti-submarine warfare and command-and-control intelligence, surveillance, and reconnaissance missions” (“InSitu, Boeing,” 2009, p. 3) and allows for two separate identifications of a single target.

6. Aerial Raids

The Navy continues to develop sUAS technology to create more effective offensive operational capabilities. sUASs are being considered as an effective way to conduct aerial swarm raids to neutralize radar defenses by saturating the target acquisition area with a swarm of drones that either operate as decoys, or have weapons payloads to destroy designated targets. The implementation of these tactics has the potential to be vastly more cost effective than traditional stealth technology (Werner, 2013).

7. Summary

In conclusion, the Navy has developed sUAS technology that can be utilized from several platforms. It can be launched off the deck of ships, air-inserted off of planes, or fired out of a submarine tube before it begins its mission. The latest sUAS technology has advanced payloads, so the ScanEagle can assist in NBC missions, offensive aerial swarm raids, identification and tracking of submarines, search and rescue, aerial communications relay, and the collection of meteorological data. sUASs demonstrate increasing value and impact in current operations and will play an increasing role in the foreseeable future.

C. LETHAL AND NON-LETHAL WEAPONIZING OF SMALL UNMANNED AERIAL VEHICLES

Recent developments in technology have made the weaponization of sUASs more feasible. Previously, only larger UASs like the MQ-1 Predator or the MQ-8 Fire Scout had the payload capability to provide weapons capabilities. A careful review of the recent advancements in technology highlight an evolutionary reduction in the capabilities gap between the MQ-8 Fire Scout and the ScanEagle, which could facilitate the ScanEagle’s becoming a viable long-term solution to the Coast Guard’s mission requirements.

The Coast Guard’s current CONOPS states that the UASs’ primary mission is to support the host cutter in surveillance, detection, classification, and identification, and support mission tasks by providing sensors that will assist in command, control, communications, computer, intelligence, surveillance, and reconnaissance (C4ISR;

DHS, 2011). The weaponization of sUASs could further leverage the assets capabilities to assist the cutter commanding officer in achieving his mission. Weaponizing assists in reducing the inherent risk faced by members of the Coast Guard during law enforcement operations including interdiction, vessel boarding, and search and rescue operations. Rather than just being a sensor that loiters over a target of interest until the cutter or short-range recovery helicopter arrives, the sUAS can provide real-time responses to meet mission requirements.

1. Weapons Management Suite Generation Two Fire Control Station

The Naval Air Warfare Center Weapons Division (NAWCWD) Weapons Management Suite (WMS) team has been developing technology to weaponize existing UAVs since 2004. They are located at China Lake, CA, and have demonstrated a miniaturized fire control system, weighing approximately two pounds, called the Weapons Management Suite Generation Two (WMS GEN2). This system is capable of providing communications to small unmanned aerial vehicle (sUAV) weapons and payloads. Additionally, it can “control four stores points, two video streams, a digital recorder, and a link to other avionic system through a MiL1553 data bus interface” (Hatcher, 2012). The NAWCWD’s WMS teams plan to test the WMS GEN2 on sUAVs weaponized with Spike missiles, ScanEagle guided munitions (SEGM), or GPS guided munitions (G2M; Hatcher, 2012). Figure 2 provides a picture of WMS GEN2.

Figure 2. **Spike Missile and WMS GEN 2**
(Naval Air Warfare Center Weapons Division [NAWCWD], 2010)

2. Mini Weapons for sUAVs

a. Spike Missile

The Spike missile was originally developed by Israeli company Rafael Advanced Defense System to be shoulder fired, but it can be modified and attached to existing sUAS platforms. The Spike missile weighs 5.2 pounds and is 2.25 inches in diameter. It is 25 inches long and has a one-pound warhead, and "it's powered by a small solid rocket motor and guided by a tiny 1-megapixel video camera" (Matthews, 2010). The target is acquired by using an electro-optical seeker "Semi-Active Laser (SAL) to engage laser designated targets from a distance of two miles" ("Arming the Shadows," n.d.). Each missile costs $5,000, making it extremely cost effective. The Spike missile has been fired from several UAVs, including the DRS Sentry HP and the Army Vigilante unmanned helicopter, where it successfully engaged seven targets, one of which was a moving truck that was struck a mile and a half away while moving 20 mph. Figure 3 provides a picture of the Spike missile.

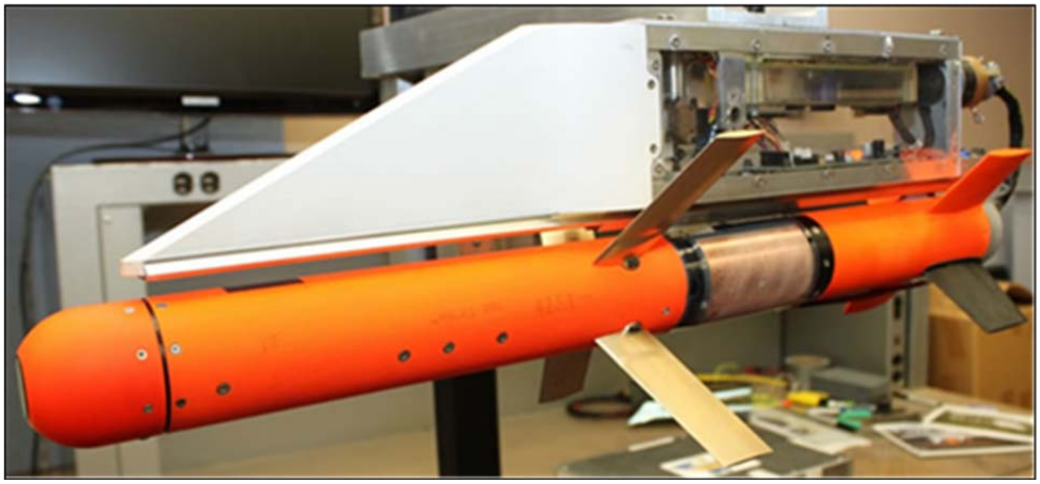


Figure 3. **Spike Missile and Fire Control System**
(NAWCWD, 2010)

b. Miniature GPS Guided Munition

This G2M was developed by ATK and weighs six pounds. It has a grenade-sized warhead (four pounds) and is stored and transported in a container launcher until it is utilized to engage a target. When the round is ejected from its container, three airfoils and fins move into place as the G2M glides in the air towards its target. The G2M also has three laser detectors that, when activated, seek the target observer's laser designation to find the target. When this occurs, the G2M's control processor activates the tail fins to make course corrections onto target. The G2M has a low signature since it does not utilize any propellant, but it is still capable of "diving silently along a glide slope determined to acquire the laser signal reflected from the designated target[;] the weapon can develop substantial offset from the flight path, reaching targets at significant standoff distance for the UAV, to achieve maximum surprise" ("Arming the Shadows," n.d.). The Shadow UAV is capable of carrying a payload of four G2Ms, in addition to its ISR and radio payloads. Figure 4 provides a picture of a G2M.

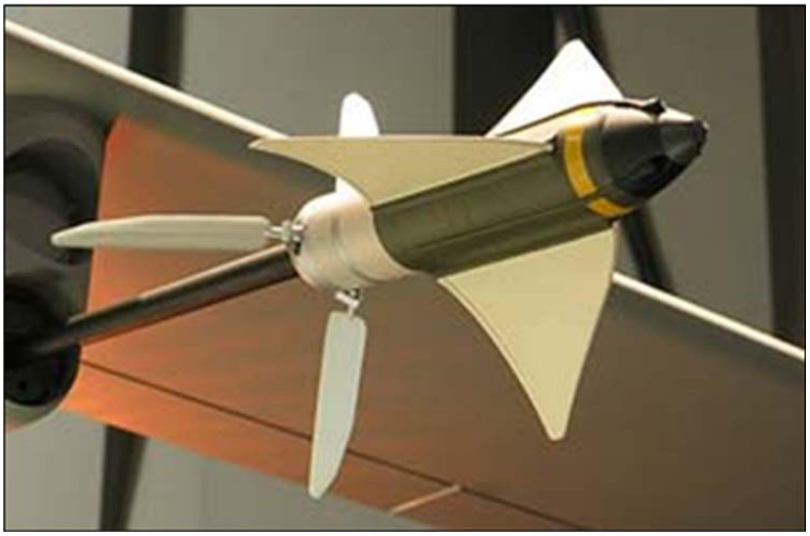


Figure 4. **G2M**
(“Arming the Shadows,” n.d.)

3. Small-Arms Fire Payloads for sUAS

At MacDill Air Force Base (AFB), in 2011, Derek J. Snyder, in collaboration with United States Special Operations Command (USSOCOM), conducted a proof of concept for arming existing sUASs with small-arms capability payloads for his systems engineering master’s thesis. The proof of concept involved attaching a small-arms payload weighing approximately 8.5 ounces, which consisted of a commercial off-the-shelf (COTS) 2.4-gigahertz electronic trigger, a six-channel receiver and COTS spectrum handheld RC radio, a carbon 50-caliber paintball barrel loaded with one round, and a 12-gram liquid CO2 propellant. He attached this payload to a Raven B (which has a 1.5-pound payload capability). The barrel was bore sighted to the Raven’s preexisting camera. The proof of concept testing found that the electronic trigger mechanism did not interfere with the Raven’s communications system and vice versa. Also, the weapons payload did not have a noticeable effect on the aerodynamics of the Raven. The UAS fired eight shots, all of which hit within 10 feet of the target. (Wind gusts were a significant factor in the paintballs’ accuracy.) Snyder found that a tactical sUAS could “at a minimum, distract a target thereby possibly changing the way the adversary views all sUAS” (Snyder, 2011, p. 62).

Snyder’s recommendation for future small-arms payload development was to “use current technology small arms weapons that use case-less, electronically-fired small arms rounds” (Snyder, 2011, p. 62). The UAS, Snyder (2011) also explained, “could be weaponized with a lethal payload made as a ‘kit’ consisting of a disposable, extremely light weight (carbon fiber) material that contains multiple rounds that could be fired electronically. This would remove much of the weight associated with conventional small-arms weapons” (p. 62). The proof of concept results showed that with further development, small-arms payloads added to existing sUASs could be a viable option to further enable sUASs to fulfill Coast Guard mission requirements with lethal and non-lethal effects. Figure 5 shows a small-arms payload added to a Raven B. Figure 6 shows the Raven B outfitted with the small-arms payload engaging a target.

Figure 5. **Small-Arms Payload Characteristics**
(Snyder, 2011, p. 59)

Figure 6. **Small-Arms Payload Firing at Target**
(Snyder, 2011, p. 61)

4. Clandestine Tagging, Tracking, and Locating Technologies

In 2011, the Air Force released a request for proposal for the development of tracking technology utilizing tiny drones to covertly paint an “individual with some kind of signal-emitting powder or liquid that allows the military to keep tabs on him or her” (Dillow, 2011). The Pentagon has a range of ideas pertaining to clandestine tagging, tracking, and locating (TTL) technologies, which include “marking targets with biological paints or micromechanical sensors. … One proposal from the University of Florida “uses insect pheromones encoded with unique identifiers that could be tracked from miles away. Other plans employ biodegradable fluorescent ‘taggants’ that can be scatted by UAVs, or paintballs that can be fired to mark and track targets of interest” (Dillow, 2011).

Voxtel, a technology company from Oregon, has a product available called NightMarks, which is a “nanocrystal that can be seen through night-vision goggles and can be hidden in anything from glass cleaner to petroleum jelly” (Dillow, 2011, p. 2). The Defense Advanced Research Projects Agency is researching a “smart dust” of tiny, dust-sized sensors that could be scattered by UAVs over an area, much like a crop duster, so that when a target or person of interest moves through it, they are tagged. The aforementioned technologies would be extremely useful to the Coast Guard in carrying out interdiction and search and rescue missions (Dillow, 2011).

D. SWARM TECHNOLOGY

Swarm technology is emerging and evolving in sUASs. The implementation of swarm technology represents a paradigm shift in tactical employment and greatly enhances the capabilities of sUASs. It is in the Coast Guard’s best interest to carefully follow swarm technology’s advances and plan for its incorporation into future Coast Guard operations.

Leaders in the fields of robotics and engineering have begun to test utilizing swarm technology in sUAVs. “In biology a swarm is a collection of individuals that manifest complex behavior without a leader calling the shots. Imagine birds spontaneously gathering on a single tree, only to lift off en masse moments later” (Hambling, 2013).

Scientists achieve swarms by programing the sUAS software with algorithms and rules that make all the individual units move together in the same direction, while simultaneously always trying to move to the center of the swarm and to maintain a set distance away from each other (Hambling, 2013). Figure 7 provides an artist’s representation of swarm technology.

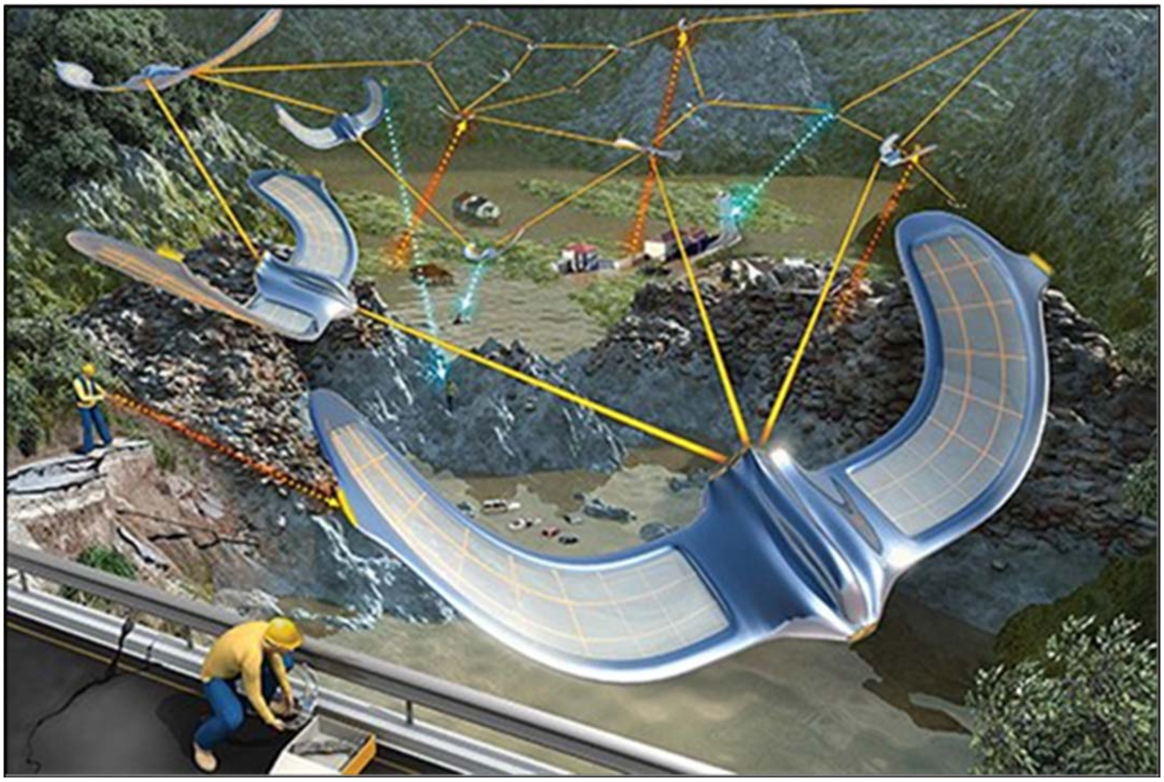


Figure 7. **Illustration of an sUAS Swarm**
(Hambling, 2013)

In 2011, Johns Hopkins University and Boeing worked together to demonstrate that two different types of UAVs could form a swarm and effectively conduct a reconnaissance mission. During the test, they utilized two ScanEagles (built by Boeing), and a Unicorn (built by Lockheed Martin). Later in 2012, they demonstrated an autonomous swarm of sUASs tasked to search an area, guided by just a laptop and tactical radio, suggesting the potential of reducing the amount of manpower and ground stations requirements (Werner, 2013).

The Naval Postgraduate School (NPS) is a leader in the field of swarm technology research within the United States. In February 2011, the school's Advanced Robotic Systems Engineering Laboratory (ARSENL), headed by Professor Timothy Chung, conducted a field trial consisting of a swarm of seven drones. In May 2012, at Camp Roberts, CA, Chung's team increased the number of drones in the swarm to 10.

