



**NAVAL
POSTGRADUATE
SCHOOL**

MONTEREY, CALIFORNIA

THESIS

**A METHODOLOGICAL APPROACH FOR
CONDUCTING A BUSINESS CASE ANALYSIS (BCA)
OF THE GLOBAL OBSERVER JOINT CAPABILITY
TECHNOLOGY DEMONSTRATION (JCTD)**

by

Thiow Yong Dennis, Lim

December 2007

Thesis Advisor:
Second Reader:

Daniel Nussbaum
Kyle Lin

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			<i>Form Approved OMB No. 0704-0188</i>
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE December 2007	3. REPORT TYPE AND DATES COVERED Master's Thesis	
4. TITLE AND SUBTITLE A Methodological Approach for Conducting a Business Case Analysis (BCA) of the Global Observer Joint Capability Technology Demonstration (JCTD)		5. FUNDING NUMBERS	
6. AUTHOR(S) Thioh Yong Dennis, Lim			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A		10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited		12b. DISTRIBUTION CODE	
13. ABSTRACT (maximum 200 words) The Global Observer is a Joint Capability Technology Demonstration (JCTD) initiative that is being managed by the United States Special Operations Command (US SOCOM). The JCTD Program seeks to accelerate the development and operational evaluation of mature advanced technologies to rapidly transition the new capability to military operations. The Global Observer is a liquid-hydrogen powered unmanned aircraft system that has been designed for deployment as a stratospheric satellite. It will provide an affordable, persistent presence over any designated area of interest for surveillance and communications relay missions. The purpose of this study is to analyze the cost savings, as well as the other benefits associated with the operational deployment of the Global Observer. This thesis will (1) Develop a model for performing business case analyses of JCTDs, including defining the methodical structure required in the business case report; and (2) Conduct the Global Observer JCTD business case analysis, including a baseline analysis and a comprehensive sensitivity analysis based on a developed operational scenario with 6 designated areas of operations, while comparing the performance with an existing analogous system, i.e., the RQ-4 Global Hawk.			
14. SUBJECT TERMS Global Observer, Unmanned Aircraft System, High Altitude Long Endurance (HALE), Liquid Hydrogen, Business Case Analysis, Joint Capability Technology Demonstration (JCTD).		15. NUMBER OF PAGES 87	16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UU

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

**A METHODOLOGICAL APPROACH FOR CONDUCTING A BUSINESS CASE
ANALYSIS OF THE GLOBAL OBSERVER JOINT CAPABILITY
TECHNOLOGY DEMONSTRATION (JCTD)**

Thiow Yong Dennis, Lim
Civilian, Defence Science and Technology Agency, Singapore
B.Eng (Hons), National University of Singapore, 2002

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

**NAVAL POSTGRADUATE SCHOOL
December 2007**

Author: Thiow Yong Dennis, Lim

Approved by: Professor Daniel Nussbaum
Thesis Advisor

Associate Professor Kyle Lin
Second Reader

Professor James Eagle
Chairman, Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The Global Observer is a Joint Capability Technology Demonstration (JCTD) initiative that is being managed by the United States Special Operations Command (US SOCOM). The JCTD Program seeks to accelerate the development and operational evaluation of mature advanced technologies to rapidly transition the new capability to military operations.

The Global Observer is a liquid-hydrogen powered unmanned aircraft system that has been designed for deployment as a stratospheric satellite. It will provide an affordable, persistent presence over any designated area of interest for surveillance and communications relay missions.

The purpose of this study is to analyze the cost savings, as well as the other benefits associated with the operational deployment of the Global Observer. This thesis will (1) Develop a model for performing business case analyses of JCTDs, including defining the methodical structure required in the business case report; and (2) Conduct the Global Observer JCTD business case analysis, including a baseline analysis and a comprehensive sensitivity analysis based on a developed operational scenario with 6 designated areas of operations, while comparing the performance with an existing analogous system, i.e., the RQ-4 Global Hawk.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

I.	INTRODUCTION.....	1
A.	PURPOSE OF THE STUDY	1
B.	PERSISTENT SURVEILLANCE AND COMMUNICATIONS BANDWIDTH.....	2
C.	LIQUID HYDROGEN (LH₂) FUEL.....	3
1.	Combustion.....	3
2.	Electrochemical Conversion in a Fuel Cell.....	4
D.	PROBLEM STATEMENTS.....	5
1.	High Cost of Global Persistent Surveillance	5
2.	High Cost and Shortage of Communications Bandwidth	5
E.	CASE FOR CHANGE — DOING THINGS BETTER	6
F.	RESEARCH METHODOLOGY, LIMITATIONS AND ASSUMPTIONS.....	7
II.	BACKGROUND	9
A.	CURRENT TECHNOLOGIES	9
1.	Fossil-fueled UAVs.....	9
2.	Satellites	11
3.	High Altitude Airships.....	12
B.	JOINT CAPABILITY TECHNOLOGY DEMONSTRATION (JCTD)..	14
1.	The ACTD Program	15
2.	The JCTD Program	16
C.	THE GLOBAL OBSERVER JCTD.....	17
D.	BUSINESS CASE ANALYSES	21
1.	Definition	22
2.	Data Collection	23
3.	Evaluation Analysis	23
4.	Results Presentation.....	23
III.	GLOBAL OBSERVER BUSINESS CASE ANALYSIS	25
A.	OPERATIONAL SCENARIO.....	25
1.	Scenario Background.....	26
a.	<i>Trans-Sahara Region.....</i>	26
b.	<i>Afghanistan / Pakistan</i>	27
c.	<i>Iraq</i>	28
d.	<i>Colombia.....</i>	29
e.	<i>Strait of Malacca.....</i>	29
f.	<i>China / North Korea</i>	30
2.	UAV Operating Bases.....	31
a.	<i>Beale Air Force Base (California, USA)</i>	31
b.	<i>Anderson Air Force Base (Guam)</i>	31
c.	<i>Al Dhafra Air Base (United Arab Emirates).....</i>	32
3.	Selection of UAV Operating Base.....	32

B.	DATA ANALYSIS	34
1.	Number of UAVs Required.....	34
2.	Number of Sorties Required Per Year by the UAVs.....	37
3.	Utility of the UAVs.....	39
4.	Life Cycle Cost	40
a.	<i>Aircraft Cost</i>	41
b.	<i>Launch and Recovery System, Mission Control System Costs</i>	41
c.	<i>Payload Cost</i>	41
d.	<i>Fuel Cost</i>	41
e.	<i>Maintenance and Repair Costs</i>	43
5.	Cost of Leased Commercial Satellite Communications	45
C.	RETURN ON INVESTMENT	46
1.	Base Case Benefits.....	46
2.	Base Case ROI.....	48
D.	SENSITIVITY ANALYSIS.....	49
1.	Discount Factor	50
2.	Investment and Operation Cost.....	51
3.	LH ₂ Fuel Cost	52
E.	RISK ANALYSIS.....	54
1.	Reliability of the Technology	54
2.	Logistical Support.....	54
IV.	CONCLUSION AND RECOMMENDATIONS	55
A.	PERFORMANCE	55
B.	COST BENEFITS	55
C.	SENSITIVITY ANALYSIS.....	56
D.	RISK ANALYSIS.....	57
E.	BOTTOMLINE.....	57
	LIST OF REFERENCES.....	59
	INITIAL DISTRIBUTION LIST	67

LIST OF FIGURES

Figure 1.	Growth in commercial satellite communications expenditure and bandwidth usage [From 13, Fig 2-1].....	6
Figure 2.	Composite Hull High Altitude Powered Platform (CHHAPP) [From 27]	13
Figure 3.	Lockheed Martin’s High Altitude Airship (HAA). [From 28]	14
Figure 4.	DARPA’s ISIS Airship. [From 30].....	14
Figure 5.	Global Observer prototype [From 34]	18
Figure 6.	BCA methodology [From 39].....	22
Figure 7.	World map [From 57] with annotation of UAV Operating bases and AO	33
Figure 8.	Typical mission sortie profile of the UAV	34
Figure 9.	Minimum number of aircraft required vs AO Distance.....	36
Figure 10.	Number of UAV sorties required per year vs AO distance	38
Figure 11.	Number of UAV sorties required per year for mission.....	39
Figure 12.	Utility of UAV for mission	40
Figure 13.	Commercial satellite bandwidth usage by region [From 12, Fig 4-15]	45
Figure 14.	Expenditure on commercial satellite bandwidth by region [From 12, Fig 4-14].....	45
Figure 15.	Discount factor analysis on total costs [FY05\$M]	50
Figure 16.	Discount factor analysis on annualized ROI.....	51
Figure 17.	Cost factor analysis on total costs [FY05\$M] for the Global Observer.....	51
Figure 18.	Cost factor analysis on annualized ROI for the Global Observer.....	52
Figure 19.	Fuel cost factor analysis on total costs [FY05\$M] for the Global Observer.....	53
Figure 20.	Fuel cost factor analysis on annualized ROI for the Global Observer.....	53

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

Table 1.	LCC comparison between Global Observer and Global Hawk.....	xiv
Table 2.	Specifications of known long endurance UAVs.....	10
Table 3.	Global Observer Specifications [From 34].....	19
Table 4.	Specific energy of commonly used fuels [After 36].....	20
Table 5.	Selection of operating base to launch the UAV.....	33
Table 6.	Cruise speed and endurance times for Global Hawk and Global Observer.....	35
Table 7.	UAV requirements for mission to respective AO.....	37
Table 8.	Annual fuel cost incurred by the UAVs.....	43
Table 9.	Costs to purchase and operate the UAVs over 15 years.....	44
Table 10.	Summary of the benefits of Global Observer.....	48
Table 11.	LCC comparison between Global Observer and Global Hawk.....	56

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

The Global Observer (GO) is an approved FY2007 Joint Capability Technology Demonstration (JCTD) initiative managed by the United States Special Operations Command (US SOCOM). The purpose of the JCTD is to accelerate the development and operational evaluation of mature advanced technologies in order to rapidly transition the new capability to military operations.

The Global Observer is a liquid-hydrogen powered unmanned aircraft system that has been designed for deployment as a stratospheric satellite. It will provide an affordable, persistent presence over any designated area of interest for surveillance and communications relay missions. Designed for a flight endurance of seven days, the operational deployment of the Global Observer can significantly reduce the high costs associated with global persistent surveillance, as well as alleviate the problem of dealing with the shortage of communications bandwidth in the operational theatre.

The purpose of this study is to analyze the cost savings, as well as the other benefits associated with the operational deployment of the Global Observer. This thesis will

- Develop a recommended model for performing business case analyses of JCTDs, including defining the methodical structure required in the business case report.
- Conduct the Global Observer JCTD business case analysis (BCA), including a baseline analysis and a comprehensive sensitivity analysis. The analysis will be based on a developed operational scenario with 6 designated areas of operation (AO), while comparing the performance with an existing analogous system, i.e., the RQ-4 Global Hawk.

The results of the analyses for a 24/7/365 persistent presence over the designated AOs is as follows:

- Performance
 - A total of 20 Global Observers were required (including 6 ground spares for each of the AOs considered) for the mission, compared to 35 Global Hawks (including the 6 ground spares).
 - A total of 490 Global Observer sorties were required, compared to 3051 for the Global Hawk. This translates to a cost savings of 90.7% on fuel costs.
 - For the various areas of operation, the utility (defined as the proportion of time spent on-station by the UAV) of the Global Observer ranged from 0.53 to 0.75, compared to 0.21 to 0.42 for the Global Hawk.

- Cost Benefits
 - The estimated life cycle cost comparison (less manpower costs) over a 15-year period between the Global Observer and the Global Hawk are summarized in the following Table 1.

Table 1. LCC comparison between Global Observer and Global Hawk

LCCE (FY05\$M)				
	Global Observer	Global Hawk	DELTA \$	DELTA %
Investment	412.4	1522.5	1110.1	72.9%
Operations & Support	467.4	2429.0	1961.7	80.8%
Total	879.8	3951.5	3071.8	77.7%

- The estimated cost to purchase and operate the Global Observer for 15 years is \$879.8M (FY05\$), compared to the Global Hawk's cost of \$3951.5M (FY05\$). This translates to a savings of 77.7%.
- There is also an estimated potential cost avoidance of about \$40M per annum on commercial satellite bandwidth usage if the Global

Observer can be deployed to provide tactical battlefield communications over the area of interest, in addition to its regular ISR mission.

- The base case annualized compounded Return on Investment (ROI) (over a 15-year period from FY09¹ [1]) is 14.3%, based on a Net Present Value (NPV) savings of \$3071.8M and NPV Investment of \$412.4M.

- Sensitivity Analysis
 - The base case annualized ROI never falls below 12.4% when the discount factor for the Global Observer was varied from 3.0% to 10%.
 - The base case annualized ROI does not fall below 8.5% even when the cost factor for the Global Observer is increased to double the current estimated cost.
 - The base case annualized ROI does not fall below 13.8% when the fuel cost of LH₂ was varied from 1 to 3 times the current estimated burdened cost of \$22.70 per pound, while maintaining a constant JP-8 burdened cost of \$17.50 per gallon.

- Risk Analysis
 - The reliability of the technology to achieve 7 days flight endurance remains unproven, as there was no demonstrator that has achieved such a capability.
 - For operational fielding, it is necessary to also look into the infrastructure and logistical support requirements, especially with regard to LH₂ handling, to adequately support the Global Observer for missions from OCONUS forward operating bases.

¹ Base Case Discount Rate was set at 5.05% [1].

- Bottom Line
 - The benefits of the Global Observer should not be limited to the factors presented in this study, as these factors are by no means a comprehensive list. The very concept of a HALE UAV achieving 7 days flight endurance is already a ground-breaking capability, especially since currently, operational UAVs can achieve no more than 2 days of flight endurance.
 - The Global Observer with its prolonged persistence (7 days) and flexibility in payload configuration appears to be a worthwhile investment that can provide the DoD with a new capability in round-the-clock surveillance for ISR and battlefield communications.

ACKNOWLEDGMENTS

The author would like to thank Professor Daniel Nussbaum for his invaluable guidance in this thesis work. It has been most fruitful and rewarding to be able to learn from the guru in the field of conducting business case analyses.

Special thanks are also extended to COL (Ret) Edward Lesnowicz, USMC, for his support, as well as for lending his operational expertise, especially in the crafting of the operational scenario for the analysis; Associate Professor Kyle Lin for his patience in meticulously reviewing the thesis until completion; Mr. Bob Curtin from Aerovironment Inc. for taking time to provide me with a “Global Observer-101,” as well as making available other relevant and pertinent information about the Global Observer in this thesis work; Ms. Mary Mulligan and Ms. Janis Higginbotham for editing the thesis.

Finally, the author would like to thank his loving wife, Magdalene, for her support and care, especially in looking after our daughters Hannah and Rachel, so that their Papa can devote more attention towards completing the thesis. Thank you for your unwavering support.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. PURPOSE OF THE STUDY

The Global Observer is a Joint Capability Technology Demonstration (JCTD) project managed by the Office of the Secretary of Defense (OSD). The JCTD program seeks to accelerate the development and operational evaluation of mature advanced technologies. In the case of the Global Observer, which is a liquid-hydrogen powered unmanned aerial vehicle (UAV), the JCTD seeks to significantly reduce the high cost of global persistent surveillance and communications, as well as to alleviate the problem of dealing with the shortage of communications bandwidth in the operational theatre. This goal is accomplished by using existing, proven systems to field an unmanned aircraft system (UAS) as a stratospheric satellite. It would provide an affordable, persistent presence over any designated area of interest for surveillance and communications relay missions.