Although there have been significant advances in the field, ARSENL's May study highlighted some of the current difficulties that the military may face when trying to implement swarm technology presently. "When the school's team flies five at a time, the command-and-control link between the ground station and the aircraft goes haywire, sending a 'warning: lost communications' message for each aircraft"

(Werner, 2013, p. 5). This phenomenon is the result of all of the sUASs trying to communicate back to the ground control station simultaneously. To fix the issue in future field tests, "school officials plan to employ a command-and-control network with more bandwidth … and schedule incoming messages so the multiple aircraft do not all bombard their handlers with constant warnings" (Werner, 2013, p. 5). Professor Chung plans to conduct the world's largest swarm demonstration by August 2015. The demonstration will consist of a battle between two swarms of 50 sUASs each. Figure 8 shows Dr. Chung conducting field-testing of swarm technology.

Figure 8. **Dr. Timothy Chung Testing sUAS Swarm Technology at the Joint Interagency Field Exploration on August 5–8, 2013**
(Stewart, 2013)

sUAS swarm technology has several applications in homeland security. For example, it could be extremely effective in search and rescue operations. sUASs could quickly cover large areas of space to map and communicate back to a single ground control station. This has the potential to drastically improve the chances of rescuing civilians in danger, as well as reducing the associated mission's costs. As time progresses in a search and rescue evolution, the required search area grows exponentially and the chance of recovering survivors decreases, demonstrating the benefit of increased surveillance assets early.

Also, swarm technology can be utilized to assist in disaster relief. One example of swarm technology's potential use in disaster relief is the Swarming Micro Air Vehicle Network Project, which "used the pheromone paths laid down by army ants [to] help plot the most economical course for MAVs that would be deploying in disaster areas to quickly create communication networks for rescuers" (Quick, 2011). In the case of an NBC disaster, it may be the safest way to survey the NBC disaster site. "Swarms could scan high-risk buildings and sites (think Fukushima post-tsunami) rapidly, whereas larger UAVs cannot" (Hambling, 2013, p. 1). These sUAS swarms could utilize newly developed NBC payloads, which could collect samples in the disaster area and communicate information back to the ground control stations, thereby reducing exposure risks to humans.

According to Dr. Chung, swarms may be the most cost-effective and only viable defense against other swarms. He stated, "I don't want to spend a million bucks to counter a $10,000 threat" (Werner, 2013, p. 3). He further articulated this point in the following analogy:

> Even if enemy drones are not sophisticated, they might be able to overwhelm U.S. air defenses. It's like a tennis match. No individual high school player could possibly beat Swiss champion Roger Federer. But if 50 high school players were lobbing balls onto his court, poor Roger wouldn't be able to defend against that. (Werner, 2013, p. 3)

In summary, as swarm technology continues to develop and the price of sUASs decreases, the field has many promising applications to the Coast Guard's disaster relief missions, search and rescue operations, and maritime law enforcement. Meanwhile, Boeing's development and demonstration of swarm technology on the ScanEagle with just a laptop and tactical radio could reduce the footprint of the UAS system on NSC, as well as increase the capabilities available to commanders.

E. MANNING—WHO SHOULD FLY SUASS IN THE COAST GUARD

The Coast Guard has specified that its sUASs will be controlled by a certified pilot. This is due to the need for the Coast Guard to operate in domestic airspace, and using a certified pilot vice a UAS operator meets or exceeds the current and expected Federal Aviation Administration (FAA) requirements. These FAA requirements currently limit the Coast Guard to officers who have completed flight training and are rated pilots, but the sUAS CONOPS leaves the possibility open that the pilot could be an officer or enlisted person (United States Coast Guard [USCG], 2013b). The requirement of a certified pilot results in a substantially larger cost.

Heiss (2012) conducted a cost–benefit analysis of the use of officer versus enlisted personnel as UAS pilots in the U.S. Army, Marine Corps, Navy, and Air Force. The Navy and Air Force require that UASs be operated by rated pilots, while the Army and Marines permit enlisted personnel to operate UASs. Heiss's recommendation was that the Navy should consider training enlisted personnel to operate its Fire Scout UASs. Conventional wisdom might suggest that a rated pilot would be the "pilot" of a UAS, but the majority of UASs do not have to be actively flown like the manned aircraft they are replacing. In general, the UAS can be controlled by the onboard computer and ground control station to fly at the altitude that the operator specifies and will simply go to a position or follow a course that the operator enters, such as a search pattern or loiter-in-vicinity pattern. The actual "flying" is done by the computers, so why use an expensive rated pilot to man the GCS (Ground Control Station)?

A financial comparison among UAS operator options requires the definition of the representatives. Heiss (2012) used a junior and senior rated pilot, a surface warfare officer (SWO), and an operations specialist (OS) in his comparison. He used the Navy's Human Resources Cost Analysis Tool (HRCAT) to extract the amortized annual costs for accession and pipeline for these representatives. All of the officers had the same accession cost, and all of the enlisted personnel had the same accession cost. The pipeline training consisted of all of the training that enabled the personnel to perform their missions, for example, flight school for the rated pilots. All members would need specific training on the UAS. Navy Fire Scout training is conducted by Northrop Grumman Corporation, and Heiss (2012), in his research, used $45,833 as the cost to train a rated pilot and $48,077 as the cost to train the SWOs and OSs. The pilot cost was based on the average between the costs of Fire Scout air vehicle operator (AVO) training and mission payload operator (MPO) training given to military pilots. The number used for the SWOs and OSs came from the average cost for the same training for non-pilot civilian contractors. Combining all of this information together, Heiss (2012) built Table 1. From a strictly financial perspective, it is obvious that using enlisted operators makes much more sense than using rated officer pilots. Heiss did not limit his analysis to dollars and cents but compared other benefits that are summarized as follows.

Table 1. Total Amortized Annual Cost per Operator Alternative
(Heiss, 2012)

	Pay Plus Incentives and Pipeline Training	Amortized NGC Training Cost for AVO/MPO	Total Amortized Annual Cost	Dollar Savings From Baseline	Percent Savings From Baseline
Pilot Lieutenant (Baseline)	$229,787.43	$45,388/10.48 = $4373.38	$234,160.81	Baseline	Baseline
SWO Lieutenant	$179,502.02	$48,077/10.48 = $4587.50	$184,089.52	$50,071.29 less	21% less
Operations Specialist CPO	$105,092.60	$48,077/7.88 = $6101.14	$111,193.74	$122,967.07 less	53% less
Operations Specialist PO3	$79,936.63	$48,077/7.88 = $6101.14	$86,037.77	$148,123.04 less	63% less

Heiss (2012) followed his financial analysis with non–cost-related factors such as the length of training, manning constraints, physiology constraints, culture, and safety considerations. All of these factors led Heiss to conclude that enlisted UAS operators are a more efficient use of resources. Fire Scout AVO training takes five weeks, and MPO training is three weeks. The training pipeline for a qualified combat pilot is as long as four years. The Navy is facing manning constraints in the current personnel downsizing environment. Training personnel who are already part of a ship's crew to operate UASs would alleviate the need to augment the crew with pilots who come aboard simply to fly the UASs. Pilots have high physical fitness requirements to be able to operate in the extremely dynamic cockpit environment. This environment does not exist for a UAS because there is no cockpit. Opening up UAS controller training to personnel who are qualified for general service, but not flight school, would greatly broaden the pool of potential operators. The Air Force has had significant cultural difficulties when using pilots to control UASs. The pilot culture tends to treat these pilots as second-class citizens. This is detrimental to the UAS pilots' morale and to their careers, even though they are performing a vital mission that they are specially trained for. Finally, there is doubt concerning whether it is more difficult to teach a pilot who is used to controlling from a cockpit to operate a UAS remotely, as opposed to teaching someone who is not a pilot. Also, rotating rated pilots through UAS controller duty removes them from their airframe, and from a cockpit entirely, for a lengthy period of time. Transitioning back to the cockpit is a potentially long and dangerous process.

Heiss (2102) recommended that the Navy develop and implement programs to transition enlisted personnel into UAS controller positions. There is one area that he did not discuss that could pose a problem for the Coast Guard, if it followed a similar path: civilian airspace. The Navy primarily operates in military training space or in combat operations. The Coast Guard also operates in military training airspace, but mission time is either on the high seas or in U.S. civilian airspace. FAA guidelines have not been finalized on the requirements to operate UAS domestically in the airspace controlled by the FAA, but the current thought is that some type of pilot license will be required. Since domestic operation is a key requirement of Coast Guard UAS missions, until these regulations have been modified to allow no-pilot operators, the Coast Guard's only choice is to have rated pilots operate UASs.

F. CONCEPT OF OPERATIONS DIFFERENCES

The CONOPS that Aparicio and Wagner (2012) received from the Coast Guard during their study was a draft document titled *Concept of Operations for the Cutter-Based Unmanned Aircraft System* (USCG, 2011). The Coast Guard Office of Aviation Acquisitions provided us with an updated, but more narrowly focused, document titled *Requirements Document for the Small UAS for National Security Cutters* (USCG, 2013b), which includes the CONOPS created specifically for sUASs onboard NSC, in addition to other procurement information such as effectiveness requirements, suitability requirements, and key performance parameters (USCG, 2013b). A major difference between the two documents is that the older document focuses on a larger UAS Level-I Major Systems Acquisition Program while the sUAS on the NSC document dramatically tailors the size and capability of the described UAS, in addition to providing specific requirements for the UAS. Aparicio and Wagner (2012) had some of this information while carrying out their research, which was focused on an sUAS, but they did not have the combined document. In our research, we explored some of the new information provided by this updated document.

1. Air Vehicle Size

One of the main differences between the UAS CONOPS and the sUAS CONOPS is the size of the airframe. The airframe choice affects all costs associated with the system: initial procurement, operations, maintenance, disposal, and equipment and tactics on the cutters. Aparicio and Wagner (2012) used the smaller sUAS in their study, and our work does as well.

2. sUAS System Definition

The UAS CONOPS calls for two UASs onboard the NSC and one aboard the OPC. The sUAS CONOPS is focused solely on the NSC and does not mention the OPC. Like Aparicio and Wagner (2012), we use two and one sUASs for the NSC and OPC, respectively, in our analysis.

3. Personnel

In their study, Aparicio and Wagner (2012) used an Aviation Detachment (AVDET) of two pilots and three enlisted operator/maintainers. This crew mix was based on the draft UAS CONOPS, Coast Guard pilot crew rest requirements contained in COMDTINST 3710.1F (USCG, 2008), and federal UAS pilot requirements. The Coast Guard provided a preliminary answer to the AVDET in the sUAS CONOPS by stating,

> Total sUAS crew will notionally consist of three pilots and four maintainers, with a desired complement of two pilots and three maintainers. Three pilots provides a conservative approach to meeting the 12 hours per day of flight time considering two pilots would be operating at the individual flight time limits of 3710.1G daily. (USCG, 2013b)

A revision to COMDTINST 3710.1 was released in February 2013, after Aparicio and Wagner (2012) completed their study. Major changes included the addition of UAS operations and the limitations shown in Table 2 pertaining to UAS crew employment (USCG, 2013a). We use the larger AVDET size in our analysis. Using a larger AVDET provided a larger but more conservative LCC. As the Coast

Guard gains more experience with UASs, the crew size will most likely decrease, and the LCC tool will allow the user to make this change at any time.

Table 2. UAS Flight Scheduling Standards per 24-Hour Period
(USCG, 2013a)

	Individual Flight Hours	Crew Mission Hours
Land-Based UAS	10	14
Shipboard UAS	6	10

4. Flight Operations Description

The UAS CONOPS describes the UAS as operating similarly to a MH-65 helicopter, requiring the flight deck to be clear for Flight Condition (FLIGHTCON) I the same way it would be for any helicopter flight evolution. There is a major difference in the sUAS CONOPS, which specifies that the sUAS must be launched and recovered while an MH-65 is spotted on the flight deck with blades extended. This position provides a much greater response capability for the MH-65 because it does not have to be removed from the hangar and have the blades unfolded before launch; however, it creates a space constraint on the sUAS. This space constraint is something that should not negatively affect the universe of choices in the sUAS because of its limited launch/recovery footprint requirements.

5. Automated Launch and Recovery

The draft UAS CONOPS specifies that the UAS will operate on an automated launch and recovery system attached to the cutter. This requirement is focused on the large vertical takeoff/landing UAV (VUAV) that was envisioned in the original Deepwater plan. The sUAS CONOPS document discusses the smaller UAS and its associated launch and recovery machinery, which is not automated. This is a much less complex and less expensive approach than the automated system, which is to be expected because of the significantly smaller footprint and lower expense of the sUAS, in comparison to the larger Fire Scout UAS.

6. Classification

The UAS CONOPS calls for the majority of communications to be unclassified, but it also states that “the capability to receive, process, and archive higher classifications will be required” (USCG, 2011). The sUAS CONOPS specifies that “the sUAS shall be an unclassified system” (USCG, 2013b). The removal of classified systems has the potential to greatly reduce the LCC due to the expense of military-grade classification hardware and software. The sUAS CONOPS also describes the requirement for secure and non-secure communications including military UHF, which may require additional expensive hardware and software. Our analysis focused on LCC for representative sUAS systems that are being explored by the Coast Guard and that meet the Coast Guard's user requirements.

G. SUMMARY

This chapter set the stage for the LCC analysis we conducted and provided research into the current and future state of technology for sUASs. Our research is a continuation of Aparicio and Wagner (2012), and it is important to clarify where there are differences in the data and assumptions we used. This research is not only an LCC analysis but also an academic analysis of current and near-future sUAS technology. The Navy, Air Force, and other agencies are conducting studies with sUASs to enhance existing capabilities and expand sUASs into new areas. The specific technologies we highlighted have the ability to greatly enhance Coast Guard mission effectiveness and should be given attention by Coast Guard policy and technology leadership.

III. METHODOLOGY

A. INTRODUCTION

The purpose of this project was to conduct a life-cycle cost analysis of sUAS deployment on Coast Guard NSCs and OPCs. This analysis required the development of a computer tool to integrate all cost feeders and calculate the life-cycle cost. The advantage provided by the tool is that the inputs and assumptions made (such as number of airframes or reliability statistics) can be changed by the user to fine-tune the LCC, adjust to changing realities, and fit the project into the available financial resources. The Life-cycle Cost Tool will be used by the Coast Guard Office of Aviation Acquisitions in support of required documentation for ADE 2 and beyond.

B. LIFE-CYCLE COST TOOL

The Life-cycle Cost Tool is a Microsoft Excel tool that is used to capture the cost of individual cost components and combine them to calculate the LCC over the entire life of a program. The tool is a derivative of the methodology learned in Professor Keebom Kang's Engineering Logistics class at NPS (Kang, 2013).

The Defense Acquisition University (DAU) defines *life-cycle cost* as "the total cost to the government of acquisition and ownership of a system over its useful life. It includes the costs of research, development, test and evaluation (RDT&E), acquisition, operations, and support (to include manpower), and where applicable, disposal. For defense systems, LCC is also called 'Total Ownership Cost (TOC)'" ("Life Cycle Cost," 2013). The ability to generate an accurate LCC is vital for the acquisition program staff. Leading up to ADE 2, decisions are made that have dramatic effects on the LCC of the system. These decisions include contract type and terms, scope of the acquisition project, possible solutions, size, weight, capabilities, system life, and so forth. Figure 9 is a conservative display of the effects of early decisions on later LCC. Over 50% of LCC is committed during the Conceptual/Preliminary Design phase, while less than 10% of the LCC is actually spent. The Coast Guard's acquisition timeline is shown in the middle of Figure 10. Blanchard and Fabrycky's (2011) Conceptual/Preliminary Design phase relates to the Coast Guard's Analyze/Select phase, which is before ADE 2, where approval is given for the creation of an acquisition project. Before construction begins (at ADE 3), nearly 80% of LCC has been committed, but less than 25% has been spent. With such a large effect on the LCC weighing on early decisions, the program manager (PM) must have complete LCC understanding of the effects of these decisions and balance them against the affordability of the project. The LCC tool enables the PM to explore multiple scenarios and see immediate impacts to LCC through an easy-to-understand interface.

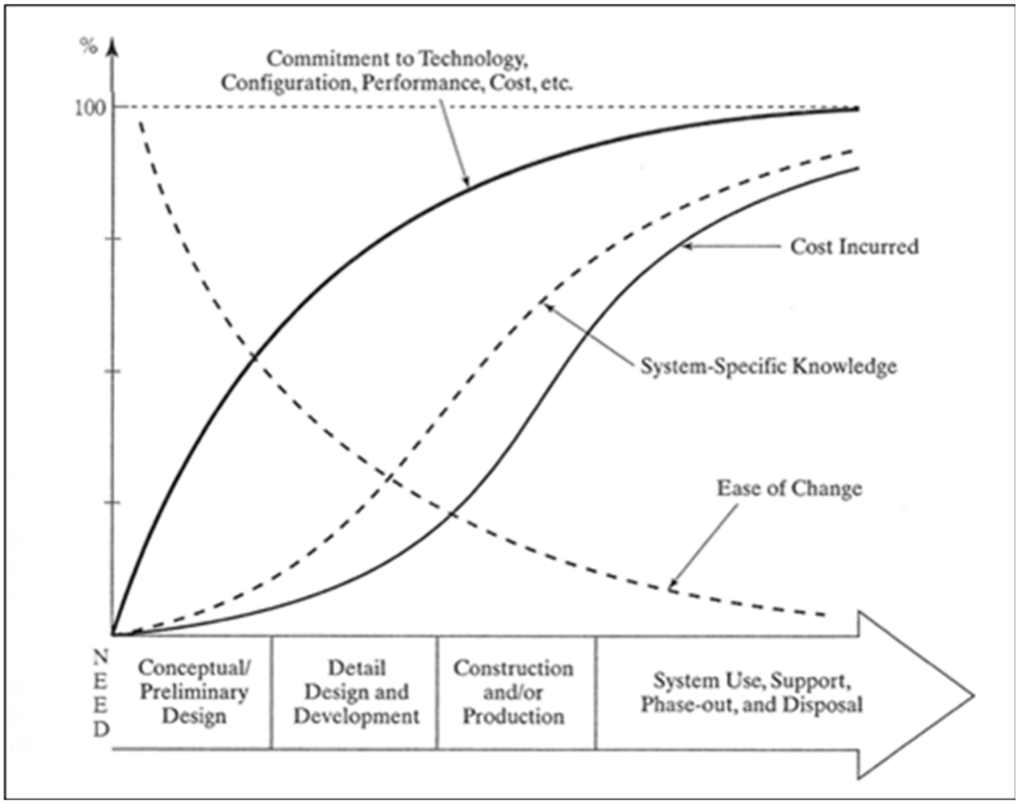


Figure 9. **Life-Cycle Commitment, System-Specific Knowledge, and Incurred Cost**
(Blanchard & Fabrycky, 2011)

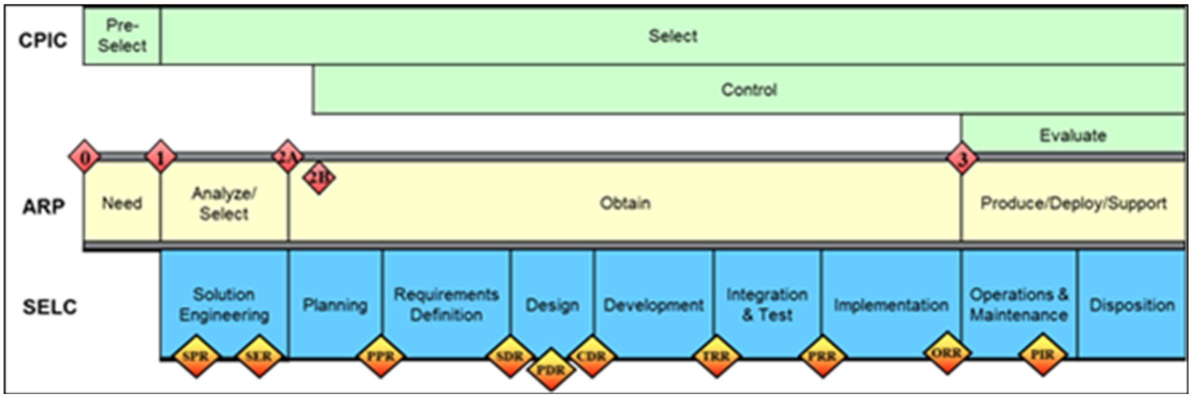


Figure 10. **Capital Planning and Investment Control and the Acquisition Management Framework**
(DHS, 2008)

The DAU definition calls out specific elements that are included in the calculation of LCC. We developed this LCC tool based on the work conducted by

Aparicio and Wagner (2012) and expanded their work to include the addition of the OPC fleet, operations on both coasts, and other new and updated information that was available to us. Specific cost drivers in the research tool include the following: R&D costs necessary to identify and test suitable UAS systems, the procurement cost of UAS systems (aircraft, sensors, and control equipment), installation costs, some support and maintenance costs, operations costs, and disposal costs. Assumptions we made during development of the Life-cycle Cost Tool are documented in the Analysis section of our report. The LCC tool has some limitations: There are future decisions that need to be made by the Coast Guard; thus, some information was not available to us and therefore had to be excluded. For example, the Coast Guard must determine a location to base and maintain the UASs on the East Coast. Our assumption is that the Coast Guard will use its existing facilities at Aviation Logistics Center in North Carolina. On the West Coast, the Coast Guard is planning on combining UAS operations with the Navy at Point Mugu, CA.

A discounted rate of 2% is used in the LCC calculations. Office of Management and Budget (OMB) Circular A-94 calls for the use of a discount rate of 7%, citing, “This rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years” (Office of Management and Budget, 1992). The discount rate takes into account the time value of money; that is, a dollar today has more buying power than a dollar tomorrow due to inflation and the fact that the money could be earning interest. The reason we chose 2% is this lower rate is the internal government investment rate. This rate is used when the project being analyzed does not have a public use, such as a weapons system, as opposed to a road project which does have a public use. This percentage can be changed by the user in the Life-Cycle Cost Model.

Based on the UAS CONOPS, our model uses a planned UAS airframe life of 20 years. The length of time that an asset is planned to be used has tremendous effects on its LCC. This portion of the life cycle after delivery is funded by operations and maintenance (O&M) money and is driven by the planned operations. For example, based on the UAS CONOPS, Aparicio and Wagner (2012) calculated that flight hours on an NSC would be 832 hours per year. A 20-year life would account for 16,640 hours per vehicle. The current sUAS program is planned to be an interim solution until funding is available for the acquisition of larger, more capable, and more expensive UAS systems. If funding becomes available sooner, the sUAS system life may be reduced as it is replaced by another UAS. Conversely, the Coast Guard has a habit of making interim solutions permanent and keeping assets longer than planned at acquisition. It is possible that the sUAS will be in service to support the NSC’s and OPC’s planned 30-year service lives. Changing to 10- or 30-year service lives for sUAS would result in 8,320 or 24,960 hours, respectively. Assuming a starting value of $1,400 per flight hour, as Aparicio and Wagner (2012) calculated, changing to a 10 or 30 year service life would be a swing of ±$11,648,000 (undiscounted dollars) in LCC for just one vehicle. With an estimated fleet size of 47 aircraft, this could be a difference of ±$547,456,000 when compared to the LCC at 20 years.

The Coast Guard UAS program is closely tied to the acquisition programs for the NSC and OPC. The driver behind the timeline is currently the NSC program, which has already delivered three cutters and has three more of the planned eight under contract. The large hole in the NSC capability—due to the lack of aerial reconnaissance provided by deployed UASs—has caused Congress to ask questions about the need to fund continuing NSC procurements if they will not be fully mission-capable due to the lack of UASs. The OPC program has not begun its procurement, but the UAS is sure to be closely tied to this schedule as well. The schedule used in the LCC tool is based on the NSC procurement schedule and proposed OPC procurement schedule.

C. LIMITATIONS

The LCC tool is limited by the quality and quantity of information that we are able to input into the tool. As discussed previously, we had to make assumptions based on data non-availability or decisions not yet made. The theory and calculations behind the tool are sound and provide the most accurate estimates available with the inputs provided. The tool can be modified in the future to include better data as it becomes available and as decisions are made.

D. SUMMARY

The LCC numbers provided later are based on the best assumptions we were able to make. We will brief the Coast Guard program staff on the results, but also on how to use the tool and update it as they gain more information and make programmatic decisions to further refine the LCC for the UAS program. Through continued maintenance and use of this tool, the program staff will be able to make the appropriate decisions to shape their program for success even in the currently tight fiscal environment. In the appendix we have provided a user manual for the LCC tool. The manual explains how to make adjustments to the tool within the framework of several scenarios that the program staff may face in decision making.

IV. ANALYSIS

The major output of this project was the Life-Cycle Cost Model for use by the Coast Guard Office of Aviation Acquisition. We discussed the tool at a high level in the Methodology sections, but the following detailed discussion of the decisions and information used to construct the tool is also necessary for understanding and use. We built the model in Microsoft Excel and organized it by major cost categories, which is the organization used in this section.

The major cost components in the LCC analysis are acquisition, personnel, training, O&M, and project office costs. Each of these topics is contained on an Excel tab. In addition, there are tabs for the NSC, OPC, and sUAS schedule; LCC compilation; and user interface pages. We discuss each in turn.

A. SYSTEM ACQUISITION COSTS

The cost of the system components was provided by the Office of Aviation Acquisition and is shown in Table 3 (Office of Aviation Acquisition, personal communication, August 8, 2013). This list includes the components that comprise an sUAS, with the exception of spare parts. Some components, such as the GCS, will be installed permanently on the cutter, while others, such as the air vehicles themselves, will be deployed to the cutter before each patrol.

Table 3. Cost of Equipment to Outfit One Cutter With sUAS, Not Including Spares

Procure Ops Test System		
Airframe Unit Cost - Baseline	$	133,671
Avionics - Baseline	$	149,047
Propulsion - HFE - Baseline	$	40,601
EO/IR - Baseline	$	268,268
Comms Relay	$	131,301
AIS	$	7,851
GCS - Ship	$	392,054
Launcher - Ship	$	236,050
Recovery - Ship	$	236,050
Peculiar Support Equipment (PSE) per System	$	69,624
EO/IR surface detect sys	$	75,000
Remove video terminal for boarding team (1)	$	10,000
One ship sys with 1 acft	$	1,749,517
One ship sys with 2 acft	$	2,515,067

B. PROJECT OFFICE COSTS

The procurement costs are simply the costs for the equipment. The project office has many other costs to execute the project and install the sUAS systems on the cutters. Estimated costs were provided by the project office. Some of these costs are personnel, such as travel and support contractors, while others are directly tied to delivery and installations.

1. Operational Testing and First Cutter Delivery

There are a number of expenses that the project must incur to field and test the sUAS system, no matter how many systems are installed. These include non-reoccurring engineering (NRE), initial training, spectrum certifications, and costs for the development and execution of the operational test on the first cutter. In addition, there are costs for the shipboard installation, which are generally higher for the first installation than for follow-on installations. The total estimated cost for installation and testing onboard the first cutter is $2.6 million. A breakdown of these costs is shown in Table 4.

Table 4. Costs to Design, Install, and Test of First NSC

Ops Test Prep	
Train sUAS pilots ($10K each)	$ 40,000
Spectrum cert	$ 25,000
NSC install (NRE)	$ 750,000
NSC install (recurring)	$ 100,000
Pubs	$ 20,000
Non-pilot initial training	$ 50,000
…add items such as Flt Cert, Avcert…	$ 75,000
Total Ops Test Prep	$ 1,060,000

Ops Test (Use STUAS as basis)	
Test plans, OTRR, Test rpt	$ 280,000
Training for Ops Test	$ 560,000
T&E support (e.g., contract mx)	$ 280,000
Test range and targets	$ 250,000
OT spares at 5%	$ 125,750
OT flight ops ($1K/hr)	$ 50,000
Ops Test	$ 1,545,750

We used similar costs for the first OPC, which will require the same developmental and testing work that will be completed on the NSC. Assuming that there will be cost savings from the reuse of some test planning and training from the

NSC tests, these costs were listed as 50% NSC costs. The differences result in approximately $600,000 in lower costs. The costs for the first OPC are displayed in Table 5.

Table 5. Costs to Design, Install, and Test of First OPC

Ops Test Prep	
Train sUAS pilots ($10K each)	
Spectrum cert	
NSC install (NRE)	
NSC install (recurring)	
Pubs	$ 20,000
Non-pilot initial training	$ 50,000
…add items such as Flt Cert, Avcert…	$ 75,000
OPC install (reoccurring)	$ 100,000
OPC install (NRE)	$ 750,000
Total Ops Test Prep	$ 995,000

Ops Test (Use STUAS as basis)	
Test plans, OTRR, Test rpt	$ 140,000
Training for Ops Test	$ 280,000
T&E support (e.g., contract mx)	$ 280,000
Test range and targets	$ 250,000
OT spares at 5%	$ 125,750
OT flight ops ($1K/hr)	$ 50,000
Ops Test	$ 1,125,750

2. sUAS Delivery Costs

The cost to deliver sUAS to the follow on NSCs and OPCs are significantly less than delivery to the first NSC and first OPC. The NRE costs to develop and finalize the installation package have been completed and can be followed with little to no modifications. The technical publications have been developed and should not need customization. Each cutter will still require initial training when the sUAS system is first installed. These costs are expected to be approximately $175,000 per cutter.

3. sUAS Operations Center Costs

The location for the sUAS operations center has not been finalized, but requirements have been developed to describe what equipment and facilities will be required. The plan calls for a single airframe sUAS system and spare parts to be located at the shore station. There will also be costs similar to those standing up any unit or office, such as office furniture, computers, and space modifications/refurbishment. The estimate for these costs is approximately $2 million and is displayed in Table 6.

Table 6. sUAS Operations Center Costs

sUAS Ops Center	
One acft sys + launch/recover + RVT as above	$ 1,749,517
Office furniture & supplies [CG-93AL]	$ -
Std work stations	$ 16,800
Facilities upgrades [CG-93AL]	$ -
Initial spares	$ 174,952
Ops Ctr	$ 1,936,473

C. NSC, OPC, AND SUAS SCHEDULES

The cost to procure and install the equipment is important, but so is the schedule of when this equipment is going to be installed. The project office provided a planned delivery schedule for the sUAS to the NSC fleet, starting with the first cutter in fiscal year (FY) 2016, which will be used for operational testing. Two NSCs will be outfitted per year until the last NSC is equipped in FY2020. The Operations Support Center will be outfitted in FY2019, and spare sUAS vehicles will be procured in FY2020. This schedule is shown in Table 7.

Table 7. Project Office NSC sUAS Deployment Schedule

FY2016	FY2017	FY2018	FY2019	FY2020
Procure OT sUAS OT&E Prep NSC#1 Airspace Safety	Complete OT&E Procure NSC #2&3	Procure NSC #4&5 Add'l sensors	Procure NSC #6&7 Ops Supt Ctr	Procure NSC #8 Spare Air Vehicles

The OPC deployment schedule is dependent on the OPC cutter delivery schedule. Ideally, the sUAS will be delivered when the new OPCs are delivered, avoiding the capability gap that the NSC fleet is currently experiencing. The OPC procurement plan calls for two phases, with multiple design contracts awarded in phase one and the best design chosen for cutter construction in phase two. The anticipated timeline for award of the phase one contracts is second quarter FY2014 (Goodwin, 2013). Phase one contract award in second quarter FY2014 is about two quarters behind the preliminary schedule we received. This schedule calls for the first OPC to be delivered in mid-FY2020 (Office of Aviation Acquisition, personal communication, August 8, 2013). Based on the anticipated two-quarter delay in contract award, we assumed the first OPC will be delivered in mid-FY2021 and procurements will follow the provided schedule with that one-year shift. The procurement schedule calls for one cutter each of the first three years and then two cutters per year until the entire fleet of 25 is delivered. This number has the potential to vary depending on factors such as cost, needs of the service, and the condition of other Coast Guard assets, but those are currently unknowns, so we used a 25-cutter OPC fleet size in this analysis. With a 20-year service life for the sUAS, this takes the life of the sUAS project to FY2055, which is the ending year for the LCC analysis.