The purpose of this study is to analyze the cost savings, as well as other benefits associated with the operational deployment of the Global Observer Program. This thesis will:

- Develop a model for performing business case analyses of JCTDs, including defining the methodical structure required in the business case report.
- Conduct the Global Observer JCTD business case analysis (BCA), with a baseline analysis followed by sensitivity analysis, as well as a general risk assessment for the Global Observer. The BCA compares the performance of Global Observer with Global Hawk in an operational scenario consisting of a 24/7/365 ISR (intelligence, surveillance and reconnaissance) and communications mission. Life Cycle Costs consist of investment costs as well as the costs to operate the platform over a 15-year period.

B. PERSISTENT SURVEILLANCE AND COMMUNICATIONS BANDWIDTH

“Surveillance” is the monitoring of behavior. It refers to the “close observation” [2] of a person or groups of persons. In the military context, surveillance allows friendly forces to monitor the activities of their targets and determine the best opportunity to commence with their next course of action. This capability is achieved with the aid of technologies that provide surveillance on any designated area as determined by the commander.

The effectiveness of all surveillance assets is related to their ability to stay on-station for extended periods of time. *Ceteris Paribus*, a surveillance asset that has a higher Effective Time-On-Station (ETOS)² [3], would naturally be preferred to one that has a lower ETOS. The objective is to achieve persistent surveillance, where the commander is able to see a continually updated situation picture that remains accurate and relevant.

Persistent surveillance enables the commander to lift the veil from the “fog of war” in many military situations, ranging from tactical warfighting situations in open terrain to conflicts in high density urban areas. This allows the commander to exploit the information, thus enabling him to make timely and accurate command decisions that can be put into action. According to Dr Bially, who is the Director of DARPA’s Information Exploitation Office, “We’ve learned that occasional or periodic snapshots don’t tell us enough of what we need to know. In order to really understand what’s going on we have to observe our adversaries and their environment 24 hours a day, seven days a week, week-in and week-out...we have to constantly upgrade our understanding of the enemy’s inherent motives so that we can effectively shape the battlespace to avoid further hostilities.” [4]

² Effective Time-On-Station (ETOS) is a reliability parameter used for systems that are designed to provide coverage (surveillance, defense, etc.) for a specified amount of time. It measures the ability of a system to remain operational for the scheduled on-station time.

Communications bandwidth, on the other hand, refers to the capacity of any given communications channel. If the available bandwidth is higher, then greater amounts of data and information can be transmitted and received using the communications channel. Bandwidth is required for the transmission of text (e.g., emails and documents), voice (e.g., audio streaming and tele-conversation) and video (e.g., video streaming and video-conferencing). A high bandwidth environment is critical for time-sensitive communication.

C. LIQUID HYDROGEN (LH₂) FUEL

Hydrogen is the most common element in the universe, constituting about 75% of the universe's elemental mass, and 90% of the universe (by atom count) [5]. It possesses the highest energy content per unit weight of any known fuel. However, hydrogen is rarely found occurring by itself in nature - it is almost always found in a combined form with other elements such as oxygen (in water) or carbon (in fossil fuels). In its elemental state, hydrogen is a clean energy carrier. It is non-polluting, as the primary emission is water.

The use of liquid hydrogen (LH₂) in fuel, though not prevalent in present-day applications, is not new, and can be implemented in one of two ways [6]:

- Combustion
- Electrochemical conversion in a fuel cell

1. Combustion

In combustion, hydrogen is burned to generate power using an internal combustion engine. This is similar to how traditional gasoline cars burn gas.

The invention of the internal combustion engine in 1807 was credited to Francois Isaac de Rivaz of Switzerland, who used a mixture of hydrogen and oxygen for fuel. Though not widespread today due to the lack of an established hydrogen economy, hydrogen is already used to power automobiles, with the BMW Hydrogen-7 being the most notable. For aircraft, the then Soviet Union had, in April 1988, successfully flown the Tupolev TU-154 plane using LH₂ fuel.

2. Electrochemical Conversion in a Fuel Cell

Using fuel cell technology, hydrogen reacts with oxygen to produce water and electricity, and this electricity is used to power an electric traction motor.

A fuel cell [7] is a device that uses hydrogen (or a hydrogen-rich fuel) and oxygen to create electricity by an electrochemical process. A single cell consists of an electrolyte sandwiched between two thin electrodes (a porous anode and a cathode). Hydrogen, or a hydrogen-rich fuel, is fed to the anode where a catalyst separates hydrogen's negatively charged electrons from the positively charged protons. The protons are conducted through the electrolyte to the cathode, whereas the electrons are forced to travel in an external circuit, due to the electrically insulating electrolyte used, resulting in an electrical current being generated. At the cathode, oxygen combines with electrons and the protons to form water.

The principle of the fuel cell was discovered in 1838 by Christian Friedrich Schönbein, a German scientist who is better known as the inventor of gun cotton. From his work, Welsh scientist Sir William Robert Grove developed the first fuel cell in 1843. In the 1950s, W. Thomas Grubb, who was then a chemist working for the General Electric Company (GE), modified the original fuel cell design by making use of a sulphonated polystyrene ion-exchange membrane as the electrolyte. His colleague, Leonard Niedrach, discovered that depositing platinum onto the membrane could catalyze the necessary redox reactions for oxygen and hydrogen respectively, resulting in the development of the "Grubb-Niedrach fuel cell," which was subsequently used by NASA on the Gemini space project in 1965 [8]. Today, NASA's space shuttles use hydrogen-powered fuel cells to operate electrical systems and the key emission, water, is consumed by the crew.

In the case of the Global Observer, the high specific energy content of LH₂ (factor of 3:1 compared to gasoline) is exploited and harnessed to significantly increase the flight endurance of the UAV.

D. PROBLEM STATEMENTS

At the strategic and operational level, two key problems that are often the bugbear of decision-makers and commanders are as follows:

1. High Cost of Global Persistent Surveillance

With America at the forefront of various military and OOTW operations around the world, expenditures of this kind, particularly in the area of ISR (intelligence, surveillance and reconnaissance) technologies, would make up a sizeable portion of the annual defense budget, which is \$481.4b [9] for FY08. Some of this invariably goes towards funding the various surveillance platforms, e.g., satellites and HALE UAVs (High Altitude Long Endurance Unmanned Aerial Vehicles), as well as the communications backbone that will provide the U.S. with a global surveillance network.

Briefly, the high cost associated with the use of satellites is largely due to the fact that once launched into space, there is no way to recover it. Hence, for cost effectiveness, the technology used must be good for at least the typical 15-year useful life-span of the satellite. In addition, there is no guarantee that the satellite will successfully reach orbit as planned, further exacerbating the risks of launching a satellite.

In the case of HALE UAVs, current technology, which makes use of traditional fossil fuels to power them, is such that the longest flight time of a UAV is no more than one to two days. Missions that require 24/7/365 coverage would be prohibitively expensive due to the many sorties required to sustain such an operation. Their high fuel consumption and frequent turn-around would also require a high level of logistics support, further increasing the cost of fielding such systems.

2. High Cost and Shortage of Communications Bandwidth

The availability of the communications network is a prerequisite to networked forces. Whether in the theatre-of-operations, where there is a lack of a terrestrial communications network, or reach-back from in-theatre to the Pentagon, networking is achieved through the use of satellite communications. In both instances, bandwidth

remains a scarce resource. As the U.S. military moves towards operating in a net-centric environment, the reliance and the dependence on the communications network will continue to increase, fuelled by the insatiable thirst for communications bandwidth.

The Pentagon maintains four satellites [10] for its dedicated use; these are reserved for the highest priority voice and simple data communications. All other forms of communication would have to be transmitted via commercial satellites that are leased by the Department of Defense (DoD). This limited available bandwidth is often maxed out during operations, which can affect the smooth running of operations. Additionally, the cost of leasing commercial satellite bandwidth is very expensive. The result is a significant increase in the DoD usage and expenditure [11] of commercial satellite bandwidth in recent years, from \$91M in 2000 (bandwidth consumed is 1324MHz) to \$330M in 2005 (6444MHz). Figure 1 shows the growth in commercial satellite expenditures and bandwidth usage from the 2000 to 2005:

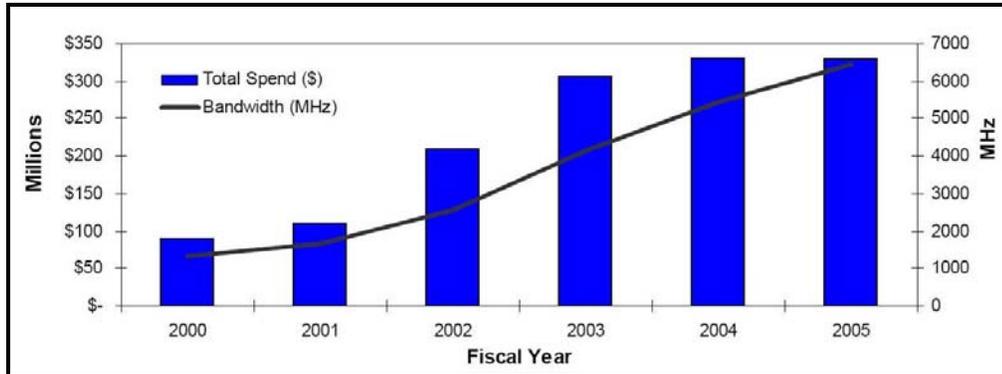


Figure 1. Growth in commercial satellite communications expenditure and bandwidth usage [From 13, Fig 2-1]

E. CASE FOR CHANGE — DOING THINGS BETTER

The Global Information Grid [12] is an all-encompassing communications project of the DoD. It will be a net-centric system [13], operating in a global context to provide processing, storage, management, and transport of information to support all DoD, national security, and related intelligence community missions and functions. The functions will be varied: strategic, operational, tactical, and business- in war, in crisis, and in peace. The goal of the program is to enable the military forces to achieve

information superiority over its potential adversaries. As former Deputy Secretary of Defense Paul Wolfowitz aptly put it, “[we must] leverage information technology and innovative network-centric concepts of operations to develop increasingly capable joint forces. Our ability to leverage the power of information and networks will be key to our success...” [14].

It is therefore imperative that new technologies be harnessed to continually improve the network that will equip the military forces with power to the edge [15] capabilities. Specifically, the Global Observer JCTD seeks to significantly reduce the high cost of global persistent surveillance and communications, as well as alleviate the problem of dealing with the shortage of communications bandwidth.

F. RESEARCH METHODOLOGY, LIMITATIONS AND ASSUMPTIONS

To achieve the objectives set out in Section A, the author will develop and recommend an analytic structure for performing business case analyses (BCA). The BCA for the Global Observer JCTD will be conducted based on the structure. This thesis would report on the results of the Global Observer JCTD BCA and formulate the appropriate recommendations to the decision makers.

The extent of comprehensiveness to which this thesis presents the BCA is limited to the data and information made available to the author. The cost saving obtained, though specific to the operational scenario, can be used to derive the savings for other similar scenarios within reasonable assumptions.

Key assumptions made while performing the BCA are as follows:

- A conservative approach is adopted, i.e., whenever a choice had to be made between higher and lower costs due to ambiguity in the data, the higher cost is used.
- Where information is not available, or not made available to the author, estimates are used and reasonable assumptions are made in regards as to how they are derived.

THIS PAGE INTENTIONALLY LEFT BLANK

II. BACKGROUND

This section provides an overview of the key technologies that are currently employed for global surveillance and communications missions. It also includes new technologies that are being developed to alleviate the high cost of global persistent surveillance, as well as addressing the problem of the existing shortage of bandwidth resources. A summary of the Joint Capability Technology Demonstration (JCTD) Program is also explained here, with details on the history and development of the Global Observer JCTD Program. Finally, the section concludes with an overview of the Business Case Analysis (BCA) methodology.

A. CURRENT TECHNOLOGIES

The three main types of technologies that are being deployed, or are in the process of being developed, for surveillance and communications missions, along with some top-level advantages and disadvantages, are as follows:

- Fossil-fueled UAVs (flexible deployment, but limited loiter capability).
- Satellites (inflexible deployment, but persistent loiter capability).
- High Altitude Airships (relatively flexible deployment, with persistent loiter capability).

The current state of these technologies is that these solutions are generally either not cost effective or not readily available (still under development). In addition, they may also not be practical for large-scale implementation.

1. Fossil-fueled UAVs

UAVs can be rapidly deployed to different designated areas for surveillance, and this makes them a highly prized sensor asset. Various types of UAVs have also been developed and designed to carry the required payload configuration for their respective missions. This payload modularity allows UAVs to be rapidly reconfigured for a variety

of missions. However, the main drawback in current UAV technologies is the fact that they are powered by traditional fossil fuels, which limits aircraft endurance.

The aircraft endurance of the internal combustion engine depends strongly on the percentage of fuel burned compared to its total weight, and this is largely independent of aircraft size. Hence, their flight duration and resulting loiter capability on-station is highly dependent on the amount of fuel carried on-board vis-à-vis their mission payload. Furthermore, the absence of any in-flight refueling capability for UAVs means that their ability to remain on-station for extended periods of time is severely limited.

For comparison, the operating ceiling, flight endurance and cruise speeds of several known long endurance UAVs are given in Table 2.

Table 2. Specifications of known long endurance UAVs

UAV Name	Operating Ceiling (feet)	Endurance	Cruise Speed (knots)	Image
MQ-1 Predator [16]	25,000	40 hours	70	
RQ-4A Global Hawk [17]	65,000	35 hours	340	
MQ-9 Predator-B [18]	50,000	30 hours	220	
Aerosonde [19]	20,000	38 hours 48 minutes	80	
IAI Heron [20]	30,000	45 hours	113	

From Table 2, it is evident that the endurance of current fossil fuel powered long endurance UAVs is typically no more than two days. Missions that require 24/7/365 coverage would be prohibitively expensive due to the many aircraft and sorties required. Their high fuel consumption and frequent turn-around would also require a high level of logistics support, further increasing the cost of fielding such systems. In addition, damage risks associated with the frequent launching and recovery of these UAVs would also be fairly high.

It is therefore apparent that current fossil-fueled UAVs are not adequate, in a life-cycle-cost sense, for missions that require all-year round persistent time-on-stations.

2. Satellites

The main strength of satellites is their ability to provide 24/7/365 persistent time-on-station capability for any given mission. However, they also have many inherent disadvantages. First, satellites are usually not recoverable, i.e., once launched into space orbit, they cannot be easily retrieved, if at all. Furthermore, in view of the huge costs associated with sending a satellite into space for a mission, a satellite's typical useful lifespan must be for a period of at least five to ten years to be cost effective. As a consequence, the technology used by the satellite must be good for at least its entire useful lifespan, as maintenance in-service would probably be more expensive than a replacement. The satellite must also have sufficient power to meet its operational requirements over its entire lifespan. As such, the cost to operate a satellite can be several times more expensive than that of a UAV. For example, the cost to launch a satellite can vary between \$50M to \$400M [21].

The complexities involved in launching and managing the satellite cannot be taken lightly. Many potential problems could arise to terminate the satellite mission prematurely, or even the satellite itself. These include the problems caused during the delicate launch process (e.g., Atlas V, Taurus), power system failure (e.g., Thaicom 3), software glitches (e.g., XM3, Yamal 202, Satmax 5), data transfer (e.g., Mars Global Surveyor), hardware failures (e.g., Suzaku, Galaxy 10R) or even faulty designs (e.g., Intelsat 804, SSETI Express). These problems are further compounded by the

uncertainty of the space environment in which the satellite operates (e.g. Gravity Probe B). Examples of failed satellites and satellite missions abound [22].