D. PERSONNEL

We accounted for two types of personnel in this model: deployable AVDET personnel and shoreside personnel at the sUAS Operations Center. The sUAS CONOPS specifies that the AVDET would consist of three pilots and four mechanics (Assistant Commandant for Capability, 2013). This information varies from the two pilots and three mechanics that Aparicio and Wagner (2012) used based on their analysis because the CONOPS was released after their study. This seemingly small difference results in a $208,000 increase in costs per AVDET per year. For annual composite pay calculations, a senior pilot is defined as an O-3/4, a junior pilot as an O-2/3, a senior mechanic as an E-5/6, and a junior mechanic as an E-3/4. The composition of the AVDETs is shown in Table 8.

Table 8. AVDET Composition and Annual Composite Pay

AVDET Composition	sUAS CONOPS	Annual Composite Pay	Total Annual Composite Pay
Officer - Senior Pilot	1	$ 162,022	$ 162,022
Officer - Junior Pilot	2	$ 133,869	$ 267,739
Enlisted - Senior Mechanic	1	$ 89,008	$ 89,008
Enlisted - Junior Mechanic	3	$ 74,141	$ 222,423
Total Cost Per AVDET Per Year			**$ 741,193**

We equated the number of AVDETs required to the number of cutters supported. Unlike AVDETs that deploy with cutters in support of short range recovery (SRR) helicopters, the sUAS AVDET will meet the cutter in homeport and complete the entire patrol. AVDET personnel have the same employment standards as cutter personnel, which is a floating average of 185 days deployed per year. Although there will be personnel turnover within the AVDET personnel pool, the basic relationship of one AVDET per supported cutter holds. The pool of AVDET personnel varies with the number of cutters supported and ranges from nine pilots and 12 mechanics in FY2017 when three NSCs are supported to 99 pilots and 132 mechanics when all eight NSCs and all 25 OPCs are online in FY2035. Personnel costs are much higher than the procurement costs of the sUAS system and are second only to O&M costs.

The Operations Center command and support staff requirements have not been fully determined. We worked with the project office and defined a notional staffing plan. For this analysis, we defined a basic command structure headed by an O-4 CO/OINC and supported by four O-3s and two CWO engineering officers (EO). We assigned four maintenance chiefs and 14 mechanics in support of the EO and a five-personnel administrative staff. The Operations Center staff is shown in Table 9. The makeup of this unit will need further study before its planned stand-up in FY2019.

Table 9. Operations Center Staffing

Operations Center Staffing		Annual Composite Pay	Total Annual Composite Pay
CO (O4)	1	$ 174,343	$ 174,343
XO (O3)	1	$ 149,702	$ 149,702
OPS (O3)	3	$ 149,702	$ 449,106
Maintenance/EO (CWO)	2	$ 148,126	$ 296,252
Maintenance Chiefs (E7)	4	$ 116,356	$ 465,424
Mechanics (E4-E6)	14	$ 81,472	$ 1,140,617
Admin (E4-E7)	5	$ 88,558	$ 442,790
Total Cost Per Year			**$ 3,118,234**

E. TRAINING

Training is vital to ensure that the Coast Guard is able to use sUASs to meet mission requirements. Specific training is required for pilots and maintainers. Our research (discussed previously in Section II.E., **Error! Reference source not found.**) found that training costs for large UASs such as Fire Scout are $45,000–$48,000 (Heiss, 2012). Due to the much smaller size and reduced complexity of an sUAS as opposed to a UAS, the project office is using $10,000 as the estimated cost for training pilots on sUAS. We used this value, along with the $7,800 that Aparicio and Wagner (2012) used for maintenance training, in our analysis.

There are two populations that need to be addressed for training: (1) personnel assigned to support new AVDET manning because of new cutter support and (2) personnel assigned due to turnover. We built our model to account for all training in the year that a new cutter, either NSC or OPC, comes online. For the second population of personnel, we used a turnover rate of 25%, equating to a standard four-year tour length. Of all the costs in this analysis, the personnel training cost is the lowest.

F. OPERATIONS AND MAINTENANCE COSTS

The largest category of costs is O&M costs, accounting for over half of the total LCC, as can be seen in Figure 11. The Life-cycle Cost Tool displays these as discounted costs because the user can simply change the discount rate to 0% to obtain undiscounted costs. The O&M costs addressed in the analysis are organizational-level O&M, initial spares, spare-part carrying costs, transportation costs, and disposal costs. Preventive maintenance and depot-level costs have not been determined and are not part of this analysis. We discuss each of the included costs in turn.

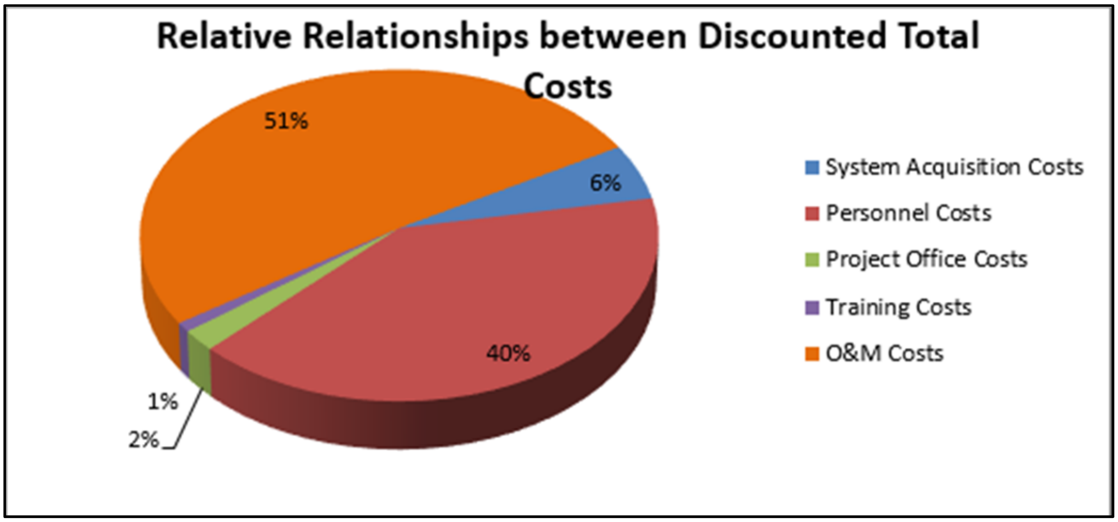


Figure 11. **Relative Relationships Between Discounted Cost Categories**

1. Initial Spares

Spare-part requirements are a function of many factors, including the number of systems, the amount of use (operations tempo), part reliability, and the amount of time that must be covered by the spares. Each of these components is discussed as follows**.**

The amount of use that an sUAS part will see is tied to flight hours for most components or number of evolutions for the launch and recovery mechanisms. Determination of flight hours and launch/recover evolutions for sUAS deployed on NSC and OPC are discussed in the Section IV.F.3, Operational Availability.

2. Organizational-Level Costs

The failure time for a part or component is known as mean time between failures (MTBF). The DAU defines *mean time between failures* as

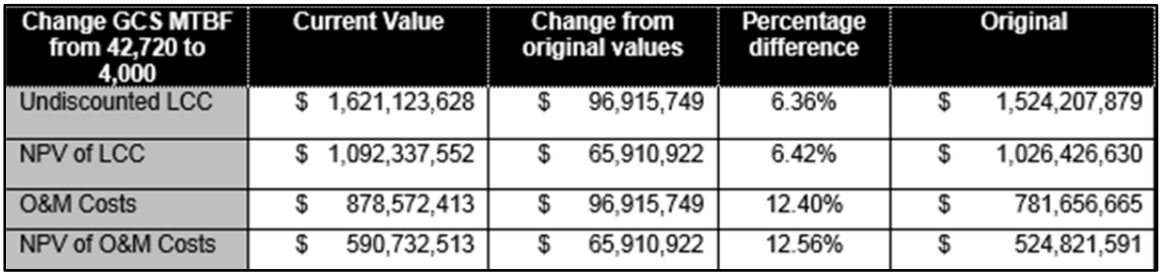
> for a particular interval, the total functional life of a population of an item divided by the total number of failures (requiring corrective

> maintenance actions) within the population. The definition holds for time, rounds, miles, events, or other measures of life unit. A basic technical measure of reliability recommended for use in the research and development (R&D) contractual specification environment, where "time" and "failure" must be carefully defined for contractual compliance purposes. (Defense Acquisition University [DAU], 2012)

More simply, MTBF is the amount of time or number of uses (i.e., sUAS launches) before a part is expected to fail. Values for MTBF are ideally determined by the manufacturer through testing programs. This is not always the case for new products or applications, and parametric estimation techniques are used to determine MTBF values for the system of interest. The principle behind MTBF calculations assumes that failures occur at a constant rate that can be approximated by an exponential distribution. While actual failures do not occur at a constant rate, the mean failure rate is constant. We used the same MTBF values as Aparicio and Wagner (2012), with a few exceptions. Based on the reliability information for military standard computers from Trenton Systems, we raised the MTBF for the GCS to 42,720, which equates to five years of 24/7 operation without a failure (Trenton Systems, n.d.). We also lowered the MTBF for the remote boarding team video terminal to 250 hours based on personal experience using this technology in the field. This adjustment is not necessarily a mark against the system, but against the abusive treatment inflicted upon it by the users.

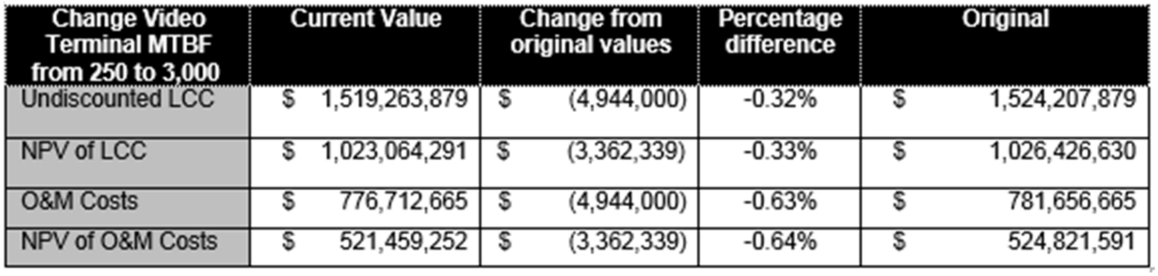
We conducted sensitivity analysis of these changes on LCC to demonstrate the power and usefulness of the LCC tool. The GCS is the most costly single component of the system and the reduction in its MTBF causes spares to be required on the cutters, raising the total LCC by over 6%, as shown in Table 10. The video terminal has a cost of only $10,000 and raising its MTBF cased the two spares per cutter to no longer be needed, resulting in the 0.3% reduction in total LCC shown in Table 11. Table 12 displays the combination of both changes.

Table 10. Change GCS MTBF From 42,720 to 4,000



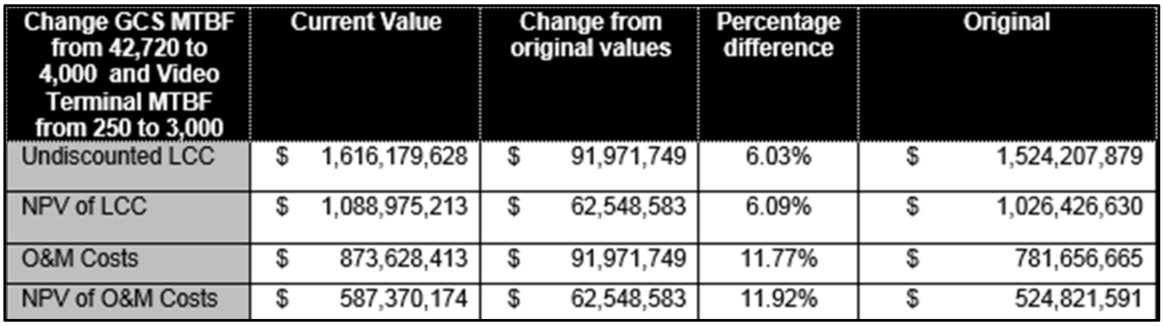
Change GCS MTBF from 42,720 to 4,000	Current Value	Change from original values	Percentage difference	Original
Undiscounted LCC	$ 1,621,123,628	$ 96,915,749	6.36%	$ 1,524,207,879
NPV of LCC	$ 1,092,337,552	$ 65,910,922	6.42%	$ 1,026,426,630
O&M Costs	$ 878,572,413	$ 96,915,749	12.40%	$ 781,656,665
NPV of O&M Costs	$ 590,732,513	$ 65,910,922	12.56%	$ 524,821,591

Table 11. Change Video Terminal MTBF From 250 to 3,000



Change Video Terminal MTBF from 250 to 3,000	Current Value	Change from original values	Percentage difference	Original
Undiscounted LCC	$ 1,519,263,879	$ (4,944,000)	-0.32%	$ 1,524,207,879
NPV of LCC	$ 1,023,064,291	$ (3,362,339)	-0.33%	$ 1,026,426,630
O&M Costs	$ 776,712,665	$ (4,944,000)	-0.63%	$ 781,656,665
NPV of O&M Costs	$ 521,459,252	$ (3,362,339)	-0.64%	$ 524,821,591

Table 12. Change GCS MTBF From 42,720 to 4,000 and Video Terminal MTBF From 250 to 3,00



Change GCS MTBF from 42,720 to 4,000 and Video Terminal MTBF from 250 to 3,000	Current Value	Change from original values	Percentage difference	Original
Undiscounted LCC	$ 1,616,179,628	$ 91,971,749	6.03%	$ 1,524,207,879
NPV of LCC	$ 1,088,975,213	$ 62,548,583	6.09%	$ 1,026,426,630
O&M Costs	$ 873,628,413	$ 91,971,749	11.77%	$ 781,656,665
NPV of O&M Costs	$ 587,370,174	$ 62,548,583	11.92%	$ 524,821,591

MTBF values are shown in Table 13 for NSC. Since there are different numbers of air vehicles and flight hours on OPC, the expected failures per year and all sparing data vary from NSC even though they share the same MTBF. The MTBF values are adjustable in the model for when actual usage data are available. “Expected failures per year” (μ) is solved by Equation 1:

$$\mu = k\lambda t \tag{1}$$

where

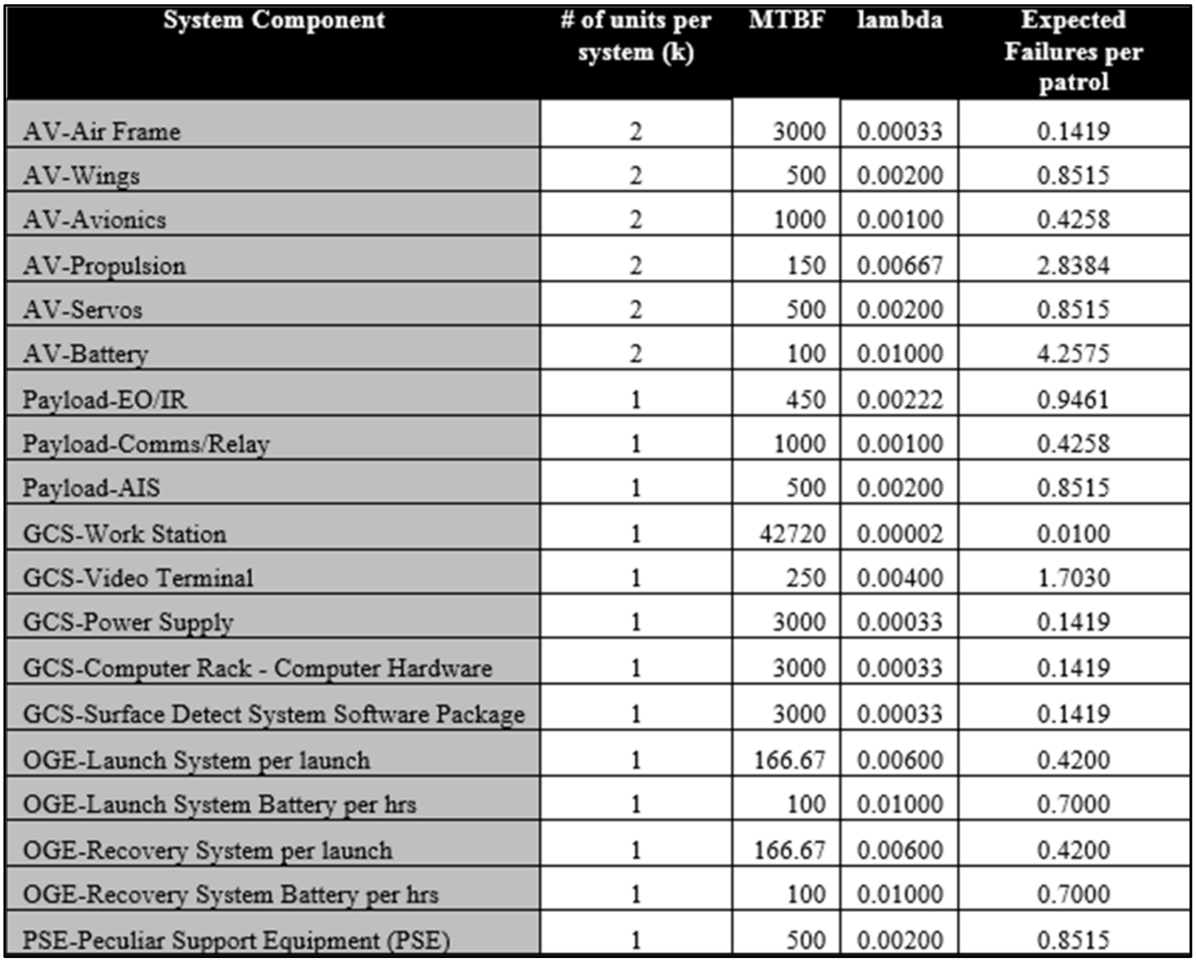
μ = # failures

k = # parts/system

λ = 1/MTBF

t = time = # flight hours/patrol

Table 13. NSC System Component Failure Information

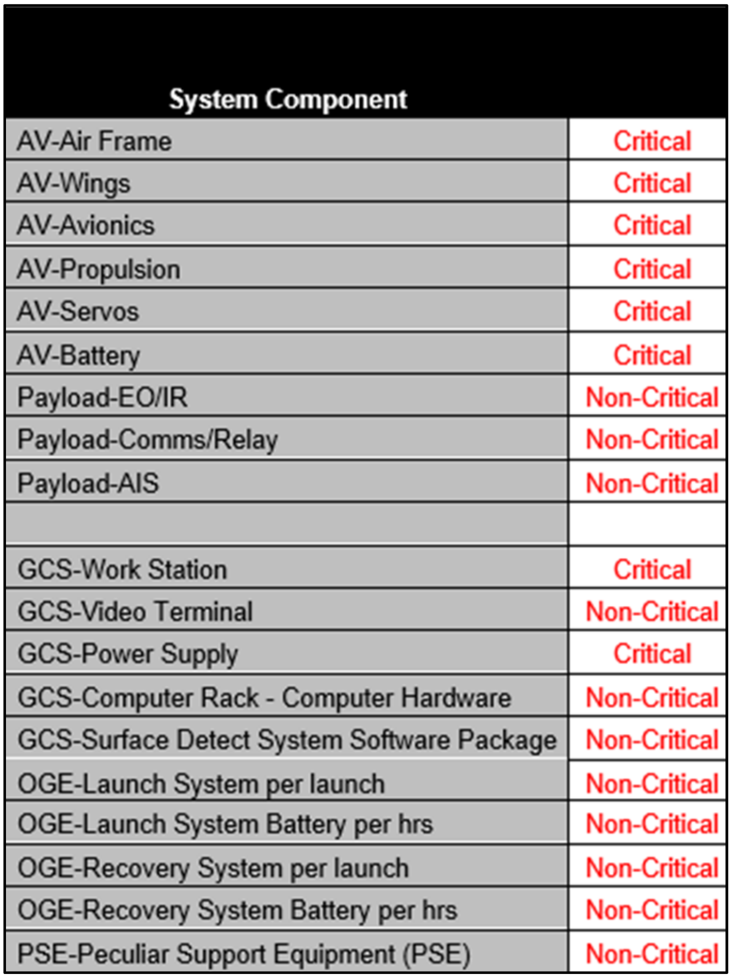


System Component	# of units per system (k)	MTBF	lambda	Expected Failures per patrol
AV-Air Frame	2	3000	0.00033	0.1419
AV-Wings	2	500	0.00200	0.8515
AV-Avionics	2	1000	0.00100	0.4258
AV-Propulsion	2	150	0.00667	2.8384
AV-Servos	2	500	0.00200	0.8515
AV-Battery	2	100	0.01000	4.2575
Payload-EO/IR	1	450	0.00222	0.9461
Payload-Comms/Relay	1	1000	0.00100	0.4258
Payload-AIS	1	500	0.00200	0.8515
GCS-Work Station	1	42720	0.00002	0.0100
GCS-Video Terminal	1	250	0.00400	1.7030
GCS-Power Supply	1	3000	0.00033	0.1419
GCS-Computer Rack - Computer Hardware	1	3000	0.00033	0.1419
GCS-Surface Detect System Software Package	1	3000	0.00033	0.1419
OGE-Launch System per launch	1	166.67	0.00600	0.4200
OGE-Launch System Battery per hrs	1	100	0.01000	0.7000
OGE-Recovery System per launch	1	166.67	0.00600	0.4200
OGE-Recovery System Battery per hrs	1	100	0.01000	0.7000
PSE-Peculiar Support Equipment (PSE)	1	500	0.00200	0.8515

We defined the amount of time that the system needs to be operational without spare-part resupply as the patrol length for a cutter. Logistical resupply is generally not an option for deployed cutters, so this was the minimum amount of time that must be covered. The patrol length is different for OPC and NSC and is user changeable.

Required part or component reliability is accounted for in “Protection Level.” The DAU defines *reliability* as “…the probability that the system will perform without failure over a specified interval under specified conditions. Reliability must be sufficient to support the warfighting capability needed in its expected operating environment” (DAU, 2012). Protection level is expressed as a value between zero and one, and indicates the probability that when a part fails, a replacement will be immediately available. This is also known as “Customer Service Level” or “Spare Part Availability.” A zero protection level indicates that the part will never be available and one indicates the part will always be available. With limitless space and funding, we would all like to always have a spare part immediately, but this is not realistic. Assignment of an appropriate protection level is a balance between the criticality of the part and the risk acceptance of not having a spare on hand. We identified two levels of parts in this analysis, and we designated critical or noncritical protection levels accordingly. Parts necessary for flight operation of the sUAS, such as wings and propulsion, were designated as critical with a protection level of 0.95. Other system components were designated as noncritical for flight and assigned a protection level of 0.75. The noncritical equipment list includes the system sensors because without them, the sUASs will still be able to fly and return to the cutter, even if they cannot perform the mission. Criticality for system components is the same for NSC and OPC. The critical/noncritical decision and the protection levels are adjustable in the model. Designated component criticality is displayed in Table 14.

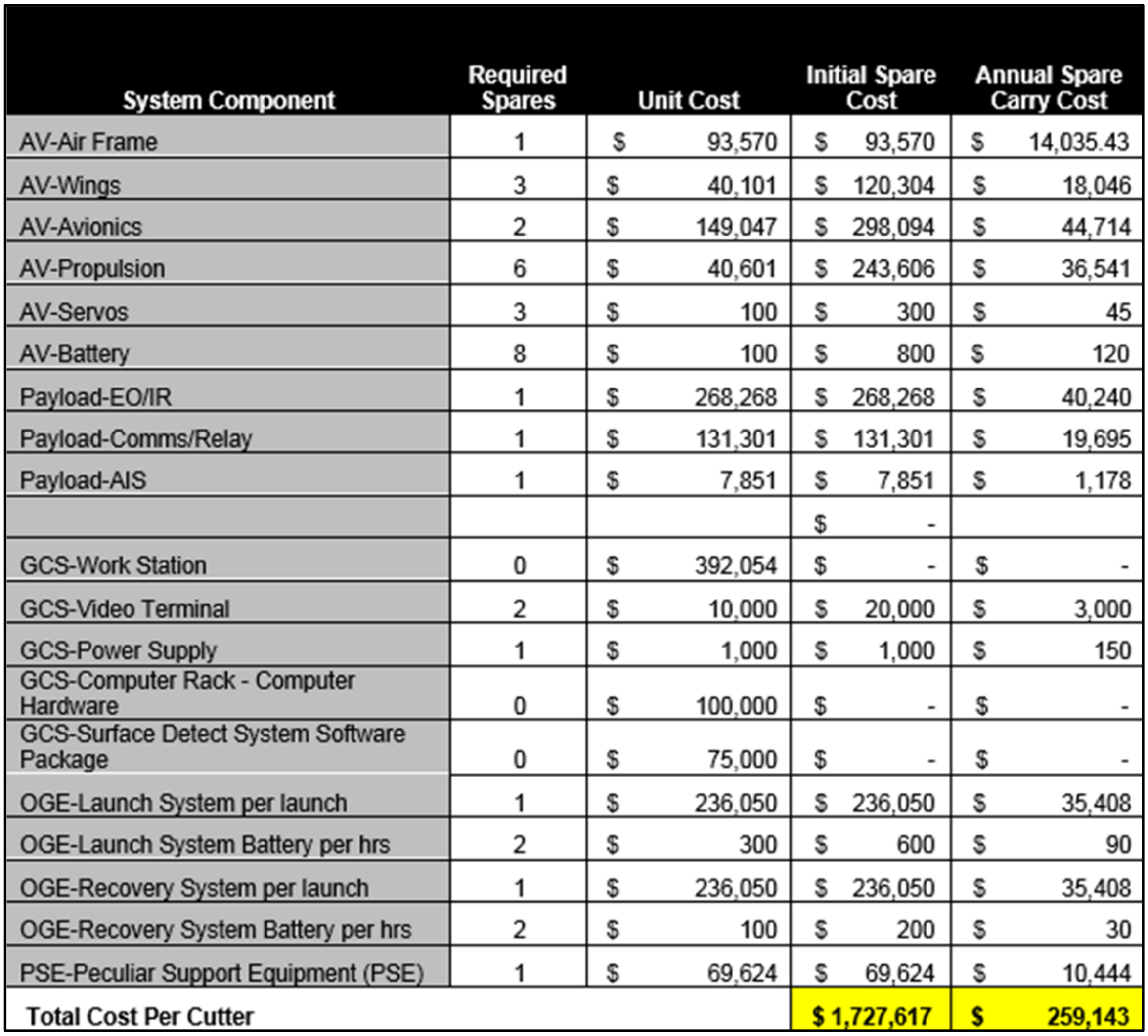
Table 14. sUAS Component Criticality



System Component	
AV-Air Frame	Critical
AV-Wings	Critical
AV-Avionics	Critical
AV-Propulsion	Critical
AV-Servos	Critical
AV-Battery	Critical
Payload-EO/IR	Non-Critical
Payload-Comms/Relay	Non-Critical
Payload-AIS	Non-Critical
GCS-Work Station	Critical
GCS-Video Terminal	Non-Critical
GCS-Power Supply	Critical
GCS-Computer Rack - Computer Hardware	Non-Critical
GCS-Surface Detect System Software Package	Non-Critical
OGE-Launch System per launch	Non-Critical
OGE-Launch System Battery per hrs	Non-Critical
OGE-Recovery System per launch	Non-Critical
OGE-Recovery System Battery per hrs	Non-Critical
PSE-Peculiar Support Equipment (PSE)	Non-Critical

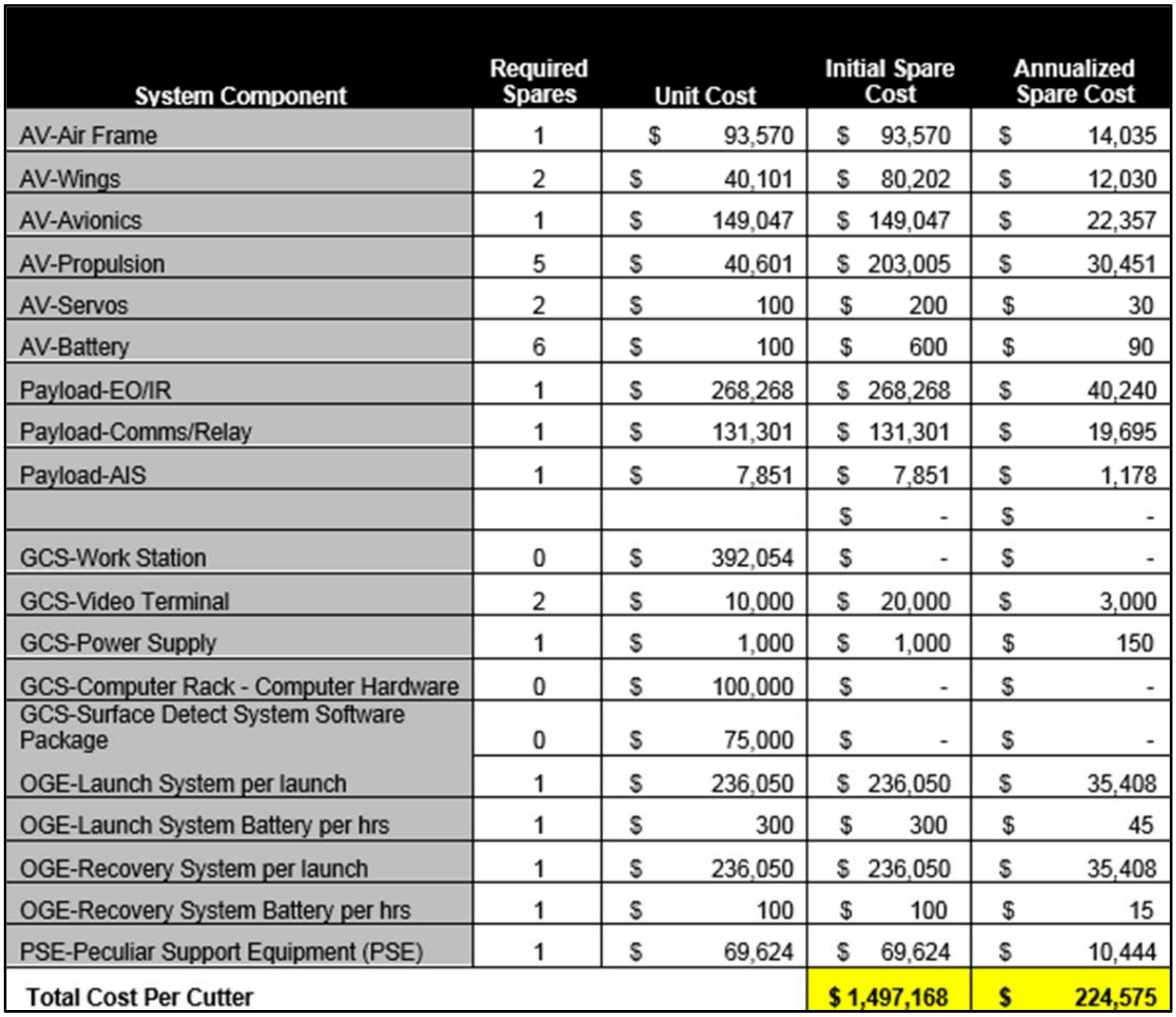
Expected failures per patrol (shown in Table 13) and protection level were used to determine the initial sparring level for sUASs deployed on both classes of cutters, shown in Table 15 and Table 16. Using the component costs from Table 3, we calculated initial spare costs along with the annual spare-part carrying cost using an annual carrying rate of 15%.