In the context of multi-mission capabilities, satellites are far less flexible in that they can only perform the type of missions they were designed for. For instance, if an imagery satellite is launched, it cannot be reconfigured easily, if at all, to become a communications satellite. This is because the payload to be mounted on the satellite is decided based on the mission and cannot be changed after launch, due to the sheer impossibility of recovering launched satellites for reuse. Any significant changes in operational requirements after launch would normally result in having another satellite take its place, making it a very tedious and very expensive process. It is thus evident that satellites do not enjoy the flexibility of reconfiguration and technology refreshment enjoyed by many other platforms, such as UAVs or airships, which can be recovered after being launched.

An example is that of the IKONOS [23] satellite, a commercial earth observation satellite that was launched in 1999 with a mission duration of 7 years. Its core mission is to provide high-resolution imagery, and its payload is configured as such. It cannot, therefore, be used for a totally different mission, e.g., as a communications or navigational satellite without the appropriate equipment and payload. To reconfigure the imagery satellite to perform any other function (e.g., for communications or navigational purposes) without the requisite equipment already configured on board is virtually impossible.

3. High Altitude Airships

Airships have been used for a variety of missions, both military and commercial, since the early 1900s, with mixed success.

Airships were deployed during World War I [24] by both the Allied and the Central Powers in scouting and observation roles. Airships were also deployed by the U.S. during World War II in Anti-Submarine Warfare (ASW), as well as for patrol and convoy escort near the U.S. coastline. Commercial applications include using the lighter-

than-air aircraft for advertising and even as media platforms for aerial video and photography at major sporting events.

However, airship deployment was not without problems. Notable failures include the British R101 Airship accident (1930), the USS Akron crash (1933), as well as the LZ 129 Hindenberg Disaster (1937).

Despite the airship's existence for many decades, the concept of developing the airship's capabilities for high altitude and long endurance deployment only gathered steam in recent years. Essentially, the idea is to deploy a self-sustainable airship into the stratosphere for long endurance missions, due to its ability to stay in the air for extended periods of time (i.e., ranging from weeks to months at a stretch). The airship, which will be powered by a solar-electric power storage system, will be able to sustain its operational requirements. Their long endurance capability translates into a relatively lower operational and maintenance cost for the airship. Furthermore, their ability to stay in the stratosphere means that they are not susceptible to a vast majority of traditional adversarial weapon threats. They can also be rapidly reconfigured for a variety of missions, depending on the specific operational requirements.

The current forerunner developments [25] in this field are as follows:

- Composite Hull High Altitude Powered Platform (CHHAPP) [26] (also known as HiSentinel High-Altitude Airship) effort by U.S. Army, U.S. Air Force, Southwest Research Institute and Aerostar International. The first test flight took place in 2005. The CHHAPP is shown in Figure 2:



Figure 2. Composite Hull High Altitude Powered Platform (CHHAPP) [From 27]

- Lockheed Martin's High Altitude Airship (HAA) [28], sponsored by the US Army Space and Missile Defense Command. The production HAA will be able to stay aloft at 65,000 ft. for six months at a time. The first test flight is scheduled in 2010. The HAA is shown in Figure 3 below:



Figure 3. Lockheed Martin's High Altitude Airship (HAA). [From 28]

- The ISIS (Integrated Sensor IS Structure) program [29] by DARPA (Defense Advanced Research Projects Agency) seeks to develop a stratospheric surveillance airship. The technological demonstrator is scheduled to fly in 2010. The ISIS airship is shown in Figure 4 below:



Figure 4. DARPA's ISIS Airship. [From 30]

However, with the as yet uncompleted development and testing of these capabilities, any possible operational deployment would still be some years away.

B. JOINT CAPABILITY TECHNOLOGY DEMONSTRATION (JCTD)

The Joint Capability Technology Demonstration (JCTD) Program has its roots in the Advanced Concept Technology Demonstration (ACTD) Program, which had its inception in 1994 by the Department of Defense (DoD). The program is headed by the

Deputy Under Secretary of Defense (Advanced Systems and Concepts), DUSD(AS&C), who has a team of ACTD/JCTD oversight executives who interact with the various AS&C divisions to harvest capabilities for the Combatant Commands.

1. The ACTD Program

The ACTD program [31] has its origins in the Packard Commission and Defense Science Board studies. The program was aimed at helping the DoD acquisition process adapt to present-day economic and threat environments. By focusing on technology assessment and integration, a prototype capability could be provided to the operational warfighter and could support his evaluation of the military utility of the capability. As such, ACTDs seek to exploit both mature and maturing technologies, and to transit the new capability into the hands of the operational warfighter.

ACTDs can be characterized by their employment of mature technologies over a fixed period of activity. They can also leverage existing technological investments. There is also a residual capability after the completion of the ACTD demonstration. In addition, ACTDs have a heavy focus on joint operations with Combatant Command warfighter participation, as well as a significant level of cross-service, cross agency/organization involvement.

The guidelines [32] developed to provide guidance for the selection criteria for ACTD candidates are given as follows:

- The timeframe for completing the evaluation of military utility is typically 2–4 years.
- The technology should be sufficiently mature.
- The project provides a potentially effective response to a priority military need.
- A lead service or agency has been designated.
- The risks have been identified, are understood, and accepted.
- Demonstrations or exercises have been identified that will provide an adequate basis for the utility assessment.

- Funding is sufficient to complete the planned assessment of utility and to provide technical support for the first two years of fielding the interim capability.
- The developer is ready to prepare a plan that covers all essential aspects. These include affordability, interoperability, sustainability, and evolutionary capability, vis-à-vis technology and threat changes.

The objectives of the ACTD are to conduct meaningful demonstrations of the capability, develop and test concepts of operations to optimize military effectiveness, and prepare to transition the capability into acquisition without loss of momentum, if warranted. An additional goal of the ACTD is to provide a residual capability to further refine CONOPS and to permit continued use prior to formal acquisition, as well as to provide the ability to proceed into formal acquisition for additional capability, if required.

Possible outcomes after the ACTD operational demonstration are as follows:

- The user sponsor may recommend the acquisition of the technology and field the residual capability that remains at the completion of the demonstration phase of the ACTD to provide an interim and limited operational capability;
- The user's need is fully satisfied by the residual capability remaining at the conclusion of the ACTD, and there is no requirement to acquire any additional units of the system;
- The capability is deemed to not demonstrate sufficient military utility, resulting in the project being terminated or returned to the technology base.

2. The JCTD Program

In FY2006, a new ACTD business process was initiated to update the successful ACTD program to meet the DoD's transformational goal of becoming capability-based, rather than threat-based, in its focus. This program, which was named the Joint Capability Technology Demonstration (JCTD) Program [33], includes many of the positive aspects of the ACTD program, as well as improvements to meet new and

evolving defense challenges. The process will integrate the ACTD program with the new Joint Integration and Development System (JCIDS) developed by the Joint Chiefs of Staff (JCS).

Current ACTD processes will be transitioned to the improved JCTD program over a 3-5 year transition period, with the intent of having the JCTDs replace the ACTDs. The new process will focus on joint and transformational technologies that are initiated in Science and Technology (S&T), and carried through the difficult transition stage. The new JCTD business model will also include a Defense Acquisition Executive (DAE) pilot program that will take a limited number of “joint peculiar” JCTDs past Milestone B, into procurement, followed by initial sustainment – a “cradle-to-grave” approach.

Similar to the ACTD program, the JCTD program possesses 3 possible transition models post-demonstration. They are:

- Transition to Program of Record (POR). The military utility of the program has been successfully demonstrated, and the concepts will be adopted by the warfighters. Products will be transferred to a new/current POR or GSA (Government Services Administration) schedule. The acquisition of additional capability will also be funded.
- Interim Capability to Meet Needs of the Warfighter. The military utility has been successfully demonstrated, and the concepts will be adopted by the warfighter. However, the products may or may not have been sent to a POR. This interim capability fully meets the warfighter’s needs and is being maintained.
- Return to Technology Base. The military utility is deemed to be not successfully demonstrated. Relevant components or capabilities may be incorporated into other systems, returned to the technology base or terminated.

C. THE GLOBAL OBSERVER JCTD

The Global Observer (GO) is a Liquid Hydrogen (LH₂)-powered High Altitude Long Endurance Unmanned Aerial Vehicle (HALE UAV) program. It was developed to

alleviate the problem of dealing with the high cost of global persistent surveillance and communications, as well as the shortage of communications bandwidth in the theatre-of-operations.

The Global Observer is being developed by AeroVironment Inc. Since 1995, the company has been active in pursuing R&D (research and development) in various technology enablers that are foundational to the development of the Global Observer. These include development in composite airframes, electric motors, LH₂ tank and propulsion, redundant flight controls and payload integration. This culminated in a one-third scale limited-payload prototype of the Global Observer (GO-0), taking its maiden flight in May 2005. In doing so, the Global Observer became the first liquid-hydrogen powered unmanned aircraft system tested in the world. The prototype is shown in Figure 5 below:



Figure 5. Global Observer prototype [From 34]

In 2007, the Global Observer was validated by the OSD as a “new start” JCTD to Congress, with the U.S. Special Operations Command (SOCOM) as the Technical Manager to lead the JCTD. Through the JCTD Program, OSD seeks to accelerate the development and operational evaluation of this technology. For the JCTD, the 175-foot wingspan GO-1 will be capable of carrying a payload of 400 lbs, with 7-day flight duration, and the scheduled completion to be in 2009. It is envisioned that the operational Global Observer (GO-2) will be a 250-foot wingspan UAV that can carry a payload of 1000lbs., with 7-day flight duration, scheduled to be completed in 2010. The specifications of the Global Observer are as given in Table 3.

Table 3. Global Observer Specifications [From 34]

Specifications	Global Observer	
	GO-1	GO-2
Maximum Take-Off Weight (lbs)	3980	9870
Wingspan (feet)	175	250
Length (feet)	160	262
Payload (lbs)	400	1000
Endurance (days)	7	7
Operating Ceiling (feet)	65,000	65,000
Speed (knots)	110	110

Equipped with this “persistence” capability, the Global Observer is a potentially highly valuable asset that can be used in both ISR (Intelligence, Surveillance and Reconnaissance) and communications missions, specifically as a wide-band communications relay node. In addition, if the Global Observer is able to demonstrate the JCTD requirements of attaining 7-day flight endurance at 65,000 feet, maintaining altitude at that height would mean that it would be safe from most conventional weapons except the “satellite-killers” [35]. Like any other UAV of similar size, the Global Observer can be easily launched, recovered and relocated. The significant payload capability of the Global Observer, at 400lbs. for GO-1 and 1000lbs. for GO-2, allows a great deal of flexibility for rapid upgrading and reconfiguration of the Global Observer to different payloads as operational requirements evolve.

The LH₂ fuel used by the Global Observer enables it to sustain a much longer endurance, as compared to UAVs powered by traditional fossil fuels. This is due to the significantly higher specific energy of LH₂ compared to other fuels. As a guide, the following Table 4 illustrates the specific energy [36] of commonly used fuels.

Table 4. Specific energy of commonly used fuels [After 36]

Energy Type	Energy Density	
	By mass	By Volume
	MJ/kg	MJ/L
Hydrazine	1.6	1.6
LPG	34.39	22.16
Jet A Aviation Fuel	42.8	33
Diesel	45.8	38.7
Gasoline	46.9	34.6
Compressed Natural Gas at 200 bar	53.6	10
Liquid Hydrogen (LH ₂)	120	8

In addition, the use of liquid hydrogen, which is a clean energy carrier, means that the water and electricity produced by the fuel cells do not contribute to any greenhouse gas emissions, unlike traditional fossil fuel powered aircraft. Furthermore, it does not matter whether or not the production GO-2 makes use of fuel-cell technology or runs on an internal combustion engine [37]. The fact that both of these technologies have been in use for several decades now would likely indicate that the complexity involved in the design and implementation of the propulsion system would not be an overwhelming cost variable. It is noted that in the GO-0 prototype test flight conducted in 2005, the global observer was powered using fuel-cell technology.

Potential challenges involved in the development of the Global Observer that were not tested during the 2005 test flight include the amount of LH₂ that can be carried for each flight to sustain the greater than 7-day endurance touted. As the LH₂ stored on board in tanks are at extremely low temperatures (boiling point of H₂ is 20.28K), insulation of the tanks is crucial to the entire operation.

In summary, for operational deployment in ISR as well as for communications missions, the Global Observer UAS possesses the flexibility for rapid payload configuration (1000 lbs. payload for GO-2), while still maintaining a significant time on-station (at least 7 days endurance) at a high altitude (at 65,000 feet) for extended deployments. In terms of the technology maturity, the Global Observer is expected to be ready by 2010, which is in a time frame that is much sooner than future technologies like

the HAA. It also possesses many advantages over its existing competitors, such as satellites, as well as fossil-fueled UAVs, e.g., RQ-1 Predator and RQ-4 Global Hawk.

On September 26, 2007, it was announced that Aerovironment Inc. had been awarded a \$57m contract [38] from SOCOM for the development and military utility assessment of the Global Observer. The cost-plus fixed-fee arrangement basic contract calls for the development of up to three GO aircraft over the next three years. The contract also includes options for the development and delivery of up to two additional GO aircraft, which gives an overall potential contract value of \$108m.

D. BUSINESS CASE ANALYSES

A Business Case Analysis [39] (BCA) is a fundamental tool used by decision-makers to evaluate different alternatives and then decide on the best courses of action required in the allocation of scarce resources. The BCA, which is a structured and systematic methodology, provides a best-value analysis that considers not only cost, but also other quantifiable and non-quantifiable factors that support the investment decision.

It is an iterative process that is conducted and updated as required throughout the life cycle of the program, due to the evolution and changes of the program plans in the business and mission environment. A typical BCA would include the following elements:

- The objectives of the case.
- The methods, assumptions and constraints.
- Possible alternatives, including the current status quo.
- The costs and benefits of each alternative in the scenario.
- Sensitivity analysis and risk analysis.
- Conclusions and suitable recommendations.

As a decision-making tool, the quality and reliability of the BCA is crucial in enabling the decision maker to make an informed choice. As such, the BCA process provides the decision maker with the relevant insights as to how the project supports the

strategic objectives and how it can achieve these objectives. This assessment is structured such that pertinent information on the scope, alternatives, costs and benefits are laid out clearly, with the potential risks highlighted so that the decision-maker can make an informed decision on whether to invest in the project.

As no two BCAs are alike in the objectives, assumptions, constraints, risk and operating scenario, it is necessary that the BCA being developed is customized for the particular case given the operating environment, i.e., there is no one size fits all solution. However, a generic BCA methodology can be described as a 4-phase process as shown in Figure 6.

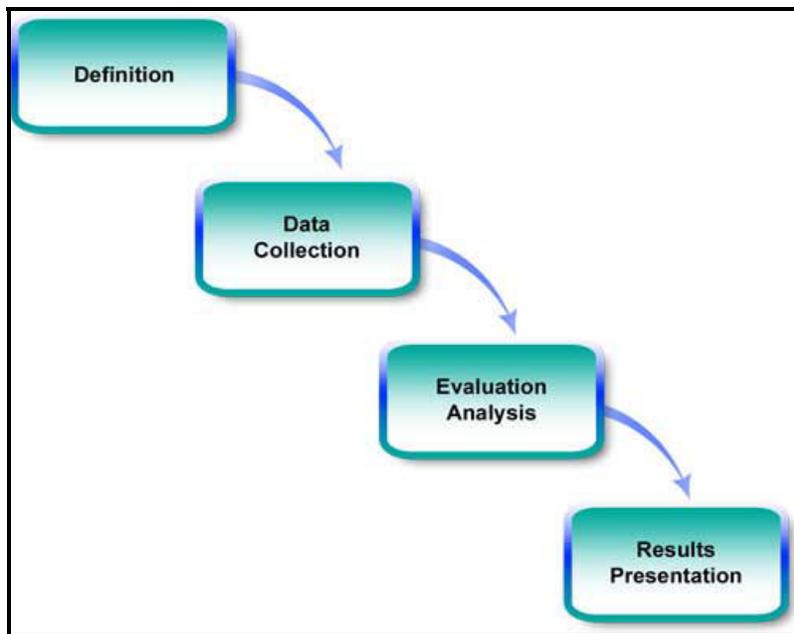


Figure 6. BCA methodology [From 39]

The steps to the process are:

1. Definition

In the first phase, the scope, assumptions and constraints will be defined to guide the analysis. Alternative options are also explored to ensure that there is a minimum of two outcomes (one of which could be maintaining the current status quo) available at the end of the analysis.

2. Data Collection

In the second phase, a data collection plan is devised, so that the types of data required, the data sources, and how they can be obtained, can be mapped out. Models will also have to be developed so that the data can be categorized and stored, while preserving the data integrity. Data normalization is also applied where required. Where the data is not available, estimates can be made, as long as they can be justified, and the methodology adopted explained clearly.

3. Evaluation Analysis

The third phase is where most of the actual BCA work is being accomplished. Data analysis is performed to build the case for each alternative. Alternatives are compared against the baseline and with one another to determine the alternative that provides the optimal cost-benefit combination. Risk analysis is performed to identify the set of risks associated with each alternative, along with proposed risk-mitigating strategies. Sensitivity analysis is also performed to provide insights as to how changes in key parameters or underlying assumptions and constraints that were made could influence the outcome of the analysis.

4. Results Presentation

The fourth and final phase is where the results are communicated to the decision maker. The information presented should be concise, with relevant supporting evidence from the previous phases. A conclusion and recommended course of action should also be provided to the decision maker based on the objectives defined in phase 1.

In summary, once completed, the BCA should be able to determine the following:

- The relative cost vs. benefits of different strategies.
- The methods and rationale used to quantify benefits and costs.
- The impact and value of Performance / Cost / Schedule / Sustainment tradeoffs.

- Data required to support and justify the strategy.
- Sensitivity of the data to change.
- Analysis and classification of risks.
- A recommendation and summary of the implementation plan for proceeding with the best value alternative.

III. GLOBAL OBSERVER BUSINESS CASE ANALYSIS

This section sets the scenarios of how the comparison of capabilities between Global Hawk and Global Observer will be conducted. These scenarios fully stress the round-the-clock intelligence, surveillance, and reconnaissance (ISR), and the communication relay missions assigned to these platforms. The business case analysis will be performed based on the comparison of these platforms performing high intensity operations. First, the scenario on which the analysis is performed will be elaborated. The available data will then be analyzed. This is followed by a computation on the return-on-investment, as well as sensitivity analysis on the key obtained. Finally, a general risk assessment for the Global Observer is made.

The purpose of this analysis is to compare the benefits that Global Observer brings, vis-à-vis the existing Global Hawk ISR platform. This analysis also factors in the communications support provided by satellites to perform tactical battlefield communications, and the cost comparison between the satellites and these two UAV platforms. An operational advantage to UAVs that cannot be quantified is the ability of re-tasking the UAV and positioning it to support quick-reaction tactical ground operations.

A. OPERATIONAL SCENARIO³

The operational scenario of this analysis is based on a strategic employment plan of these ISR platforms (i.e., the Global Observer or the Global Hawk) over six areas of interest which reflect a U.S. National Security Strategy. These ISR missions require continuous coverage, and additionally, they perform tactical battlefield communications missions in Afghanistan and in Iraq in support of Operation Enduring Freedom. The following six regions form the tasking requirements for the analytical scenarios:

³ The crafting of the operational scenario was based on discussions with COL (Ret) Edward Lesnowicz, USMC, who is a Research Advisor at the Naval Postgraduate School. His previous appointments include being the Chief of Staff of Marine Forces Europe as well as the Commanding Officer of the 11th Marine Regiment. COL (Ret) Lesnowicz holds a Masters in Public Policy at the School of Advanced International Studies at the John Hopkins University.

- Trans-Sahara Region. To support the Trans-Sahara Counter-terrorism Initiative (TSCI).
- Afghanistan / Pakistan. To support the on-going military operations in Afghanistan and Pakistan.
- Iraq. To support Task Force ODIN (Observe, Detect, Identify and Neutralize) and the on-going peace-support operations in Iraq.
- Colombia. To support the on-going fight against the illegal flow of drugs into CONUS (CONTinental United States).
- Strait of Malacca. To maintain surveillance of possible terrorist activities that would restrict a ship's passage across the narrow strait.
- China / North Korea. To maintain U.S. surveillance of nuclear facilities and military defenses in the region.

1. Scenario Background

The global threat to U.S. interest is significant. In order to develop a realistic scenario and identify the operational requirements that the Global Hawk and Global Observer must meet the following descriptions of the security environment of the United States is developed.

a. Trans-Sahara Region

The Pan Sahel Initiative (PSI) [40] is a State Department funded program initiated in November 2002 in the northern African countries of Mali, Mauritania, Niger, and Chad. It was designed to enhance border capabilities, track movement of people (especially transnational terrorists), combat terrorism, and enhance regional cooperation and stability. Its goals support two U.S. national security interests in Africa, namely waging the war on terrorism and enhancing regional peace and security.

As follow-on to the successful PSI, the Trans-Sahara Counter-terrorism Initiative (TSCI) [41] was introduced in 2005. The TSCI is a multi-facet, multi-year strategy aimed at defeating terrorist organizations by strengthening regional counterterrorism capabilities, enhancing and institutionalizing cooperation among the

region's security forces, promoting democratic governance, discrediting terrorist ideology, and reinforcing bilateral military ties with the U.S. The overall goals are to enhance the indigenous capacities of governments in the pan-Sahel (Mauritania, Mali, Chad, and Niger, as well as Nigeria and Senegal) regions, to confront the challenge posed by terrorist organizations in the region, and to facilitate cooperation between those countries and the Maghreb partners (Morocco, Algeria, and Tunisia) in the global war on terror.

The deployment of a strategic ISR asset (Global Hawk or Global Observer type) would be able to significantly enhance the U.S. forces' ISR capabilities in this effort. In addition, with the heavy reliance on commercial satellite communications due to the lack of existing terrestrial networks, the Global Observer would also function as an airborne communications satellite for in-theatre communications. Due to the large geographical region to be covered, the mission requires two UAV assets (based on the UAV footprint) to cover this north African region.

b. Afghanistan / Pakistan

U.S. military operations in Afghanistan in the War On Terror have been ongoing after Operation Enduring Freedom (OEF). Although the U.S.-led coalition forces managed to defeat the Taliban regime and dissolve the Taliban-led conventional forces, the war has since been turned into one against insurgency. Al-Qaeda and other associated militant activities continue in the region. Frequent clashes between the insurgents using guerilla-style attacks against the Allied peace-support forces have been on-going. Increased warlord and Taliban activity, coupled with the growing illegal drug trade [42], and compounded by the fragile government, has resulted in Afghanistan becoming increasingly unstable.

Similarly, U.S. and Pakistani forces have been involved in trying to remove Al-Qaeda and Taliban forces in the Federally Administered Tribal Areas of Pakistan's Waziristan region, since the Pakistani Army launched a campaign against them in 2004. To date, the Taliban resistance still operates there.

The deployment of an ISR asset (Global Hawk or Global Observer type) would be able to significantly enhance the U.S. forces' ISR capabilities in their War Against Terror. In addition, with the heavy reliance on commercial satellite communications due to the lack of existing terrestrial networks, the Global Observer would also function as an airborne communications satellite for in-theatre communications. The mission requires one UAV asset to cover this region.

c. Iraq

Since President George W. Bush's declaration of the "end of major combat operations" [43] in Operation Iraqi Freedom (OIF) in 2003, insurgent forces have not ceased their guerilla-style attacks on both Allied peace-support forces, as well as against the newly installed Iraqi Security Forces. This has significantly hampered the ongoing reconstruction efforts by the international community to repair and improve the infrastructure of Iraq after the war.

Even with the installation of the new Iraqi government in May 2006, Iraq has continued to experience an increase in sectarian violence and attacks on the Allied coalition forces, leading to the United Nations to call it a "civil war-like situation and its people would become the victims of an unprecedented human rights catastrophe" [44].

In a bid to curtail the violence in Iraq, President Bush announced that the United States would be "deploying reinforcements of more than 20,000 additional soldiers and Marines to Iraq" at his January 23, 2007, State of the Union Address [45]. More than 3 months into the troop reinforcement, in June 2007, it was reported that the American and Iraqi troops "control fewer than one-third of the city's neighborhoods, far short of the initial goal for the operation." [46].

Task Force ODIN (Observe, Detect, Identify and Neutralize) [47] was started for the conduct of RSTA (Reconnaissance, Surveillance, Targeting and Acquisition) operations in support of the Counter-Improvised Explosive Device (C-IED) fight in OIF. The deployment of an ISR asset like the Global Hawk or Global Observer type would be able to significantly enhance the U.S. forces' ISR capabilities in this effort.

In addition, with the heavy reliance on commercial satellite communications due to the lack of existing terrestrial networks, the Global Observer would also function as an airborne communications satellite for in-theatre communications. The mission requires one UAV asset to cover this region.

d. Colombia

Colombia has been facing low intensity conflicts involving paramilitary militias and rebel guerilla groups for more than 40 years since the founding of the Revolutionary Armed Forces of Colombia (FARC) and the National Liberation Army (ELN) in the mid-1960s. These groups have been waging ongoing guerilla insurgency campaigns against successive Colombian governments [48].

With the emergence of drug cartels from the late 1970s, and their strengthening in the 1980s and 1990s, the illegal drug trade in Colombia has remained very much alive up to today. Through their sheer financial clout, they were able to finance and influence various paramilitary, guerillas and illegal armed groups.

With the U.S. government at the forefront in the combat against the illegal drug trade, coupled with the need to stem the flow of illegal drugs into CONUS, the deployment of a strategic ISR asset (Global Hawk or Global Observer type) enables special operation forces and the Drug Enforcement Agency (DEA) to operate in the region, and significantly enhances host nation's capabilities in their combat against this illegal drug trade. This mission requires one UAV asset to cover this region.

e. Strait of Malacca

The Strait of Malacca is one of the main water passageways between the Indian Ocean and the Pacific Ocean. More than 30% of world commerce, and half of the world's oil, pass through the narrow straits, with the narrowest point being only 1.5 nautical miles (~2.8km) wide [49]. Disruptions to these vital sea lanes would have immediate economic and strategic repercussions that would be felt far beyond the South-east Asian region.

The two-fold threats of terrorism and piracy along the Malacca and Singapore Strait is a threat to U.S. economic interest and is a threat to regional stability. The U.S. protection of the passage is a significant contribution to stability in the Far East. Therefore, U.S. interests in the region can be advanced by keeping a close watch on the region and working with the respective littoral states of Malaysia, Singapore and Indonesia to ensure the security of the Strait. There has been an unspecified threat to shipping in the region.

The deployment of a strategic ISR asset (Global Hawk or Global Observer type) for round-the-clock surveillance of the region supports U.S. operations and coalition partners in the region. This mission requires one UAV asset to cover this region.

f. China / North Korea

With North Korea's withdrawal from the nuclear Non-Proliferation Treaty (NPT) in 2003, as well as its assertion that it currently possesses nuclear weapons (which remains unconfirmed), the U.S. is concerned over the possible proliferation of nuclear material and technology know-how by North Korea to interested countries like Iran and Syria. There has been some success by the six-party talks (comprising the United States, North Korea, South Korea, China, Japan and Russia) in February 2007, culminating in a landmark action-for-action agreement [50]. While initial steps have been taken with the confirmation of the shut down of the Yongbyon nuclear reactor [51] in July 2007, this is but the start of a long process to achieve the goal of a nuclear-free Korean Peninsula.

In the past, U.S.-China relations have generally been unpredictable, with mutual suspicion the order of the day. However, U.S. relations with China have dramatically improved after China's strong support for the War On Terrorism, post-9/11. Despite this warming of relations, there remain various thorny issues still to be resolved. Of great military concern are the following:

- China's increasing but unclear military spending [52].
- The protection of Taiwan from any potential invasion from China.

From the above, it is evident that the deployment of a strategic ISR asset (Global Hawk or Global Observer type) for round-the-clock surveillance of the region would keep the U.S. updated on ground events. This mission requires one UAV asset to cover this region.

2. UAV Operating Bases

For the purpose of comparison, it is assumed that both the Global Hawk and the Global Observer missions can be launched from any one of the following 3 existing or designated-future Global Hawk operating bases. These bases are:

- Beale Air Force Base (California, USA) – Current Global Hawk Operating Base [53]
- Anderson Air Force Base (Guam) – New Global Hawk Forward Operating Base to be ready in 2009. [54]
- Al Dhafra Air Base (United Arab Emirates) – Existing Expeditionary Global Hawk Forward Operating Base. [55]

a. Beale Air Force Base (California, USA)

Beale Air Force Base, located in California, was selected as the first Global Hawk main operating base in 2001, and is the home base of the 9th Reconnaissance Wing which operates the Global Hawk UAV.

b. Anderson Air Force Base (Guam)

Plans are currently underway to build maintenance facilities for the Global Hawk UAV in Anderson Air Force Base in Guam. The facilities that would house up to seven Global Hawks are scheduled to be built by May 2009, with an expected cost of about \$42M.

c. Al Dhafra Air Base (United Arab Emirates)

Since the early phases of Operational Enduring Freedom (OEF), the U.S. Air Force has been operating both the U-2 and the Global Hawk UAV from the Al Dhafra Air Base in the UAE.

It should be noted that the continued use of this base is subject to negotiations between the respective governments, and that although U.S. forces will likely continue to use this base, it need not be a permanent operating base like Beale (California) or Anderson (Guam). The UAE operations point to a need to maintain some level of expeditionary capability at both Beale and Anderson AFBs. This would be for contingency operations where relocation of UAV assets improves operational performance.

3. Selection of UAV Operating Base

The following Table 5 illustrates the distances [56] from the nearest operating base (correct to the nearest 10 nautical miles) to the various Areas of Operations (AO). For the purpose of distance computation, the following locations were used as proxy for the respective AO:

- Trans-Sahara Region: Niger-Algeria-Mali boundary
- Afghanistan / Pakistan: Kabul
- Iraq: Baghdad
- Colombia: Bogota
- Strait of Malacca: Singapore
- China / North Korea – Pyongyang

Table 5. Selection of operating base to launch the UAV

	Area of Operation	Nearest UAV Operating Base	Distance (nm)
1	Trans-Sahara Region	Al Dhafra AB	2810
2	Afghanistan / Pakistan	Al Dhafra AB	980
3	Iraq	Al Dhafra AB	760
4	Colombia	Beale AFB	3290
5	Strait of Malacca	Anderson AFB	2540
6	China / North Korea	Anderson AFB	1860

The following Figure 7 shows the geographical locations of the various AO and the UAV operating bases.