Table 15. NSC-Required Spares and Costs



System Component	Required Spares	Unit Cost	Initial Spare Cost	Annual Spare Carry Cost
AV-Air Frame	1	$ 93,570	$ 93,570	$ 14,035.43
AV-Wings	3	$ 40,101	$ 120,304	$ 18,046
AV-Avionics	2	$ 149,047	$ 298,094	$ 44,714
AV-Propulsion	6	$ 40,601	$ 243,606	$ 36,541
AV-Servos	3	$ 100	$ 300	$ 45
AV-Battery	8	$ 100	$ 800	$ 120
Payload-EO/IR	1	$ 268,268	$ 268,268	$ 40,240
Payload-Comms/Relay	1	$ 131,301	$ 131,301	$ 19,695
Payload-AIS	1	$ 7,851	$ 7,851	$ 1,178
			$ -	
GCS-Work Station	0	$ 392,054	$ -	$ -
GCS-Video Terminal	2	$ 10,000	$ 20,000	$ 3,000
GCS-Power Supply	1	$ 1,000	$ 1,000	$ 150
GCS-Computer Rack - Computer Hardware	0	$ 100,000	$ -	$ -
GCS-Surface Detect System Software Package	0	$ 75,000	$ -	$ -
OGE-Launch System per launch	1	$ 236,050	$ 236,050	$ 35,408
OGE-Launch System Battery per hrs	2	$ 300	$ 600	$ 90
OGE-Recovery System per launch	1	$ 236,050	$ 236,050	$ 35,408
OGE-Recovery System Battery per hrs	2	$ 100	$ 200	$ 30
PSE-Peculiar Support Equipment (PSE)	1	$ 69,624	$ 69,624	$ 10,444
Total Cost Per Cutter			**$ 1,727,617**	**$ 259,143**

Table 16. OPC-Required Spares and Costs



System Component	Required Spares	Unit Cost	Initial Spare Cost	Annualized Spare Cost
AV-Air Frame	1	$ 93,570	$ 93,570	$ 14,035
AV-Wings	2	$ 40,101	$ 80,202	$ 12,030
AV-Avionics	1	$ 149,047	$ 149,047	$ 22,357
AV-Propulsion	5	$ 40,601	$ 203,005	$ 30,451
AV-Servos	2	$ 100	$ 200	$ 30
AV-Battery	6	$ 100	$ 600	$ 90
Payload-EO/IR	1	$ 268,268	$ 268,268	$ 40,240
Payload-Comms/Relay	1	$ 131,301	$ 131,301	$ 19,695
Payload-AIS	1	$ 7,851	$ 7,851	$ 1,178
			$ -	$ -
GCS-Work Station	0	$ 392,054	$ -	$ -
GCS-Video Terminal	2	$ 10,000	$ 20,000	$ 3,000
GCS-Power Supply	1	$ 1,000	$ 1,000	$ 150
GCS-Computer Rack - Computer Hardware	0	$ 100,000	$ -	$ -
GCS-Surface Detect System Software Package	0	$ 75,000	$ -	$ -
OGE-Launch System per launch	1	$ 236,050	$ 236,050	$ 35,408
OGE-Launch System Battery per hrs	1	$ 300	$ 300	$ 45
OGE-Recovery System per launch	1	$ 236,050	$ 236,050	$ 35,408
OGE-Recovery System Battery per hrs	1	$ 100	$ 100	$ 15
PSE-Peculiar Support Equipment (PSE)	1	$ 69,624	$ 69,624	$ 10,444
Total Cost Per Cutter			**$ 1,497,168**	**$ 224,575**

3. Operational Availability

Operational availably (A_O) is the "probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon (i.e., at any random time)" (Kang, 2013). This measure is used by program managers as a trade off with cost to meet the user's needs at the most economical cost. The calculation of A_O is shown in Equation 2.

$$A_O = \frac{UpTime}{UpTime + DownTime} = \frac{TotalTime - CMDowntime - PMdowntime}{TotalTime} \qquad (2)$$

CMDowntime = Corrective Maintenance Downtime
PMDowntime = Preventive Maintenance Downtime

We calculated A_O for NSC and OPC using CMDowntime and PMDowntime and also calculated A_O using just CMDowntime to indicate the operational availability that should be expected on deployed cutters when no depot maintenance is planned. We used the same data for common maintenance times as Aparicio and Wagner (2012). These are shown in Table 17.

Table 17. Corrective Maintenance Times

			Two AV	One AV
Maintenance Time to change Propulsion	4.00	hours	46.04	49.33
Maintenance Time to change Wings	4.00	hours	13.81	14.80
Maintenance Time to change AV Battery	1.00	hours	17.27	18.50
Maintenance Time to change servos	4.00	hours	13.81	14.80
Total Hours for O-Level Maintenance		hours	90.94	97.43
Total Days of O-Level Maintenance		days	3.79	4.06
Maintenance Required for D-Level (per vehicle)		days		10.00

The corrective and preventive maintenance times were entered into Equation 2 with flight hours for each cutter class used for TotalTime. The results are shown in Table 18.

Table 18. Operational Availability for NSC and OPC

NSC Operational Availability	**0.808**
OPC Operational Availability	**0.818**
Deployed Operational Availability	**0.947**

The presentation of A_O along with LCC makes the Life-Cycle Cost Model we created more of a decision support tool for the program manager than simply a mathematical calculation tool.

4. Operations and Maintenance Costs

The cost to operate sUASs is dependent on the number of hours that the vehicles are flown. The sUAS CONOPS specifies one 12-hour mission per day (Assistant Commandant for Capability, 2013). Starting with this mission definition, the number of deployed days needed to be determined to calculate the number of flight hours per year. Standard employment rates for Coast Guard cutters are 185 days per year. Each cutter would not be able to fly an sUAS every deployed day due to transit time, mid-patrol breaks, weather, and other factors. The standard deployment is 90 days for an NSC and 60 days for an OPC. The cutters' operational areas are varying distances from homeport, so we applied factors of twice the 10-

and five-day transit times to NSC and OPC, respectively, to account for all of the days during a patrol when the sUASs would not be flying. We calculated employment percentages for each cutter using Equation 3:

$$\frac{PatrolLength - 2 * TransitTime}{PatrolLength} = Employment\ Pecentage \qquad (3)$$

Flight hours per year were calculated using Equation 4:

$$Employment\ Percentage * Mission\ Length * \frac{Days}{Year} = Flight\ Hours \qquad (4)$$

These data are shown in Table 19. Keep in mind that NSC flight hours are shared between two sUASs.

Table 19. sUAS Flight Hours per Year on NSC and OPC

Mission Length	12
Cutter Employment per year	185
OPC average patrol length	60
OPC average transit time	5
OPC employment percentage	83.33%
NSC average patrol length	90
NSC average transit time	10
NSC employment percentage	77.78%
Calculated % days in op area	80.56%
NSC UAS hours per year	1726.67
OPC UAS hours per year	1850

Like Aparicio and Wagner (2012), we used a calculated operational cost per flight hour. Wyle Laboratories (2010) completed a study for the Coast Guard that compared the MQ-8 Fire Scout to an SRR helicopter and found that the Fire Scout had an anticipated cost of $2,016 per flight hour. The Coast Guard stated that the cost per flight hour of sUAS “is projected to be only 10–15% of the cost of the Fire Scout procurement” (United States Coast Guard Office of Aviation Forces [CG-711], 2010). Fifteen percent of $2,016 results in an sUAS cost per flight hour of $302.

The maintenance cost per flight hour is based on the consumption of spare parts. Using the initial spare-parts costs for NSC and OPC of $1,727,617 and $1,497,168, respectively, and the flight hours per year from Table 19 results in annualized spare part costs per flight hour of $370 for NSC and $202 for OPC.

5. Transportation Cost

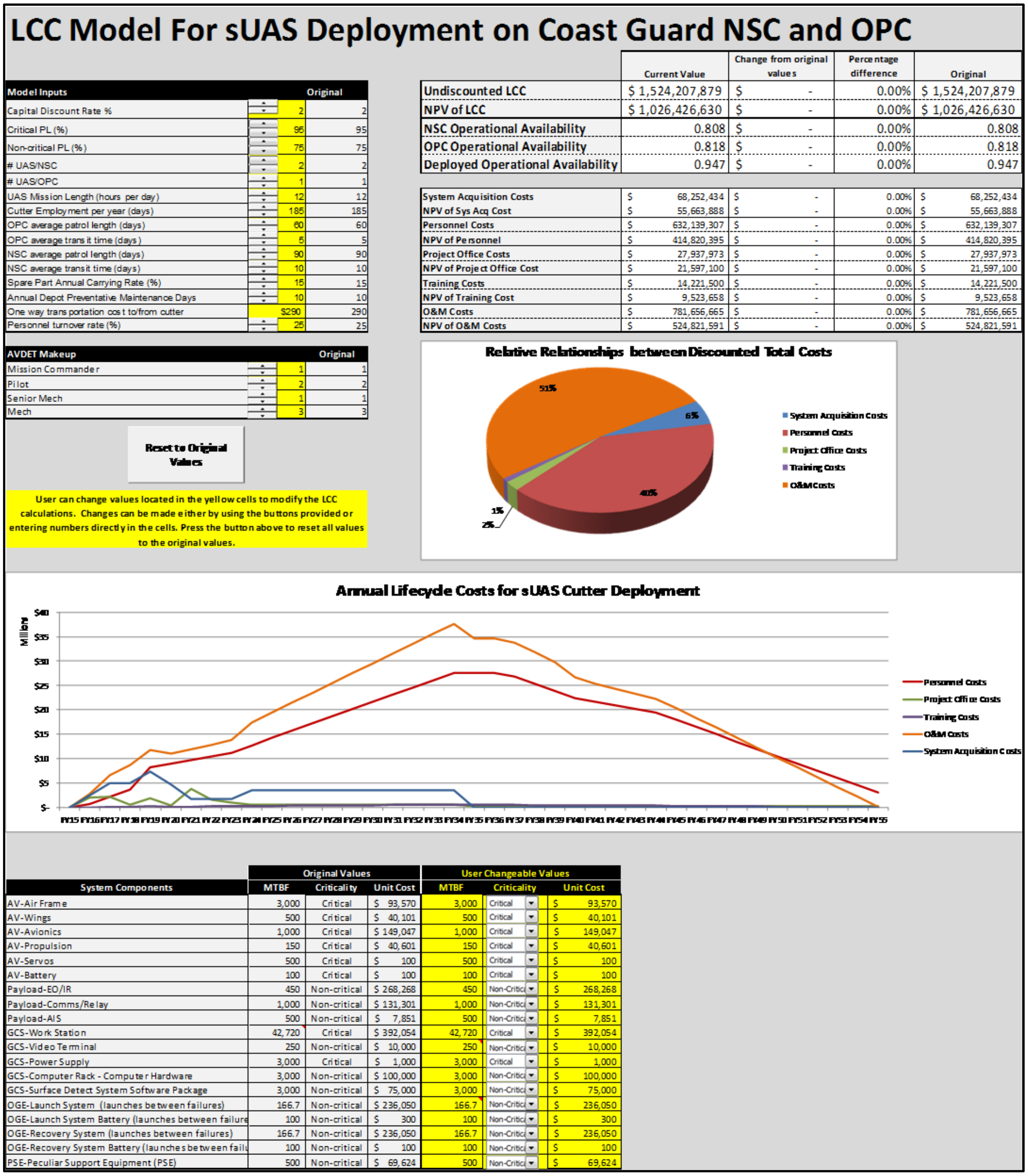
Transportation cost in this model is defined as the cost to ship the sUAS system from the Operations Center to or from a cutter for deployment. The value of $290 was provided by the project office.

6. Disposal Cost

Disposal cost includes all costs to remove an asset from service. The DAU includes four processes/decisions in its definition of *disposal*—deactivation, disposition, demilitarization, and disposal (“Disposal and Disposition,” 2013). The sUAS is basically a commercially available system, so the disposal cost used in this analysis is 10% of procurement cost.

G. DASHBOARD

The value in developing an LCC model is that it is easily modified by the user through the interface screen, or dashboard. A screen capture is shown in Figure 12. We built the model using the most accurate data available and the current decisions in place, but the data and decisions may change in the future. As these changes occur, the inputs can be easily adjusted to reflect the new reality. The impacts of these changes are immediately available numerically and graphically.



LCC Model For sUAS Deployment on Coast Guard NSC and OPC

Model Inputs		Original
Capital Discount Rate %	2	2
Critical PL (%)	95	95
Non-critical PL (%)	75	75
# UAS/NSC	2	2
# UAS/OPC	1	1
UAS Mission Length (hours per day)	12	12
Cutter Employment per year (days)	185	185
OPC average patrol length (days)	60	60
OPC average transit time (days)	5	5
NSC average patrol length (days)	90	90
NSC average transit time (days)	10	10
Spare Part Annual Carrying Rate (%)	15	15
Annual Depot Preventative Maintenance Days	10	10
One way transportation cost to/from cutter	$290	290
Personnel turnover rate (%)	25	25

	Current Value	Change from original values	Percentage difference	Original
Undiscounted LCC	$ 1,524,207,879	$ -	0.00%	$ 1,524,207,879
NPV of LCC	$ 1,026,426,630	$ -	0.00%	$ 1,026,426,630
NSC Operational Availability	0.808	$ -	0.00%	0.808
OPC Operational Availability	0.818	$ -	0.00%	0.818
Deployed Operational Availability	0.947	$ -	0.00%	0.947

System Acquisition Costs	$ 68,252,434	$ -	0.00%	$ 68,252,434
NPV of Sys Acq Cost	$ 55,663,888	$ -	0.00%	$ 55,663,888
Personnel Costs	$ 632,139,307	$ -	0.00%	$ 632,139,307
NPV of Personnel	$ 414,820,395	$ -	0.00%	$ 414,820,395
Project Office Costs	$ 27,937,973	$ -	0.00%	$ 27,937,973
NPV of Project Office Cost	$ 21,597,100	$ -	0.00%	$ 21,597,100
Training Costs	$ 14,221,500	$ -	0.00%	$ 14,221,500
NPV of Training Cost	$ 9,523,658	$ -	0.00%	$ 9,523,658
O&M Costs	$ 781,656,665	$ -	0.00%	$ 781,656,665
NPV of O&M Costs	$ 524,821,591	$ -	0.00%	$ 524,821,591

AVDET Makeup		Original
Mission Commander	1	1
Pilot	2	2
Senior Mech	1	1
Mech	3	3

User can change values located in the yellow cells to modify the LCC calculations. Changes can be made either by using the buttons provided or entering numbers directly in the cells. Press the button above to reset all values to the original values.

	Original Values			User Changeable Values		
System Components	MTBF	Criticality	Unit Cost	MTBF	Criticality	Unit Cost
AV-Air Frame	3,000	Critical	$ 93,570	3,000	Critical	$ 93,570
AV-Wings	500	Critical	$ 40,101	500	Critical	$ 40,101
AV-Avionics	1,000	Critical	$ 149,047	1,000	Critical	$ 149,047
AV-Propulsion	150	Critical	$ 40,601	150	Critical	$ 40,601
AV-Servos	500	Critical	$ 100	500	Critical	$ 100
AV-Battery	100	Critical	$ 100	100	Critical	$ 100
Payload-EO/IR	450	Non-critical	$ 268,268	450	Non-Critica	$ 268,268
Payload-Comms/Relay	1,000	Non-critical	$ 131,301	1,000	Non-Critica	$ 131,301
Payload-AIS	500	Non-critical	$ 7,851	500	Non-Critica	$ 7,851
GCS-Work Station	42,720	Critical	$ 392,054	42,720	Critical	$ 392,054
GCS-Video Terminal	250	Non-critical	$ 10,000	250	Non-Critica	$ 10,000
GCS-Power Supply	3,000	Critical	$ 1,000	3,000	Critical	$ 1,000
GCS-Computer Rack - Computer Hardware	3,000	Non-critical	$ 100,000	3,000	Non-Critica	$ 100,000
GCS-Surface Detect System Software Package	3,000	Non-critical	$ 75,000	3,000	Non-Critica	$ 75,000
OGE-Launch System (launches between failures)	166.7	Non-critical	$ 236,050	166.7	Non-Critica	$ 236,050
OGE-Launch System Battery (launches between failure	100	Non-critical	$ 300	100	Non-Critica	$ 300
OGE-Recovery System (launches between failures)	166.7	Non-critical	$ 236,050	166.7	Non-Critica	$ 236,050
OGE-Recovery System Battery (launches between failu	100	Non-critical	$ 100	100	Non-Critica	$ 100
PSE-Peculiar Support Equipment (PSE)	500	Non-critical	$ 69,624	500	Non-Critica	$ 69,624

Figure 12. **LCC Model Dashboard Screen Capture**

The dashboard interface provides the user with more than a way to update data to reflect current conditions. Through this interface, the user can easily change multiple model inputs and see immediate impacts to LCC. This is useful for analyzing the effects of policy decisions and choosing the best course of action or answering budget and capability questions. For example, the current guidance defines the NSC sUAS system as two air vehicles, the OPC system as one air vehicle, and the AVDET as three pilots and four mechanics. A possible scenario is that the AVDET composition may change and commanding officers will request additional air vehicles to support their missions, especially as swarm technology becomes more readily available. The user can remove one mechanic from the AVDET and change the OPC sUAS definition to 1.5 air vehicles, providing for one air vehicle when conducting fisheries patrols and two air vehicles when conducting counternarcotics or migrant interdiction patrols. In this case, there are higher procurement and O&M costs, but reductions in personnel and training costs result in an overall $43 million undiscounted savings over the life of the project.