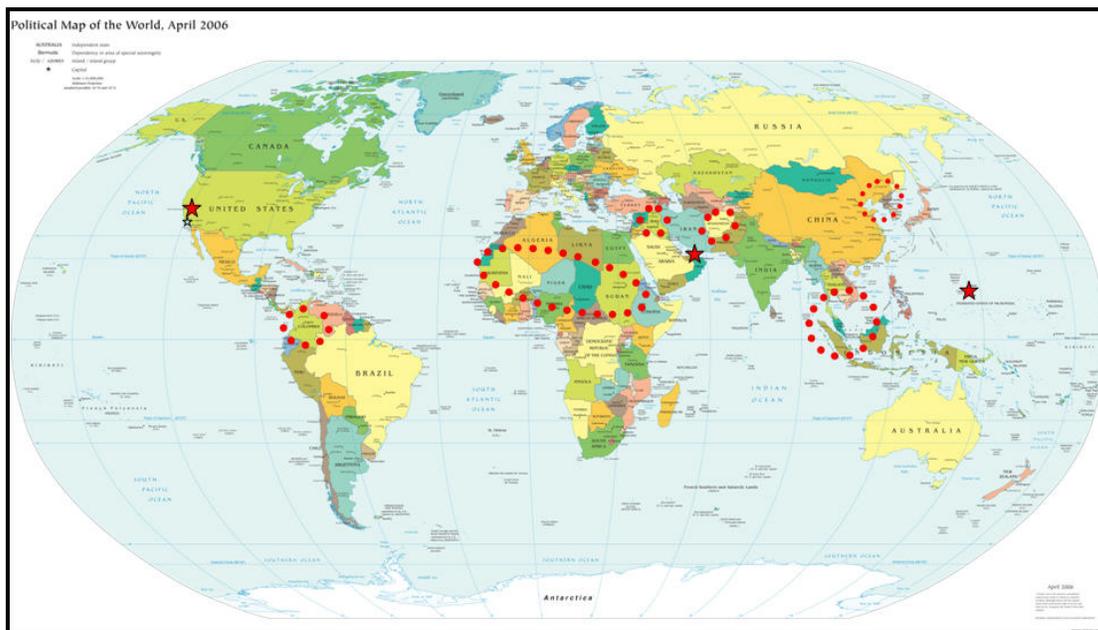


Figure 7. World map [From 57] with annotation of UAV Operating bases and AO

B. DATA ANALYSIS

The following sections provide an analysis of the data based on the given operational scenario.

1. Number of UAVs Required

A typical mission sortie profile for the UAV is for it to be launched from its operating base, and ingress to the designated AO. It will then loiter and perform its mission until it is time for it to return to the base, by which time another UAV would have arrived to take its place. The first UAV will then egress and return to base for maintenance work. The cycle continues for the second UAV, which will return only after a third UAV has reached the AO to take its place. The following Figure 8 illustrates the typical mission sortie profile of the UAV.

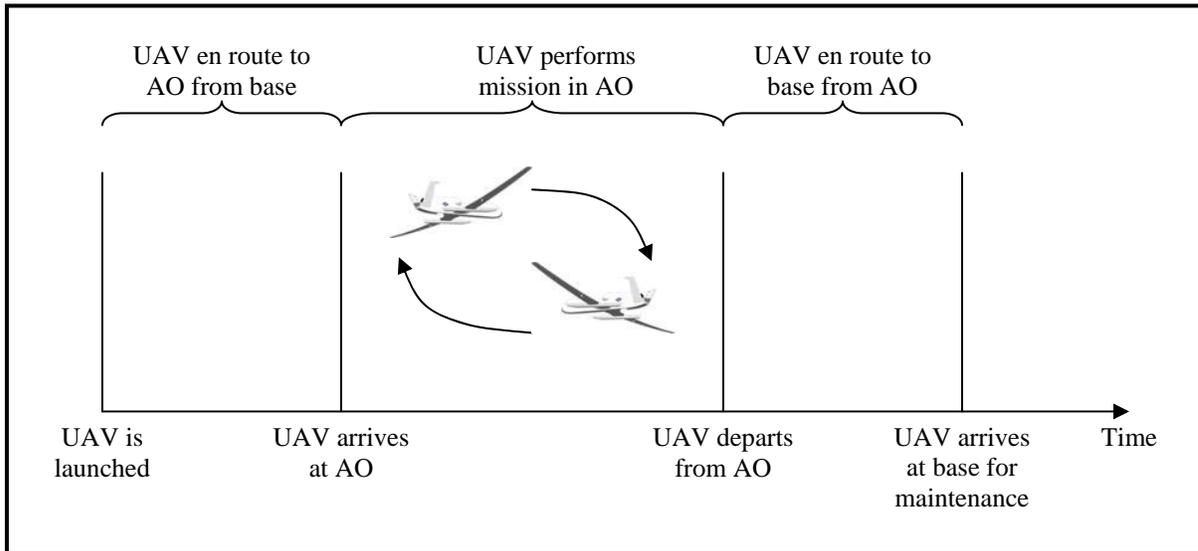


Figure 8. Typical mission sortie profile of the UAV

The following Table 6 summarizes the cruise speeds and flight endurance times for both the Global Hawk and the Global Observer used in the calculations:

Table 6. Cruise speed and endurance times for Global Hawk and Global Observer

Attribute	Global Hawk	Global Observer
Cruise Speed (knots)	340	110
Endurance (hrs)	35	168

The following key assumptions were made in the computation of the minimum number of UAVs required:

- The returning UAV will have an hour of spare flight time (i.e., reserve fuel load) remaining when it arrives back at base.
- The time required for maintenance is assumed to take an average of 36 hours after each mission sortie. This takes into account the fact that maintenance can be as short as a few hours (for normal refueling operations), or possibly as long as a week at a stretch (for complete structural maintenance and inspection) after the UAV is deployed for a certain number of missions.
- Weather factors such as headwind or tailwind, which may affect the distance covered vis-à-vis the endurance of the UAV, is not taken into account in the analysis.
- The time taken to climb to cruise altitude is assumed to be negligible compared to the UAV's flight endurance. This assumption is reasonable because the Global Hawk has a cruise altitude of 55,000 ft. and a climb rate of 3,400 feet per minute. The time it takes for a Global Hawk to climb to cruise altitude is less than 20 minutes, compared to 35hrs. of flight endurance at cruise altitude.
- Air spares for redundancy coverage is not required.
- Ground spares were not included in the calculations at this point, but will be factored in subsequently for the mission to each of the AOs.

The following Figure 9 shows the number of UAVs required (excluding spares) for a 365/24/7 Time On-Station mission vis-à-vis the distance of the operating base from the AO.

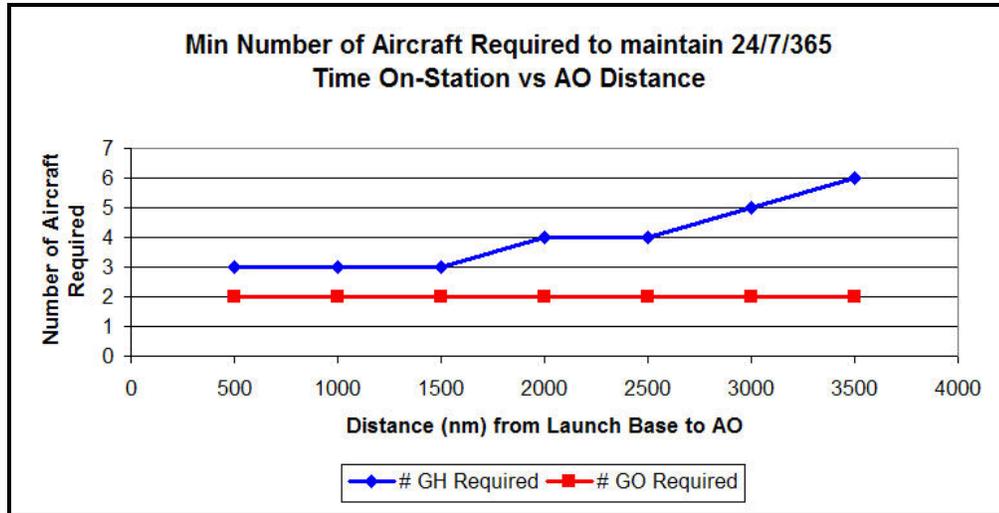


Figure 9. Minimum number of aircraft required vs AO Distance

For each AO, the number of UAVs required is computed based on the following formula:

$$\begin{aligned} &\text{Number of UAVs Required} \\ &= \left\lceil \frac{\text{Mission Cycle Time}}{\text{UAV Time On-Station}} \right\rceil \times \text{Number of UAVs required on-station} \\ &\quad + 1 \text{ Ground Spare} \end{aligned}$$

where:

$$\begin{aligned} \text{Mission Cycle Time} &= \text{UAV Time On-Station} + \text{UAV Transit Time} \\ &\quad + \text{UAV Maintenance Time} \end{aligned}$$

$\lceil x \rceil$ is the ceiling function of x

The UAV requirements are summarized in the following Table 7 as shown below:

Table 7. UAV requirements for mission to respective AO

	Area of Operation	Distance (nm)	# GH Required (incl. spare)	# GO Required (incl. spare)
1	Trans-Sahara Region	2810	11	5
2	Afghanistan / Pakistan	980	4	3
3	Iraq	760	4	3
4	Colombia	3290	6	3
5	Strait of Malacca	2540	5	3
6	China / North Korea	1860	5	3
Total			35	20

Based on the operational scenario considered, a total fleet size of 35 Global Hawks and 20 Global Observers are required to provide 24/7/365 ISR and communications capabilities.

2. Number of Sorties Required Per Year by the UAVs

It is useful to look at the required number of sorties to fulfill the operational requirements. This measure of effectiveness will provide insights to the decision maker on the operational tempo and the potential differences in staffing requirements for the crew supporting the Global Observer vis-à-vis the Global Hawk. As a quantum, the number of sorties is measured for continuous operations in the AO over the period of one year.

The number of sorties required per year is computed based on the following formula:

$$\text{Number of Sorties Required Per Year} = \left\lceil \frac{365 \times 24}{\text{UAV Loiter Time}} \right\rceil \times \text{Number of UAVs required on-station}$$

where:

$\lceil x \rceil$ is the ceiling function of x

The following Figure 10 illustrates the number of sorties required per annum by both alternatives vis-à-vis the distance of the AO from the operating base.

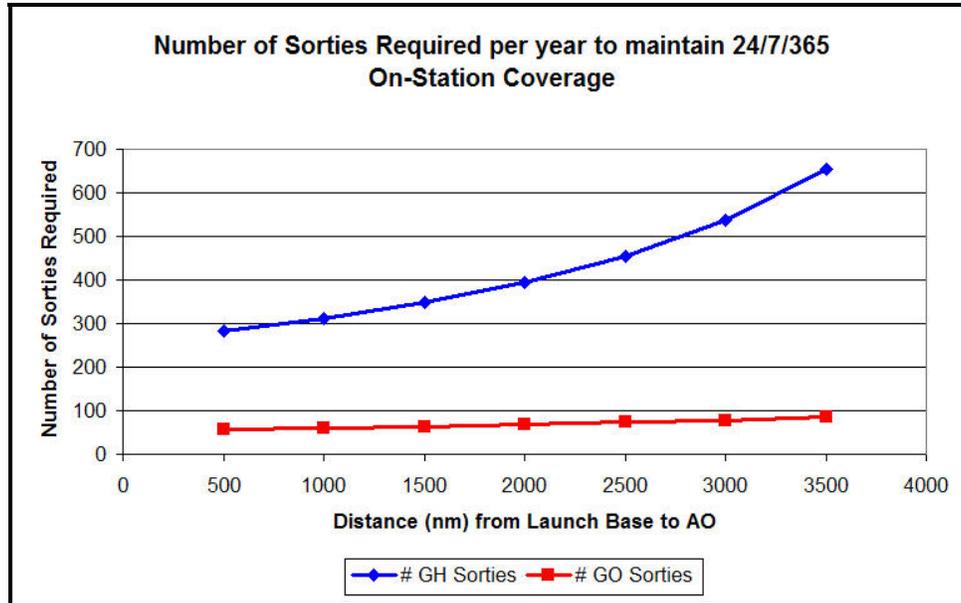


Figure 10. Number of UAV sorties required per year vs AO distance

For the operational scenario, Figure 11 illustrates the number of sorties required per annum by both UAVs to each of the AO. To fly the entire operational scenario to all 6 AOs, a total of 490 Global Observer sorties is required vis-à-vis 3051 Global Hawk sorties.

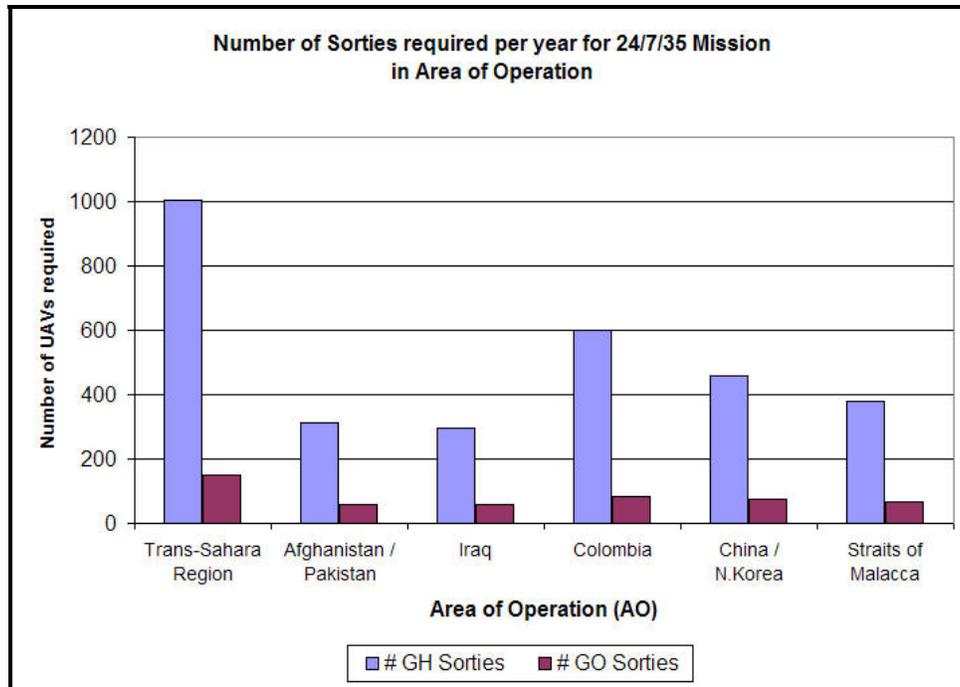


Figure 11. Number of UAV sorties required per year for mission

3. Utility of the UAVs

With the given number of UAVs and sorties generated per year to maintain 24/7/365 continuous coverage over their respective designated areas of operation, another useful MOE would be to compare the utility of the UAVs in performing their mission. The utility is defined as the proportion of time spent on-station by the UAV in performing its mission, i.e., time in the AO, over its mission cycle time, and is computed as follows:

$$\text{Utility of UAV} = \frac{\text{UAV Time On-Station}}{\text{UAV Mission Cycle Time}}$$

where:

$$\begin{aligned} \text{Mission Cycle Time} = & \text{UAV Time On-Station} + \text{UAV Transit Time} \\ & + \text{UAV Maintenance Time} \end{aligned}$$

The following Figure 12 illustrates the utility of the UAVs for each of the AO.

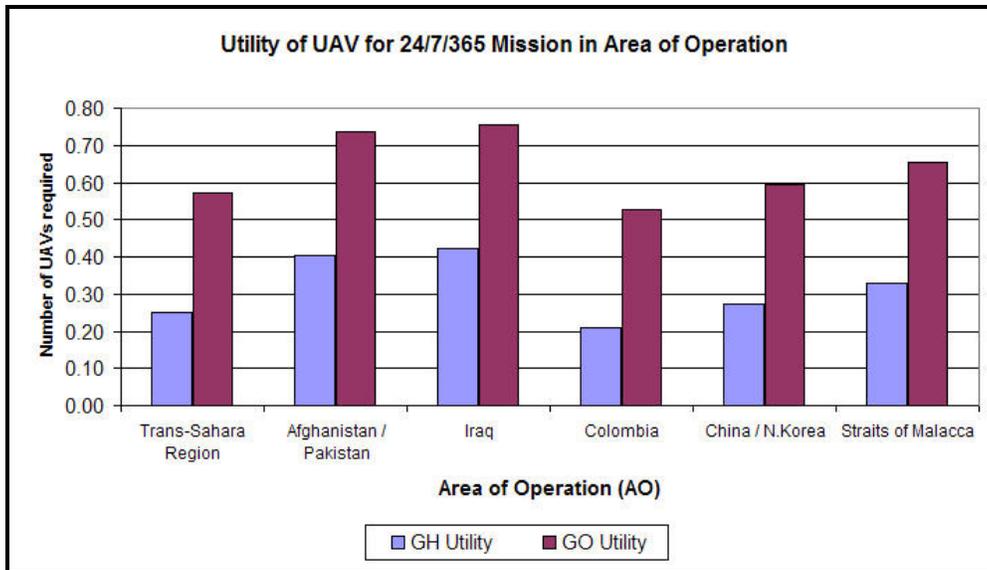


Figure 12. Utility of UAV for mission

4. Life Cycle Cost

The Life Cycle Cost of the Global Observer UAS comprises the program acquisition cost, as well as the operations and support (O&S) cost (per UAV) over its lifespan [58], which is assumed to be over a period of 15 years. The O&S cost is made up of Operations and Maintenance (O&M) costs as well as Personnel costs.

To compute and compare the life cycle cost of the Global Observer vis-à-vis the Global Hawk, the following key cost considerations will be used. Manpower costs are assumed to be the same for both, and it is not considered in this analysis. Costs are computed in FY05\$, assuming a discount factor of 5.05% per annum [1].

- Aircraft Cost
- Launch and Recovery System (LRS), and Mission Control System (MCS) Costs
- Payload Cost
- Fuel Cost
- Maintenance and Repair Costs

a. Aircraft Cost

The cost of the Global Observer, based on the production of at least 10 aircraft, is estimated to be \$14.2M for the GO-1, and \$18.5M for the GO-2 [59], whereas the cost of the RQ-4B Global Hawk is approximately \$35M per aircraft [60].

b. Launch and Recovery System, Mission Control System Costs

Taking into account the fact that the Launch and Recovery System (LRS) and the Mission Control System (MCS) do not follow a 1:1 relationship with the number of UAVs, it is assumed that the cost of the LRS and MCS comes up to 10% of the total platform cost for both the Global Hawk and the Global Observer. Hence, the LRS and MCS costs are estimated to be \$3.5M for each Global Hawk and \$1.4M for each Global Observer in the inventory.

c. Payload Cost

For all missions, it is assumed that since both the Global Hawk and the Global Observer perform similar missions, they would carry similar payloads, and this payload cost is assumed to be \$5M⁴ [61].

d. Fuel Cost

The Global Hawk is powered by JP-8, the standard aviation fuel used by all U.S. Air Force aircraft since 1996. The unburdened cost of JP-8 is \$2.31/gallon for FY 2008 [62]. Taking the specific gravity of JP-8 to be 0.80 [63], the unburdened cost of JP-8 is computed to be \$0.35/pound based on the following formula:

$$\begin{aligned} &\text{Cost of Liquid Fuel in pounds} \\ &= \text{Specific Gravity of Fuel} \times \text{Gallon to Pound Factor} \\ &\quad \times \text{Cost of Fuel in gallons} \end{aligned}$$

where:

⁴ Global Hawk's Integrated Sensor Suite costs about \$12M in mid-2002 [From 61]. Global Observer's payload cost is assumed to be about \$5M based on their smaller payload size compared to the Global Hawk.

Gallon to Pound Factor = 8.3452641

A report from OUSD(AT&L) estimated the burdened cost of JP-8 to be about \$17.50/gallon [64], or about \$2.62/pound.

It is estimated that the fuel capacity of the Global Hawk is about 15,000 lbs of JP-8. Using the formulae:

$$\begin{aligned} \text{Cost of Fuel per sortie} \\ = \text{Burdened Cost of Fuel per pound} \times \text{Fuel Capacity of UAV} \end{aligned}$$

and

$$\begin{aligned} \text{Cost of Fuel per year} \\ = \text{Cost of Fuel per sortie} \times \text{Number of sorties per year} \end{aligned}$$

The burdened cost of fuel per sortie for the Global Hawk is about \$39,300 per sortie. For 3051 Global Hawk sorties, which comes up to a fuel requirement of 38.2 million lbs. of JP-8, the cost of JP-8 is about \$120.0M per annum.

The unburdened cost of LH₂ is \$3.00/pound for FY 2008 [65]. With the Department of Energy's new hydrogen cost goal [66] of \$2.00-3.00/gge (delivered, untaxed, FY05\$, by 2015), which is independent of the pathway used to produce and deliver hydrogen, the cost of liquid hydrogen is expected to drop in future. A similar cost factor for the unburdened and burdened cost of JP-8 (1:7.6) was used as the basis to estimate the burdened cost of LH₂. Based on this, the burdened cost for LH₂ is estimated to be about \$22.70/pound.

It is estimated that the fuel capacity of the Global Observer is about 1000lbs. of LH₂. Using the similar equations, the burdened cost of LH₂ per sortie for the Global Observer is computed to be \$22,700. For 490 GO sorties, which come up to a fuel requirement of 490,000 lbs. of LH₂, the cost is about \$11.1M per annum.

The following Table 8 summarizes the results:

Table 8. Annual fuel cost incurred by the UAVs

UAV	Fuel	Unburdened Fuel Cost [\$ per lb]	Burdened Fuel Cost [\$ per lb]	Usage per sortie [lbs]	Fuel Cost per sortie [\$K]	Number of sorties per annum	Annual Fuel Cost [\$M]
Global Hawk	JP-8	0.35	2.62	15000	39.3	3051	120.0
Global Observer	LH ₂	3.00	22.70	1000	22.7	490	11.1

e. Maintenance and Repair Costs

Based on analysis of historical data (FY05 and FY06) [67] for the Global Hawk, the annual maintenance and repair cost is found to be about 10% of the cost of the operating inventory (taken to be the aircraft, LRC, MCS and payload). It is assumed that this rate holds for both the Global Hawk and the Global Observer. Hence, the annual maintenance and repair cost is estimated to be about a tenth of the cost of the respective platforms, i.e., \$4.4M for each Global Hawk and \$2.1M for each Global Observer.

The following Table 9 illustrates the total costs to purchase and operate the respective UAVs over 15 years. This is for the operational scenario based on the respective cost elements. It is assumed that the fuel costs and the maintenance costs remain constant over the 15-year period.

Table 9. Costs to purchase and operate the UAVs over 15 years

[CY, FY05\$M]

Cost Element	Global Observer	Global Hawk	Percentage Savings
UAV Cost	284.0	1225.0	76.8%
LRS + MCS Cost	28.0	122.5	76.8%
Payload Cost	100.0	175.0	42.9%
Fuel Cost	99.4	1070.5	90.7%
Maintenance and Repair Cost	368.0	1358.6	72.9%
Total Cost	879.8	3951.5	77.7%

The estimated cost to purchase and operate the Global Observer for 15 years is \$879.8M (2005\$), compared to the Global Hawk's cost of \$3951.5M (2005\$). This translates to a savings of 77.7%. The following Table 10 illustrates the overall Life Cycle Cost Table for both the Global Observer and the Global Hawk.

Life cycle cost table for the UAVs over 15 years

[CY, FY05\$M]

LCCE (FY05\$M)				
	Global Observer	Global Hawk	DELTA \$	DELTA %
Investment	412.4	1522.5	1110.1	72.9%
Operations & Support	467.4	2429.0	1961.7	80.8%
Total	879.8	3951.5	3071.8	77.7%

5. Cost of Leased Commercial Satellite Communications

Figure 13 illustrates the commercial satellite communications bandwidth usage. The high bandwidth consumed from 2003 to 2005 in the Middle East / Africa region is due largely to the significant bandwidth requirements resulting from OIF / OEF. In FY05, the bandwidth consumed was more than 2500MHz.

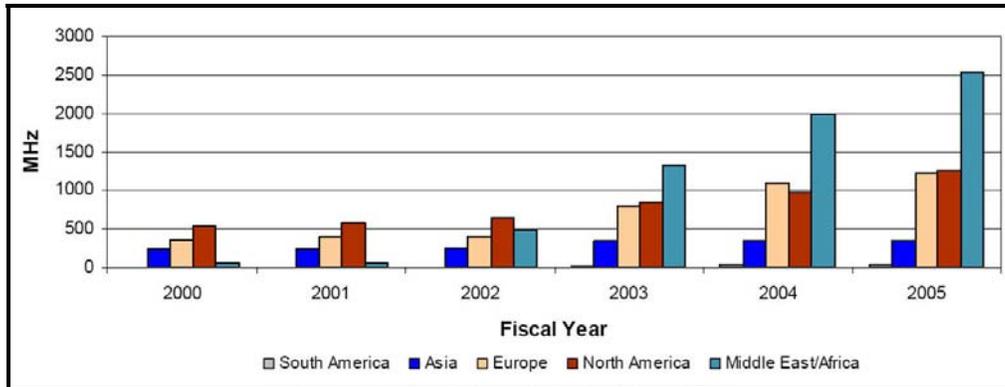


Figure 13. Commercial satellite bandwidth usage by region [From 12, Fig 4-15]

The corresponding expenditure incurred by the DoD for the commercial satellite bandwidth consumption is as shown in Figure 14 below. For FY05, the expenditure for the Middle East / Africa region was in excess of \$80M.

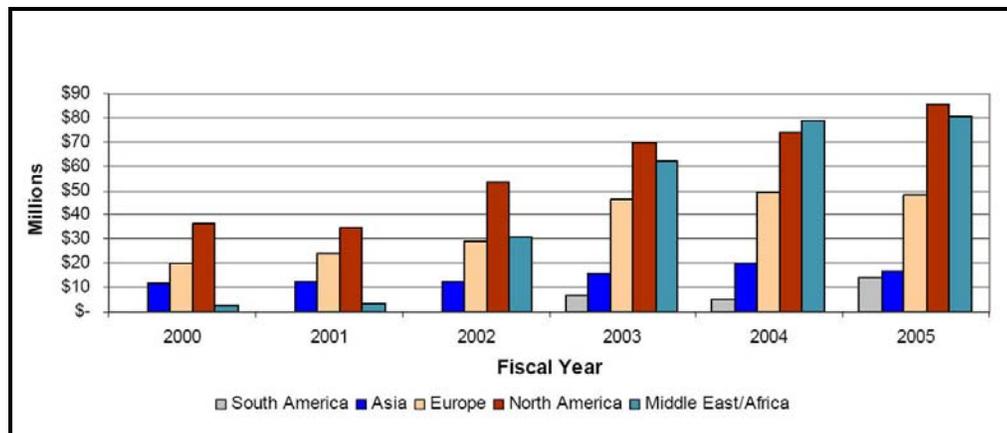


Figure 14. Expenditure on commercial satellite bandwidth by region [From 12, Fig 4-14]

It is conservatively estimated that due to the lack of terrestrial communications networks in the Middle East / Africa area of operations, in-theatre battlefield communications account for 50% of the total commercial satellite bandwidth consumed. Hence, based on the FY05 data, the cost of leased commercial satellite bandwidth is estimated to be \$40M. For the purpose of comparison, it is assumed that the bandwidth usage for in-theatre communications remains constant at \$40M per annum for subsequent years. This translates to a potential savings of \$40M per annum, as well as the fact that more of the scarce satellite communications bandwidth resources can now be used for inter-AO or reach-back communications.

C. RETURN ON INVESTMENT

The approach for the Return-on-Investment (ROI) analysis is to establish a base case with quantitative benefits that can be attributed to the operational deployment of the Global Observer vis-à-vis the use of Global Hawk, as well as the potential savings in commercial satellite communications utilization.

1. Base Case Benefits

A summary of the benefits is listed in Table 11. For the base case, the following benefits are considered:

- Other than satellites, no other existing platforms are able to provide 24/7/365 persistent capability over any given area of interest. Although the Global Hawk can be used to perform such missions, it has not happened in real-life operations due to the high associated costs. Instead, the Global Hawk had only been deployed for specific missions and only for a limited period of time.
- On a per UAV basis, the investment cost required for a Global Observer is 59.4% cheaper than the Global Hawk. For 24/7/365 persistent capability based on the scenario, the estimated investment savings is 76.8%. (See Table 11)

- Fuel cost for the Global Observer is estimated to be 90.7% cheaper than for the Global Hawk. (See Table 11)
- Maintenance and Repair cost for the Global Observer is estimated to be 72.9% cheaper than for the Global Hawk. (See Table 11)
- The number of sorties required to be flown for the Global Observer is estimated to be 83.9% less than for the Global Hawk. As a significant proportion of aircraft damage is caused during takeoff and landings, this huge reduction in the number of sorties to be flown will invariably result in a lower logistic footprint required to support the operation.
- In areas of operation where there is a lack of terrestrial communication networks, the Global Observer can now provide high-bandwidth battlefield communications for intra-theatre communications, compared to existing low-bandwidth satellite communications.
- Savings can also be achieved in the form of cost avoidance for the expenditure on commercial satellite communications bandwidth for in-theatre communications (conservatively estimated to be 50% of the total expenditure) in the Middle-East / Africa region. (See Table 11)

Table 10. Summary of the benefits of Global Observer

S/No.	Benefit Description	Remarks
1.	Provide 24/7/365 ISR capability	New Capability
2.	Savings in investment cost	76.8%
3.	Savings in fuel cost	90.7%
4.	Savings in maintenance and repair	72.9%
5.	Reduced number of sorties flown	83.9%
6.	Provide high-bandwidth Tactical Battlefield Communications network capability	New Capability
7.	Savings in usage and expenditure on commercial satellite communications bandwidth	50%

2. Base Case ROI

The base case ROI was computed over a period of 15 years from FY09 (when the Global Observer is first expected to be delivered), with base year of FY05. The budget appropriation / cost element is based on Operations and Management (Purchases), with the discount factor set at 5.05% [1]. The savings attained by the Global Observer would be compared against that of the Global Hawk for 24/7/365 surveillance and communications networking missions.

The ROI computation will be performed for two cases (1) the first which does not include the estimated \$40M cost avoidance for not using commercial satellite bandwidth and (2) the second which does include the cost avoidance. The first case takes into account the fact that the Global Hawk can, in theory, also be used to provide the required in-theater battlefield communications networking.