H. SUMMARY

This chapter described the LCC tool that we developed to support the Coast Guard Office of Aviation Acquisition sUAS procurement. This quantitative tool provides information that the project office needs to manage the acquisition project and prepare for an upcoming ADE 2 decision. The output of the tool is an LCC based on a snapshot of the data and decisions that were current when we created the tool; however, the built-in adjustment ensures that future changes can easily be captured and an updated LCC provided. The tool also displays numerically and graphically the breakdown in costs by the major categories of procurement, personnel, training, and O&M. These categories are each funded by different sources, and the demands of this project on each of them must be supportable, or the entire project cannot succeed.

V. CONCLUSION AND RECOMMENDATIONS FOR FURTHER RESEARCH

A. SUMMARY

As the Coast Guard endeavors to close the operational gaps created by the postponements in the NSC delivery schedule, it is important to assess the cost implications of sUASs on NSC with reasonable accuracy. The purpose of this research was to conduct an LCC analysis of sUAS deployment on Coast Guard cutters to assist the program management team. This research provides the program management team with an LCC analysis tool that incorporates the most current and accurate data available. We also provide research on current and emerging technologies in the sUAS field that could benefit the Coast Guard (e.g., swarm technology). Further, as the Coast Guard sUAS acquisition program requirements potentially change, the LCC analysis tool provides the program team with a custom tailored instrument that they can update themselves and use in providing accurate forecasting of LCC and program decision-making.

1. LCC Tool

The LCC tool created during the research project will directly support the Coast Guard Office of Aviation Acquisition in the attainment of an ADE 2 approval. The major cost components analyzed in the model are acquisition, personnel, training, O&M, and project office costs. Based on the information provided by the project office and this research and analysis, the tool outputs a detailed LCC broken down by these cost categories. The tool enables the user to determine the anticipated cost of the system and to budget appropriately in each cost category.

The functionality of the tool is not limited to a static LCC. The user interface was designed to allow the user to easily change the model parameters and compare the resultant LCC. This is useful when updated information is available. It also enables the user to generate scenarios that could be used to answer budget, policy, or equipment questions and quickly see the outcomes numerically and visually. For example, if the manufacturer offers to switch to a more expensive propulsion system that has a higher reliability, the user can enter the new data and get an immediate answer about whether it is a cost-effective change. The composition of the sUAS Operations Center has not been finalized. The user can easily change the number and rank mix of personnel to see the LCC implications. In short, this LCC tool is more than just a single-use project. It is a tool that can be used over the long term to manage the sUAS project.

2. Market Research of sUAS Technology

Additionally, we conducted research on emerging technology in the field of sUAS. This research provides information on what other agencies, such as the Navy and Air Force, in collaboration with the commercial market, are currently developing. The Navy has made significant advancements in the utilization of sUASs in operations. As sUAS payload technology has advanced, payload weights have significantly reduced. As a result, sUASs are becoming more capable of providing the same capabilities as larger UASs with the benefit of longer durations of flights. sUAS payloads are being utilized to contribute to operations in the collection of meteorology data, NBC disaster detection, search and rescue, and HA/DR.

The Navy and commercial partners are also making advances in swarm technology. Swarm technology will revolutionize sUAS applications in the future and be the impetus for a paradigm shift in how UASs are utilized. The purchasing of a commercially developed and demonstrated swarm technology algorithm would greatly assist the Coast Guard by multiplying its ISR capabilities and increasing its effectiveness and efficiency in search and rescue operations. This research in the current state of sUAS technology reaffirms the value of the Coast Guard's collaborating with the Navy in the development and acquisition of sUAS technology.

The state of technology with aerial tagging capabilities is another promising area that can benefit the Coast Guard. This technology can be deployed by an sUAS and used to enhance the tracking of persons or vessels of interest by the sUAS or other Coast Guard assets.

B. AREAS FOR FURTHER RESEARCH

1. Integration of Swarm Technology

We reviewed the current and near-future state of swarm technology. There is a hardware cost for the additional air vehicles and additional maintenance costs for more flight hours, but there would not necessarily be additional personnel costs because the same AVDET could operate a swarm. The benefits of a swarm of sUASs under control of the cutter CO are tremendous. A substantially larger area could be searched in the same amount of time, or multiple sUASs with different sensors could be flown near each other to provide an enhanced surveillance capability. This technology has been demonstrated and should be reviewed by the Coast Guard for future integration.

2. Further Research Into the sUAS as a Final Requirement Solution

The literature review on the advances in emerging sUAS payload capabilities and swarm technology revealed the potential of sUASs to fulfill the long-term ISR requirements for NSCs. The utilization of sUASs as a final requirement solution would have significant program life-cycle cost-savings implications when compared with the LCC of a large UAS such as the Navy's MQ-4 Fire Scout. These technological advances, coupled with the reality of the fiscal constraints affecting the Coast Guard into the foreseeable future, highlight the need for further research to assess the potential sUAS as a final requirement solution.

The unit cost and LCC of the sUAS should fall as this type of UAS moves into widespread commercial use in the coming years. There are already two sUAS platforms approved by the FAA for domestic use. There are both government (police, fire, search and rescue) and commercial uses for these vehicles. An ever-expanding population of users will drive down the cost to procure and maintain the equipment while continually pushing the capability envelope. This is an opportunity for the Coast Guard to take advantage of its government/military position as an early adopter of the sUAS to provide some direction to the market and then capitalize on the benefits of an almost-COTS solution for long-term mission support.

3. sUAS Operations Center Staffing Requirements

The creation of the LCC model required a basic manpower analysis. We used the AVDET size specified in the sUAS CONOPS to determine the number of pilots and mechanics needed to support deployable components of the sUAS mission. We worked with the project office to determine a basic command structure for the Operations Center. Additional research to determine the optimal command structure and the rates and ranks required to fill out the shoreside support for the deployable sUAS mission has the potential to reduce the personnel LCC while enhancing operational support.

4. Deployment on Legacy Assets

The NSC program is in place to replace the aging WHEC cutters. This transition has already begun with NSC commissionings and WHEC decommissionings. The WMEC fleet is scheduled to be replaced by the OPC. However, the decommissioning of the WMEC fleet is not scheduled to start until the latter half of the second decade of this century and will not be completed until after 2033. WMEC cutters will conduct hundreds of thousands of patrol hours before decommissioning. Deployment of sUASs to these platforms would provide the same enhanced mission effectiveness that is designed into the NSC and OPC platforms.

5. Employment of Aerial Tagging Technologies

There are multiple aerial deployed tagging technologies available or in development by numerous government agencies. Incorporating these technologies into the sUAS, or even current and future SRR helicopter, would enhance tracking capabilities. Narcotics traffickers know that a non-moving boat covered in a blue tarp is very difficult to see and maintain visual contact with if discovered. The ability to actively tag this type of vessel with a marker that makes relocation or tracking easier will improve overall mission effectiveness. Another scenario would be to tag a person in the water. Once located, maintaining visual contact with a person can be difficult even in the calmest seas. Tagged persons would be more easily tracked until rescue assets arrive on-scene.

C. CONCLUSION

This research sought to assist the Coast Guard’s UAS program management team. We developed an LCC analysis tool based on the most current and accurate data. This tool has lasting value to the program team because it can be adjusted in the future to reflect the evolving program requirements environment and provide the associated changes’ cost implications. Additionally, we provided recommendations for further research into the implementation of enhancing technologies for sUASs on Coast Guard vessels, such as swarm technology. Swarm technology would increase an NSC’s ISR capabilities and potentially make sUASs a viable final requirement solution to fill the current NSC’s capabilities gap with potential cost-savings implications.

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APPENDIX. USER INSTRUCTIONS FOR VARIOUS SCENARIOS

We provided some examples of how users could answer questions using the LCC Tool we created throughout this document. This section will provide some specific instructions for some selected scenarios. The format for these instructions is based on work by Keebom and Doerr (working paper (obtained from the authors)). The scenarios discussed include:

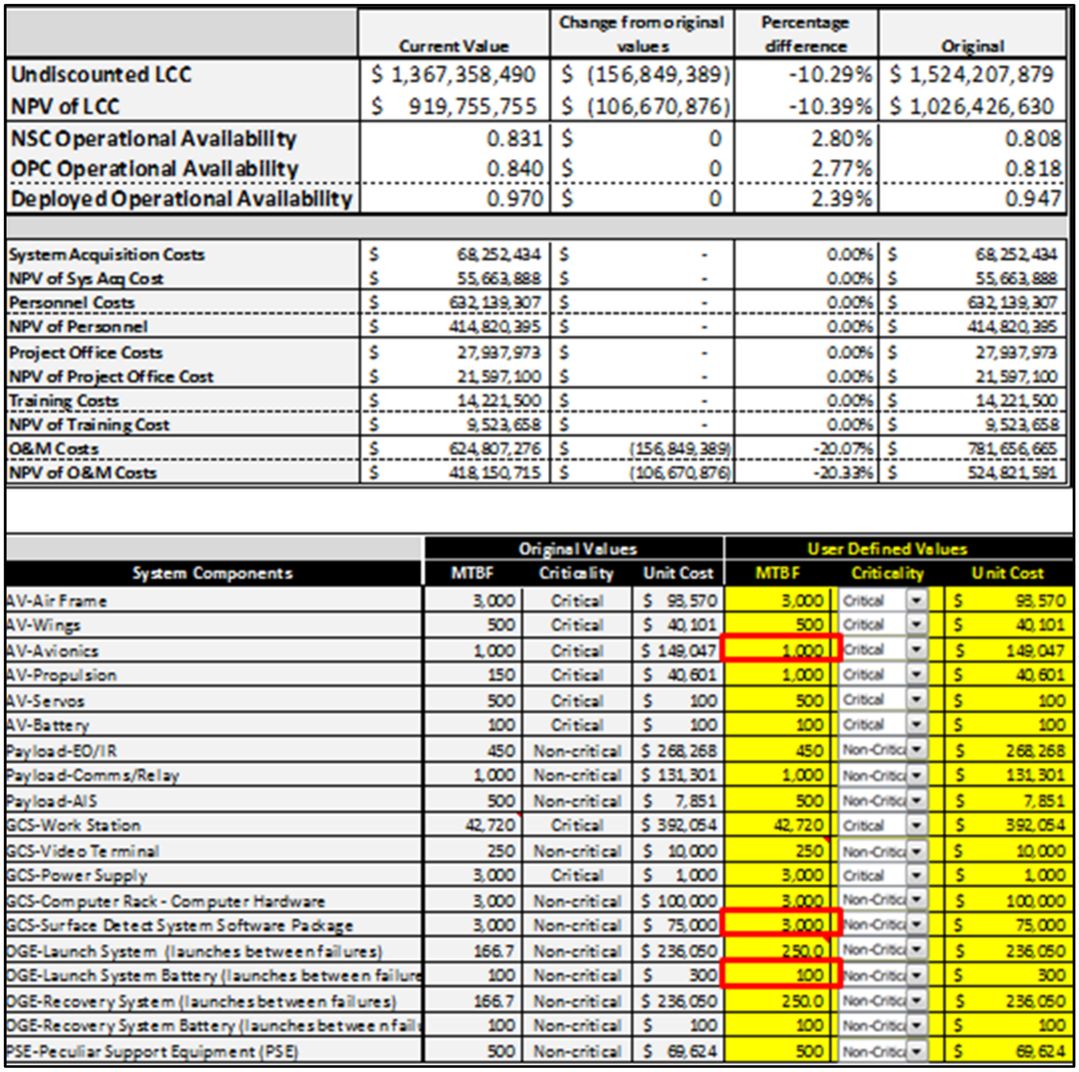
- Reduction in project funding by X% due to sequestration or other external budget constraints
- Change in policy allowing non-pilot-rated operators combined with reduced AVDET size. New AVDET will consist of a mission commander (officer) with five enlisted operators/maintainers.
- Manufacturer offers to improve reliability of the propulsion system from 150 to 500 hours MTBF for a $10,000,000. Is it worth it?

A. BUDGET REDUCTION

Forced budget reductions are not uncommon in acquisition projects and are not limited to sequestration. Project managers generally have to come up with answers to the effects on their project with 1%, 2%, 5%, and 10% reductions. The mathematical answer is known, but the important answer to higher ups is how the reduction was achieved. We will describe a 10% reduction in the scenario.

One possible way to achieve a 10% reduction is to improve the reliability of some components. This would reduce spare parts costs and the overall LCC. In this example we improved the reliability of the launch and recovery systems to a MTBF of 250 launches and the propulsion system to a MTBF of 1000 flight hours. On the reliability section of the dashboard, values are changed by simply entering the new values in the yellow-background cells under the “User Defined Values” heading. The changes made are shown in Figure A1 and highlighted with red boxes.

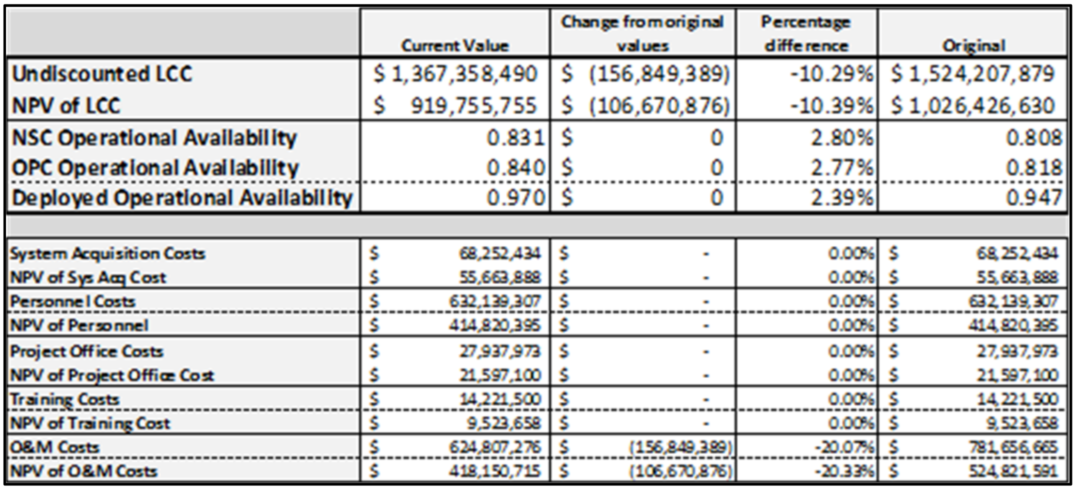
Figure A2 displays the resulting 10% reduction in LCC.