A summary of the key parameters used in the ROI computation are given below:

- The estimated investment cost of the Global Observer is \$412.4M while the cost to operate it over 15 years is \$467.4M. (From Table 10)

- The estimated investment cost of the Global Hawk is \$1522.5M while the cost to operate it over 15 years is \$2429.0M. (From Table 10)
- The estimated expenditure for in-theatre usage of commercial satellite bandwidth over 15 years is \$386.4M.

The annualized ROI is computed based on the following formula:

$$\begin{aligned}
 \text{ROI} &= \left(\frac{\text{Net Present Value of Savings}}{\text{Net Present Value of Investment}} \right)^{1/15} - 1 \\
 &= \left(\frac{3951.5\text{M} - 879.8\text{M}}{412.4\text{M}} \right)^{1/15} - 1 \\
 &= 14.3\%
 \end{aligned}$$

A **14.3%** annualized return on investment is obtained, based on NPV Savings of \$3071.8M and NPV Investment of \$412.4M. If the cost avoidance for in-theater commercial satellite communications bandwidth is taken into account, the annualized return on investment is **15.2%**.

D. SENSITIVITY ANALYSIS

The purpose of sensitivity analysis is to study how the variation of input model parameters will affect the outputs. In this way, assumptions used in the model can be scrutinized to see how the uncertainty in the input parameters can affect the model outputs. The sensitivity analysis provides confidence to the decision maker on the robustness of the model with regard to varying input parameters. For this study, the factors to be varied are as follows:

- Discount Factor - To be varied from 3% to 10%. A large discount factor would affect the computed benefits for the Global Observer in terms of total costs. However, it is not expected to significantly affect the computed ROI, as Global Hawk would also face a similar discount.
- Investment and Maintenance Costs – To be varied from a factor of 1 to 2. A higher investment cost would also correspondingly affect the LRS/MCS and maintenance and repair costs, which will invariably affect the computed benefits for the Global Observer.

- LH₂ Fuel Costs – To be varied from a factor of 1 to 3. A higher LH₂ fuel cost would result in a higher operational cost, thereby affecting the computed benefits for the Global Observer.

It is to be highlighted that the ROI analysis is strictly based on quantifiable measures such as cost savings, and does not take into account operational benefits and other unquantifiable benefits such as the increased wear and possible loss of UAVs due to sortie take-offs and landings.

1. Discount Factor

The following Figure 15 illustrates the estimated total costs for the purchase and 15-year operation for both the Global Hawk and the Global Observer when the discount factor varies from 3% to 10%.

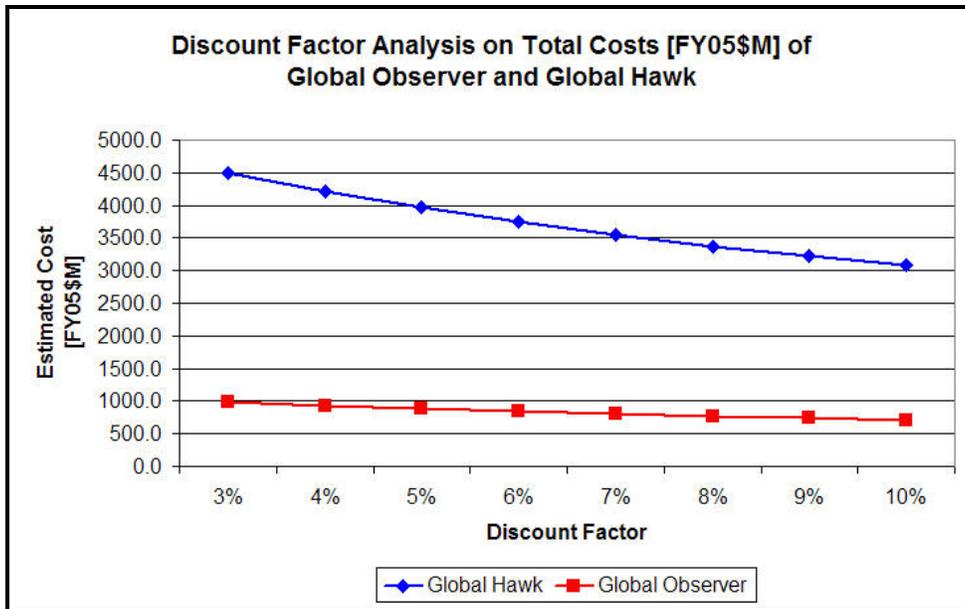


Figure 15. Discount factor analysis on total costs [FY05\$M]

Figure 16 below illustrates the annualized ROI for the Global Observer based on varying the Discount Factor. Even with a discount factor of 10%, the annualized ROI for the Global Observer never falls below 12.4% (case without commercial satellite bandwidth savings).

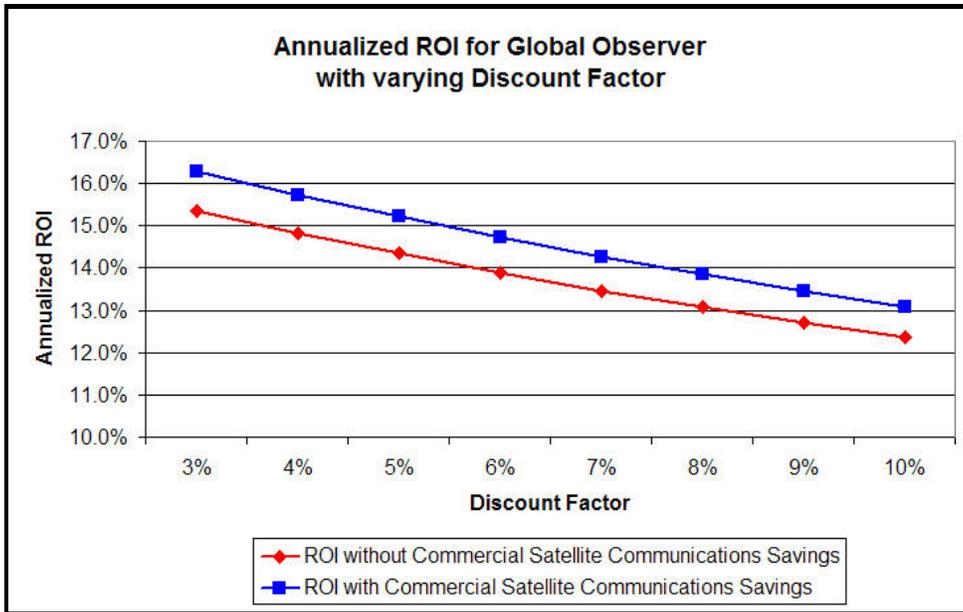


Figure 16. Discount factor analysis on annualized ROI

2. Investment and Operation Cost

Figure 17 illustrates the estimated total costs for the Global Observer vis-à-vis the Global Hawk when the Investment and corresponding Operation Costs of the Global Observer vary by a factor of 1 to 2.

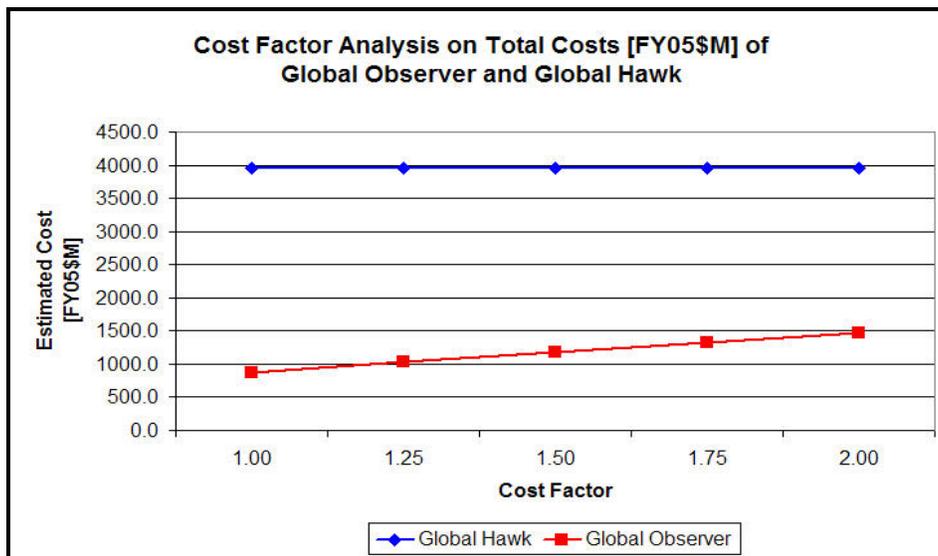


Figure 17. Cost factor analysis on total costs [FY05\$M] for the Global Observer

Figure 18 below illustrates the annualized ROI for the Global Observer based on varying the Cost Factor. It is observed that the annualized ROI does not fall below 8.5%, even if the investment and operations cost of the Global Observer reaches a factor of 2.0 from the current estimated cost of \$14.2M per aircraft (case without commercial satellite bandwidth savings). This indicates that the Global Observer is indeed a cost-attractive investment.

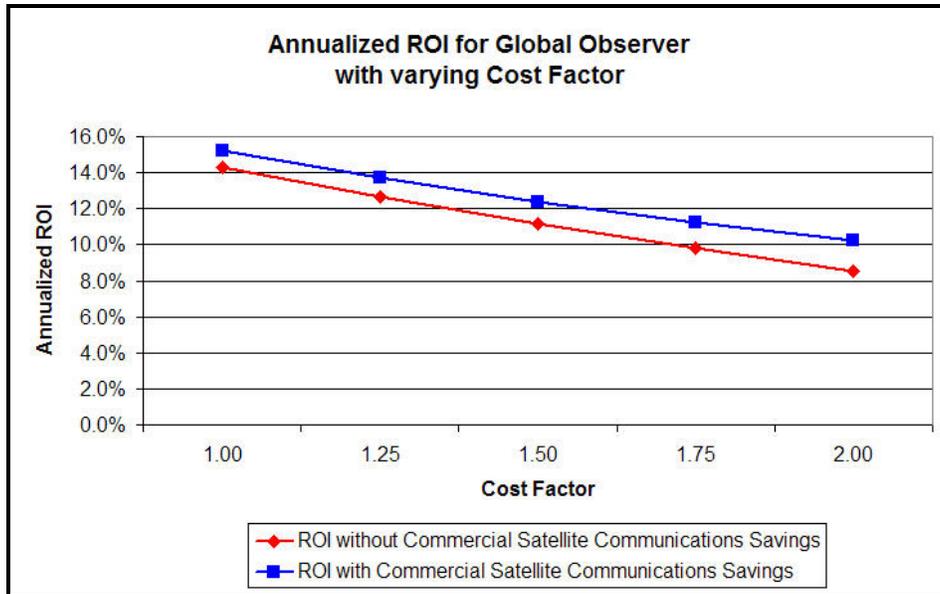


Figure 18. Cost factor analysis on annualized ROI for the Global Observer

3. LH₂ Fuel Cost

The analysis varies the LH₂ cost, while maintaining a constant cost of JP-8. Figure 19 illustrates the estimated total costs for the Global Observer vis-à-vis the Global Hawk when the LH₂ cost for the Global Observer vary by a factor of 1 to 3.

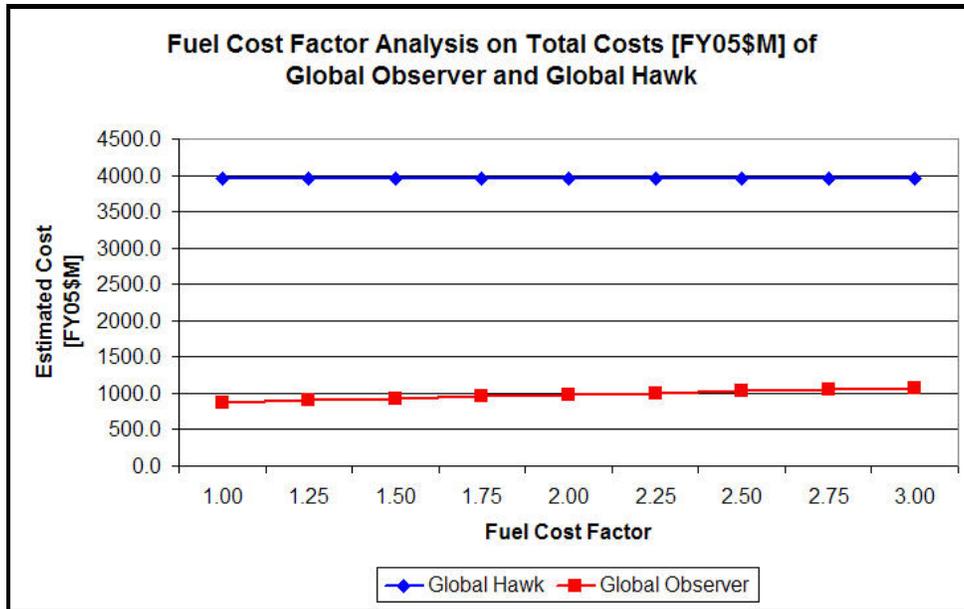


Figure 19. Fuel cost factor analysis on total costs [FY05\$M] for the Global Observer

Figure 20 below illustrates the annualized ROI for the Global Observer based on varying the Fuel Cost Factor. It is observed that the change in annualized ROI for the Global Observer does not vary significantly (does not fall below 13.8%), due to the fact that fuel costs account for only about 10% of the total costs.

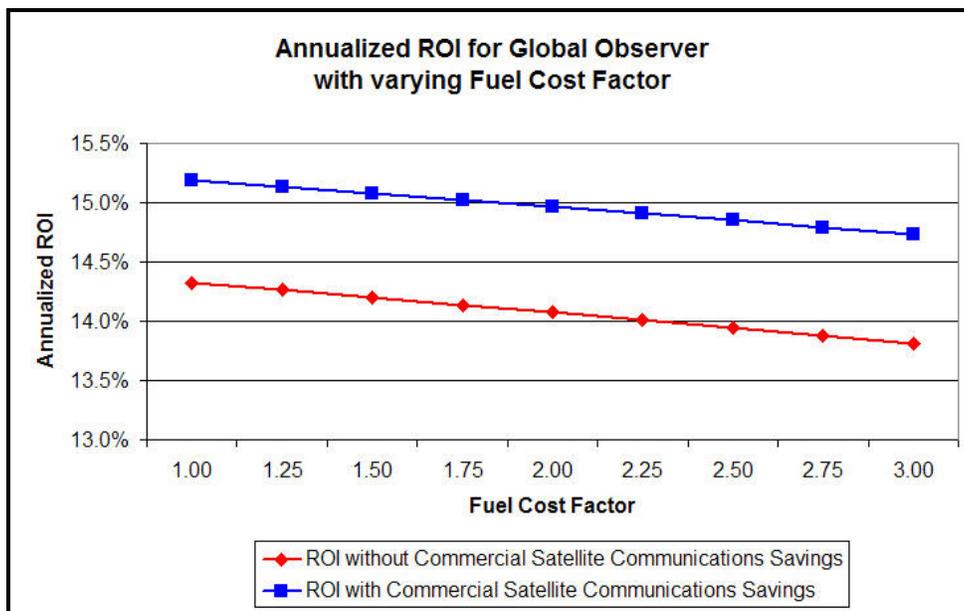


Figure 20. Fuel cost factor analysis on annualized ROI for the Global Observer

E. RISK ANALYSIS

While performing analysis on the cost and the return on investment for the Global Observer is necessary for any business case analyses, it would be pertinent to also examine the potential risks involved in a new and unproven technology. The following are potential sources of risk for the Global Observer:

1. Reliability of the Technology

While the technology for powering platforms using liquid hydrogen is fairly mature, there has not been any prototype that has demonstrated such ground-breaking capabilities. The only demonstration so far by the Global Observer prototype was a one-day flight performed in 2005. Hence, the reliability of the platform to perform as well as it claims remains unproven.