	Current Value	Change from original values	Percentage difference	Original
Undiscounted LCC	$ 1,367,358,490	$ (156,849,389)	-10.29%	$ 1,524,207,879
NPV of LCC	$ 919,755,755	$ (106,670,876)	-10.39%	$ 1,026,426,630
NSC Operational Availability	0.831	$ 0	2.80%	0.808
OPC Operational Availability	0.840	$ 0	2.77%	0.818
Deployed Operational Availability	0.970	$ 0	2.39%	0.947
System Acquisition Costs	$ 68,252,434	$ -	0.00%	$ 68,252,434
NPV of Sys Acq Cost	$ 55,663,888	$ -	0.00%	$ 55,663,888
Personnel Costs	$ 632,139,307	$ -	0.00%	$ 632,139,307
NPV of Personnel	$ 414,820,395	$ -	0.00%	$ 414,820,395
Project Office Costs	$ 27,937,973	$ -	0.00%	$ 27,937,973
NPV of Project Office Cost	$ 21,597,100	$ -	0.00%	$ 21,597,100
Training Costs	$ 14,221,500	$ -	0.00%	$ 14,221,500
NPV of Training Cost	$ 9,523,658	$ -	0.00%	$ 9,523,658
O&M Costs	$ 624,807,276	$ (156,849,389)	-20.07%	$ 781,656,665
NPV of O&M Costs	$ 418,150,715	$ (106,670,876)	-20.33%	$ 524,821,591

	Original Values			User Defined Values		
System Components	MTBF	Criticality	Unit Cost	MTBF	Criticality	Unit Cost
AV-Air Frame	3,000	Critical	$ 93,570	3,000	Critical	$ 93,570
AV-Wings	500	Critical	$ 40,101	500	Critical	$ 40,101
AV-Avionics	1,000	Critical	$ 149,047	1,000	Critical	$ 149,047
AV-Propulsion	150	Critical	$ 40,601	1,000	Critical	$ 40,601
AV-Servos	500	Critical	$ 100	500	Critical	$ 100
AV-Battery	100	Critical	$ 100	100	Critical	$ 100
Payload-EO/IR	450	Non-critical	$ 268,268	450	Non-Critic	$ 268,268
Payload-Comms/Relay	1,000	Non-critical	$ 131,301	1,000	Non-Critic	$ 131,301
Payload-AIS	500	Non-critical	$ 7,851	500	Non-Critic	$ 7,851
GCS-Work Station	42,720	Critical	$ 392,054	42,720	Critical	$ 392,054
GCS-Video Terminal	250	Non-critical	$ 10,000	250	Non-Critic	$ 10,000
GCS-Power Supply	3,000	Critical	$ 1,000	3,000	Critical	$ 1,000
GCS-Computer Rack - Computer Hardware	3,000	Non-critical	$ 100,000	3,000	Non-Critic	$ 100,000
GCS-Surface Detect System Software Package	3,000	Non-critical	$ 75,000	3,000	Non-Critic	$ 75,000
DGE-Launch System (launches between failures)	166.7	Non-critical	$ 236,050	250.0	Non-Critic	$ 236,050
DGE-Launch System Battery (launches between failure	100	Non-critical	$ 300	100	Non-Critic	$ 300
DGE-Recovery System (launches between failures)	166.7	Non-critical	$ 236,050	250.0	Non-Critic	$ 236,050
DGE-Recovery System Battery (launches between fail	100	Non-critical	$ 100	100	Non-Critic	$ 100
PSE-Peculiar Support Equipment (PSE)	500	Non-critical	$ 69,624	500	Non-Critic	$ 69,624

Figure A1. Changes Made to MTBF Values



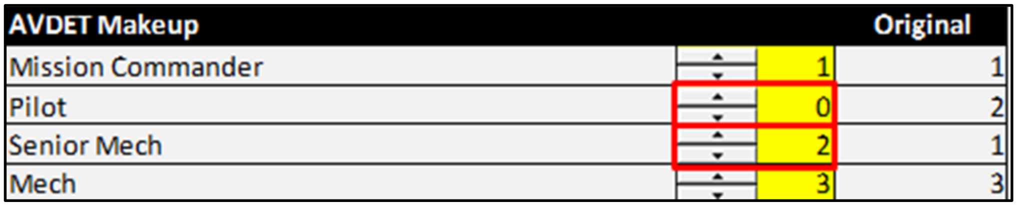
	Current Value	Change from original values	Percentage difference	Original
Undiscounted LCC	$ 1,367,358,490	$ (156,849,389)	-10.29%	$ 1,524,207,879
NPV of LCC	$ 919,755,755	$ (106,670,876)	-10.39%	$ 1,026,426,630
NSC Operational Availability	0.831	$ 0	2.80%	0.808
OPC Operational Availability	0.840	$ 0	2.77%	0.818
Deployed Operational Availability	0.970	$ 0	2.39%	0.947
System Acquisition Costs	$ 68,252,434	$ -	0.00%	$ 68,252,434
NPV of Sys Acq Cost	$ 55,663,888	$ -	0.00%	$ 55,663,888
Personnel Costs	$ 632,139,307	$ -	0.00%	$ 632,139,307
NPV of Personnel	$ 414,820,395	$ -	0.00%	$ 414,820,395
Project Office Costs	$ 27,937,973	$ -	0.00%	$ 27,937,973
NPV of Project Office Cost	$ 21,597,100	$ -	0.00%	$ 21,597,100
Training Costs	$ 14,221,500	$ -	0.00%	$ 14,221,500
NPV of Training Cost	$ 9,523,658	$ -	0.00%	$ 9,523,658
O&M Costs	$ 624,807,276	$ (156,849,389)	-20.07%	$ 781,656,665
NPV of O&M Costs	$ 418,150,715	$ (106,670,876)	-20.33%	$ 524,821,591

Figure A2. Reduction in LCC Through MTBF Improvements

B. AVDET CHANGES

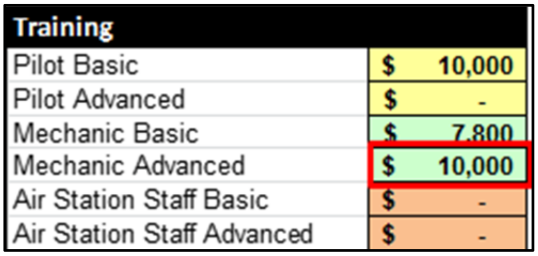
This scenario describes one possible outcome if the FAA determines that rated pilots are not required to pilot sUASs. The project office may need to restructure the AVDET personnel to consist of a mission commander and five enlisted operator/maintainers.

Completing this change in the LCC Tool is more complicated than the above LCC reduction because information must be changed in multiple places. First, the personnel numbers that make up the AVDET are changed on the dashboard using the up and down arrows for the respective positions. These are highlighted by red boxes in Figure A3. The second change is to add flight training cost for the enlisted personnel. Since the model is built to only have officer pilots, the cost for flight training can be added as advanced mechanic training on the second worksheet in the tool titled “List Input Page.” The $10,000 for flight training was added as advanced maintenance training, shown in Figure A4. The results of these changes on LCC are shown in Figure A5.



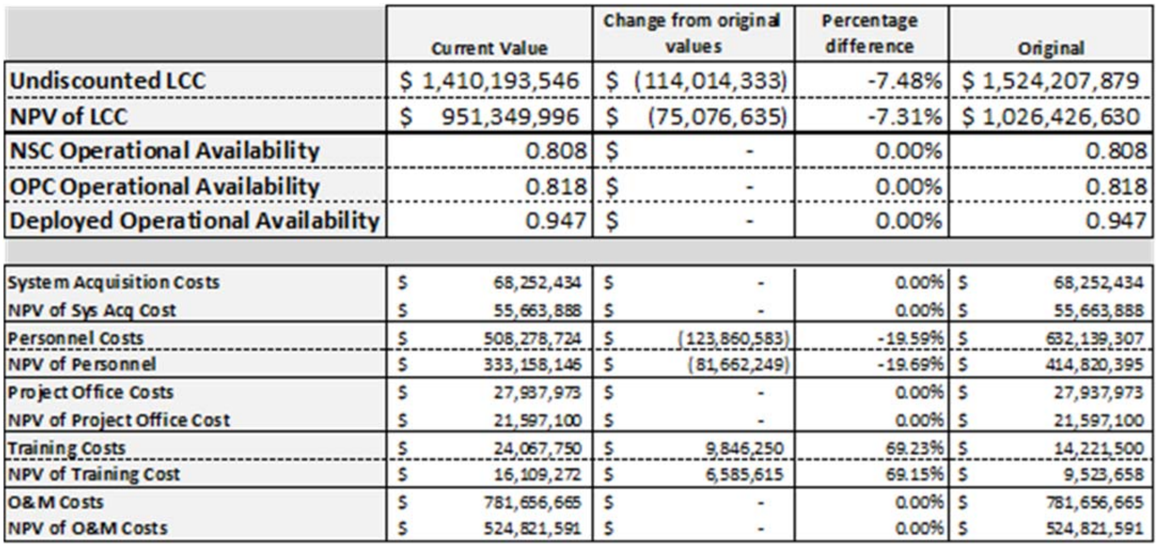
AVDET Makeup		Original
Mission Commander	1	1
Pilot	0	2
Senior Mech	2	1
Mech	3	3

Figure A3. Changes to AVDET Personnel



Training	
Pilot Basic	$ 10,000
Pilot Advanced	$ -
Mechanic Basic	$ 7,800
Mechanic Advanced	$ 10,000
Air Station Staff Basic	$ -
Air Station Staff Advanced	$ -

Figure A4. Insertion of Pilot Training Costs



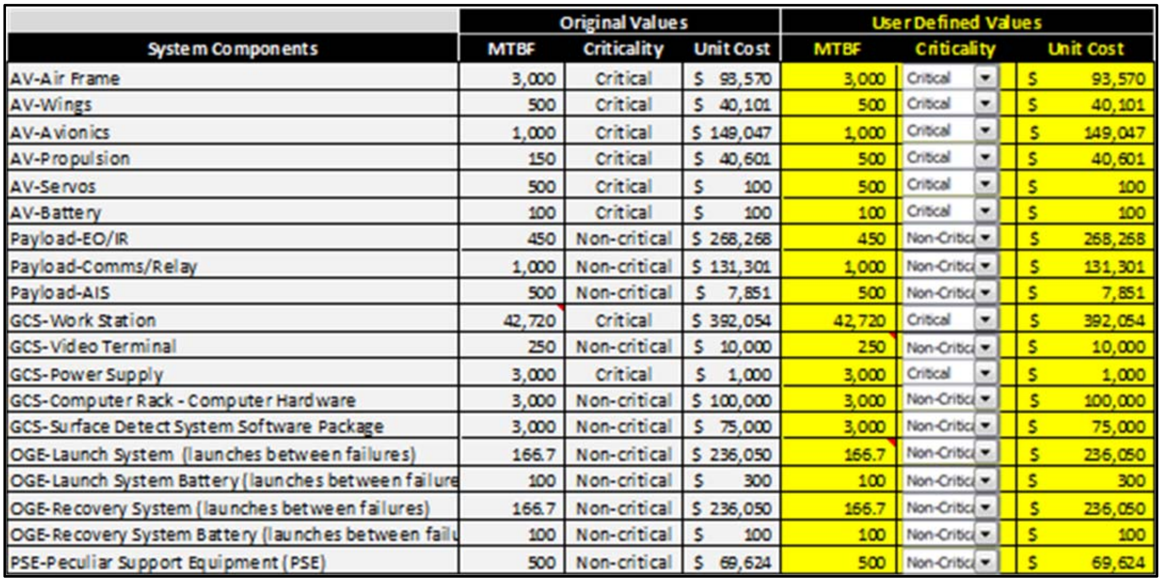
	Current Value	Change from original values	Percentage difference	Original
Undiscounted LCC	$ 1,410,193,546	$ (114,014,333)	-7.48%	$ 1,524,207,879
NPV of LCC	$ 951,349,996	$ (75,076,635)	-7.31%	$ 1,026,426,630
NSC Operational Availability	0.808	$ -	0.00%	0.808
OPC Operational Availability	0.818	$ -	0.00%	0.818
Deployed Operational Availability	0.947	$ -	0.00%	0.947
System Acquisition Costs	$ 68,252,434	$ -	0.00%	$ 68,252,434
NPV of Sys Acq Cost	$ 55,663,888	$ -	0.00%	$ 55,663,888
Personnel Costs	$ 508,278,724	$ (123,860,583)	-19.59%	$ 632,139,307
NPV of Personnel	$ 333,158,146	$ (81,662,249)	-19.69%	$ 414,820,395
Project Office Costs	$ 27,937,973	$ -	0.00%	$ 27,937,973
NPV of Project Office Cost	$ 21,597,100	$ -	0.00%	$ 21,597,100
Training Costs	$ 24,067,750	$ 9,846,250	69.23%	$ 14,221,500
NPV of Training Cost	$ 16,109,272	$ 6,585,615	69.15%	$ 9,523,658
O&M Costs	$ 781,656,665	$ -	0.00%	$ 781,656,665
NPV of O&M Costs	$ 524,821,591	$ -	0.00%	$ 524,821,591

Figure A5. LCC Results of AVDET Composition Change

C. PROPULSION SYSTEM IMPROVEMENT

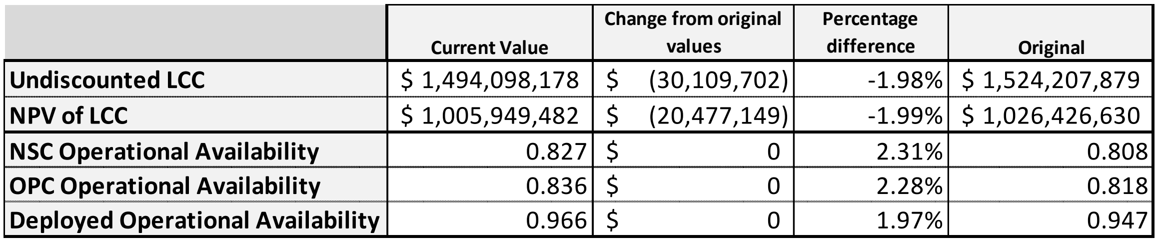
The propulsion system is vital to operation of the sUAS, but it has a relatively high failure rate at 150 hours MTBF. The manufacturer understands this, but must conduct extensive R&D to improve the propulsion system to 500 hours MTBF. They estimate this R&D will cost $20,000,000 and requests the project office pay half the expense. Is this arrangement worth the investment?

The change to propulsion system MTBF was discussed above. The numerical value is changed in the yellow-background slides, shown in Figure A6. The question then becomes, “Are there enough savings to cover the investment?” The resulting change in LCC is shown in Figure A7. We can see that there is a $30,000,000 (undiscounted) savings in LCC by improving propulsion system reliably. This is a good use of the project’s money. The LCC Tool does not answer the question of where the project manager will find the money or whether the arrangement is in accordance with the contract, but it does provide the project staff with the information necessary to determine whether it is a worthwhile investment.



	Original Values			User Defined Values		
System Components	MTBF	Criticality	Unit Cost	MTBF	Criticality	Unit Cost
AV-Air Frame	3,000	Critical	$ 93,570	3,000	Critical	$ 93,570
AV-Wings	500	Critical	$ 40,101	500	Critical	$ 40,101
AV-Avionics	1,000	Critical	$ 149,047	1,000	Critical	$ 149,047
AV-Propulsion	150	Critical	$ 40,601	500	Critical	$ 40,601
AV-Servos	500	Critical	$ 100	500	Critical	$ 100
AV-Battery	100	Critical	$ 100	100	Critical	$ 100
Payload-EO/IR	450	Non-critical	$ 268,268	450	Non-Critica	$ 268,268
Payload-Comms/Relay	1,000	Non-critical	$ 131,301	1,000	Non-Critica	$ 131,301
Payload-AIS	500	Non-critical	$ 7,851	500	Non-Critica	$ 7,851
GCS-Work Station	42,720	Critical	$ 392,054	42,720	Critical	$ 392,054
GCS-Video Terminal	250	Non-critical	$ 10,000	250	Non-Critica	$ 10,000
GCS-Power Supply	3,000	Critical	$ 1,000	3,000	Critical	$ 1,000
GCS-Computer Rack - Computer Hardware	3,000	Non-critical	$ 100,000	3,000	Non-Critica	$ 100,000
GCS-Surface Detect System Software Package	3,000	Non-critical	$ 75,000	3,000	Non-Critica	$ 75,000
OGE-Launch System (launches between failures)	166.7	Non-critical	$ 236,050	166.7	Non-Critica	$ 236,050
OGE-Launch System Battery (launches between failure	100	Non-critical	$ 300	100	Non-Critica	$ 300
OGE-Recovery System (launches between failures)	166.7	Non-critical	$ 236,050	166.7	Non-Critica	$ 236,050
OGE-Recovery System Battery (launches between failu	100	Non-critical	$ 100	100	Non-Critica	$ 100
PSE-Peculiar Support Equipment (PSE)	500	Non-critical	$ 69,624	500	Non-Critica	$ 69,624

Figure A6. Change Propulsion System MTBF



	Current Value	Change from original values	Percentage difference	Original
Undiscounted LCC	$ 1,494,098,178	$ (30,109,702)	-1.98%	$ 1,524,207,879
NPV of LCC	$ 1,005,949,482	$ (20,477,149)	-1.99%	$ 1,026,426,630
NSC Operational Availability	0.827	$ 0	2.31%	0.808
OPC Operational Availability	0.836	$ 0	2.28%	0.818
Deployed Operational Availability	0.966	$ 0	1.97%	0.947

Figure A7. LCC Changes Resulting From Improved Propulsion System Reliability

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