2. Logistical Support

LH₂ has traditionally been used as a propellant for missiles and other space-borne platforms. As such, the operating procedures for the use of LH₂ as a fuel have already been formalized. However, infrastructure and logistical support issues also need to be examined, as these issues may inhibit the deployment and support of the Global Observer, especially in OCONUS forward operating bases.

IV. CONCLUSION AND RECOMMENDATIONS

The report has presented a generic structure for performing a business case analysis, with specific application to the Global Observer JCTD. The BCA compares the performance of Global Observer with Global Hawk (augmented with existing commercial satellite communications networks) in an operational scenario consisting of a 24/7/365 ISR and communications mission. Life Cycle Costs (LCC) consist of investment costs, as well as the costs to operate the platform over a 15-year period.

The key results of the business case analyses are summarized as follows:

A. PERFORMANCE

- A total of 20 Global Observers were required (including 6 ground spares for each of the AOs considered) for the mission, compared to 35 Global Hawks (including the 6 ground spares).
- A total of 490 Global Observer sorties were required, compared to 3051 for the Global Hawk. This translates to a cost savings of 90.7% on fuel costs.
- For the various areas of operation, the utility (defined as the proportion of time spent on-station by the UAV in performing its mission, i.e., time in the AO, over its mission cycle time) of the Global Observer ranged from 0.53 to 0.75, compared to 0.21 to 0.42 for the Global Hawk.

B. COST BENEFITS

- The estimated life cycle cost comparison (less manpower costs) over a 15-year period between the Global Observer and the Global Hawk are summarized in the following Table 12.

Table 11. LCC comparison between Global Observer and Global Hawk

LCCE (FY05\$M)				
	Global Observer	Global Hawk	DELTA \$	DELTA %
Investment	412.4	1522.5	1110.1	72.9%
Operations & Support	467.4	2429.0	1961.7	80.8%
Total	879.8	3951.5	3071.8	77.7%

- The estimated cost to purchase and operate the Global Observer for 15 years is \$879.8M (FY05\$), compared to the Global Hawk’s cost of \$3951.5M (FY05\$). This translates to a savings of 77.7%.
- There is also an estimated potential cost avoidance of about \$40M per annum on commercial satellite bandwidth usage if the Global Observer can be deployed to provide tactical battlefield communications over the area of interest, in addition to its regular ISR mission.
- The base case annualized compounded Return on Investment (ROI) (over a 15-year period from FY09) is 14.3%, based on a Net Present Value (NPV) savings of \$3071.8M and NPV Investment of \$412.4M.

C. SENSITIVITY ANALYSIS

- The base case annualized ROI never falls below 12.4% when the discount factor for the Global Observer was varied from 3.0% to 10%.
- The base case annualized ROI does not fall below 8.5%, even when the cost factor for the Global Observer is increased to double the current estimated cost.
- The base case annualized ROI does not fall below 13.8% when the fuel cost of LH₂ was varied from 1 to 3 times the current estimated burdened cost of \$22.70 per pound, while maintaining a constant JP-8 burdened cost of \$17.50 per gallon.

D. RISK ANALYSIS

- The reliability of the technology to achieve 7 days flight endurance remains unproven, as there was no demonstrator that has achieved such a capability.
- For operational deployment, it is necessary to also look into the infrastructure and logistical support requirements, especially with regard to LH₂ handling, to adequately support the Global Observer for missions from OCONUS forward operating bases.

E. BOTTOMLINE

The benefits of the Global Observer should not be limited to the factors presented in this study, as these factors are by no means a comprehensive list of factors by which the Global Observer ought to be measured. The very concept of a HALE UAV achieving 7 days flight endurance is already a ground-breaking capability, especially since currently, operational UAVs can achieve no more than 2 days of flight endurance.

The Global Observer, with its prolonged persistence (7 days) and flexibility in payload configuration, appears to be a worthwhile investment that can provide the DoD with a new capability in round-the-clock ISR and battlefield communications.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

- [1] Office of Management and Budget, *2007 Discount Rates for OMB* (Circular No. A-94). 2007.
- [2] Oxford English Dictionary. "Surveillance." [Online]. Available: Oxford English Dictionary Online, http://www.askoxford.com/concise_oed/surveillance?view=uk [Accessed September 10, 2007].
- [3] C.N. Ford, "Reliability and Maintainability Symposium," *Proceedings Annual Volume*, pp.118-121, January 1999.
- [4] T. Bially, "Home of the Fog-Lifters," presented at DARPA Tech 2005, California, U.S.A. [Online]. Available: http://dtsn.darpa.mil/ixodarpatech/ixo_FeatureDetail.asp?id=129 [Accessed October 23, 2007].
- [5] Thomas Jefferson National Accelerator Facility – Office of Science Education. "Hydrogen." *Thomas Jefferson National Accelerator Facility – Office of Science Education* [Online]. Available: <http://education.jlab.org/itselemental/ele001.html> [Accessed September 29, 2007].
- [6] G.W. Crabtree, M.S. Dresselhaus and M. V. Buchanan, "The Hydrogen Economy." *Physics Today*, vol 57, no.12, December 2004. [Online]. Available: <http://www.physicstoday.org/vol-57/iss-12/p39.html> [Accessed November 5, 2007].
- [7] FuelCellWorks. "How Fuel Cells Work." *fuelcellworks.com*. [Online]. Available: <http://fuelcellworks.com/Justthebasics.html> [Accessed September 29, 2007].
- [8] Smithsonian National Museum of American History. "Proton Exchange Membrane (PEM) Fuel Cell History," *Smithsonian National Museum of American History*. [Online]. Available: <http://americanhistory.si.edu/fuelcells/pem/pemmain.htm> [Accessed September 30, 2007].
- [9] Office of the Under Secretary of Defense (Comptroller). (February 5, 2007). *Fiscal 2008 Department of Defense Budget Released*. [Online]. Available: http://www.defenselink.mil/comptroller/defbudget/fy2008/2008_Budget_Rollout_Release.pdf [Accessed September 29, 2007].
- [10] N. Shachtman, "Military Faces Bandwidth Crunch," *Wired News*, January 31, 2003. [Online]. Available: <http://www.wired.com/techbiz/it/news/2003/01/57420>. [Accessed September 30, 2007].

- [11] Department of Defense. *Commercial Satellite Communications (COMMSATCOM) Service Spend Analysis and Strategy Report*. June 7, 2006.
- [12] Department of Defense. *Global Information Grid (GIG) – Overarching Policy*. DoD Directive 8100.1. September 19, 2002. [Online]. Available: <http://www.dtic.mil/whs/directives/corres/pdf/810001p.pdf> [Accessed October 23, 2007].
- [13] National Security Agency / Central Security Service. *GIG Information Assurance*. [Online]. Available: <http://www.nsa.gov/ia/industry/gig.cfm> [Accessed September 29, 2007].
- [14] L. Kozaryn, “Military Works to meet Transformation Goals,” *DefenseLINK*, April 10, 2002. [Online]. Available: <http://www.defenselink.mil/news/newsarticle.aspx?id=44179> [Accessed October 23, 2007].
- [15] D. S. Alberts and R. E. Hayes, “Power to the Edge: Command and Control in the Information Age,” *U.S. DoD Command and Control Research Program*, 2003. [Online]. Available: http://www.dodccrp.org/files/Alberts_Power.pdf [Accessed September 19, 2007].
- [16] Air Force Link. “MQ-1 Predator Unmanned Aerial Vehicle Factsheet,” *Air Force Link*. [Online]. Available: <http://www.af.mil/factsheets/factsheet.asp?id=122> [Accessed September 29, 2007].
- [17] Air Force Link. “RQ-4 Global Hawk Unmanned Aerial Vehicle Factsheet,” *Air Force Link*. [Online]. Available: <http://www.af.mil/factsheets/factsheet.asp?id=175> [Accessed September 29, 2007].
- [18] Air Force Link. “MQ-9 Reaper Unmanned Aerial Vehicle Factsheet,” *Air Force Link*. [Online]. Available: <http://www.af.mil/factsheets/factsheet.asp?fsID=6405> [Accessed September 29, 2007].
- [19] Aerosonde. “Aerosonde Aircraft Overview,” *Aerosonde*. [Online]. Available: <http://www.aerosonde.com/aircraft/> [Accessed September 29, 2007].
- [20] Israeli Aircraft Industries Ltd. “Heron I,” *Israeli Aircraft Industries Ltd.* [Online]. Available: <http://www.iai.co.il/Default.aspx?docID=16382&FolderID=18900&lang=en>. [Accessed September 29, 2007].

- [21] D.S. Goldin, "Statement to Subcommittee on Science, Technology, and Space Committee on Commerce, Science, and Transportation United States Senate," *National Aeronautics and Space Administration*, September 23, 1998. [Online]. Available: <http://www.hq.nasa.gov/office/legaff/9-23gold.html> [Accessed November 4, 2007].
- [22] Satellite News Digest. "Satellite Outages and Failures," *Satellite News Digest*. [Online]. Available: <http://www.sat-index.com/failures/> [Accessed August 29, 2007].
- [23] GeoEye. "GeoEye Imagery Products: IKONOS." GeoEye. [Online]. Available: <http://www.geoeye.com/products/imagery/ikonos/default.htm> [Accessed November 4, 2007].
- [24] Digger History. "Inflatable Aircraft of the Great World War," *Digger History*. [Online]. Available: <http://www.diggerhistory.info/pages-air-support/inflatable.htm> [Accessed November 5, 2007].
- [25] Armada International. "Lighter Than Air," *Armada International*, June 1, 2007. [Online]. Available: [http://www.thefreelibrary.com/Lighter+than+air.\(Complete+Guide\)-a0166350176](http://www.thefreelibrary.com/Lighter+than+air.(Complete+Guide)-a0166350176) [Accessed September 27, 2007].
- [26] Aerostar International. "Near Space Applications," *Aerostar International*. [Online]. Available: http://www.aerostar.com/aerospace/near_space.htm [Accessed September 29, 2007].
- [27] NetComposites. "Airship Reaches Near-Space Altitude," *NetComposites* [Online]. Available: www.netcomposites.com/news.asp?3490 [Accessed November 29, 2007].
- [28] Lockheed Martin. "High Altitude Airship," *Lockheed Martin*. [Online]. Available: <http://www.lockheedmartin.com/products/HighAltitudeAirship/index.html> [Accessed September 25, 2007].
- [29] Defense Advanced Research Projects Agency (DARPA) Microsystems Technology Office (MTO). "Integrated Sensor IS Structure (ISIS)," *Defence Advanced Research Projects Agency*. [Online]. Available: <http://www.arpa.mil/mto/programs/isis/index.html> [Accessed September 25, 2007].
- [30] Defense Industry Daily. "DARPA's ISIS Project Seeks Slow, Soaring Surveillance Superiority," *Defence Industry Daily*. [Online]. Available: <http://www.defenseindustrydaily.com/darpas-isis-project-seeks-slow-soaring-surveillance-superiority-updated-02189/>. [Accessed November 29, 2007].

- [31] Under Secretary of Defense (Acquisition and Technology). *Advanced Concept Technology Demonstrations (ACTDs) Masterplan*, 1996. [Online]. Available: http://www.fas.org/spp/military/docops/defense/actd_mp/ [Accessed September 25, 2007].
- [32] Deputy Under Secretary of Defense (Advanced Systems and Concepts). *Joint Capability Technology Demonstrations. AC/JCTD Guidelines: Formulation, Selection and Initiation*. [Online]. Available: <http://www.acq.osd.mil/jctd/formulat.htm> [Accessed September 25, 2007].
- [33] Deputy Under Secretary of Defense (Advanced Systems and Concepts). *Joint Capability Technology Demonstration (JCTD) Program Overview*. Briefing Materials.
- [34] Aerovironment Inc. “UAS Advanced Development Center: Global Observer (2004 to present),” *Aerovironment Inc.* [Online]. Available: http://www.avinc.com/ADC_Project_Details.asp?Prodid=35 [Accessed November 29, 2007].
- [35] Time Magazine. “To Kill A Satellite,” *Time Magazine*, September 2, 1985. [Online]. Available: <http://www.time.com/time/magazine/article/0,9171,959735,00.html> [Accessed November 5, 2007].
- [36] “Aircraft Fuels.” *Energy, Technology and the Environment* Ed. Attilio Bisio. Vol. 1. New York: John Wiley and Sons, Inc., 1995. 257-259.
- [37] L. Page, “US Special Ops Buys Hydrogen Droid Strato-comms Tech,” *The Register*, October 2, 2007. [Online]. Available: http://www.theregister.co.uk/2007/10/02/special_ops_hydrogen_3g_hdtv_strato_droid/ [Accessed October 3, 2007].
- [38] Aerovironment Inc. “AeroVironment Awarded Contract for Development of Global Observer Stratospheric Unmanned Aircraft System,” *Aerovironment Inc. Press Release*, September 26, 2007. [Online]. Available: http://www.avinc.com/pr_detail.asp?ID=63 [Accessed September 29, 2007].
- [39] Defense Acquisition University. “Business Case Analysis,” *Defense Acquisition University*, 2007. [Online]. Available: <https://acc.dau.mil/CommunityBrowser.aspx?id=32524> [Accessed September 25, 2007].
- [40] Department of State. Office of Counterterrorism. *Pan Sahel Initiative*, November 7, 2002. [Online]. Available: <http://www.state.gov/s/ct/rls/other/14987.htm> [Accessed September 30, 2007].

- [41] Department of State. Office of the Coordinator for Counterterrorism. *Country Reports on Terrorism*, April 28, 2006. [Online]. Available: <http://www.state.gov/s/ct/rls/crt/2005/64335.htm> [Accessed September 30, 2007].
- [42] H. Mili and J. Townsend, "Afghanistan's Drug Trade and How it Funds Taliban Operations," *Terrorism Monitor*, vol. 5, issue 9, May 10, 2007. [Online]. Available: http://www.jamestown.org/terrorism/news/article.php?issue_id=4103 [Accessed November 5, 2007].
- [43] CBS News. "Text of Bush Speech – President Declares End to Major Combat in Iraq," *CBS News*, May 1, 2003. [Online]. Available: <http://www.cbsnews.com/stories/2003/05/01/iraq/main551946.shtml> [Accessed October 2, 2007].
- [44] UN News Center. "Decrying violence in Iraq, UN envoy urges national dialogue, international support," *UN News Center*, November 25, 2006. [Online]. Available: <http://www.un.org/apps/news/story.asp?NewsID=20726&Cr=Iraq&Cr1=> [Accessed October 2, 2007].
- [45] G.W. Bush, "President Bush Delivers State of the Union Address," *The White House*, January 23, 2007. [Online]. Available: <http://www.whitehouse.gov/news/releases/2007/01/20070123-2.html> [Accessed October 2, 2007].
- [46] D.S. Cloud and D. Cave, "Commanders Say Push in Baghdad Is Short of Goal," *New York Times*, June 3, 2007. [Online]. Available: <http://www.nytimes.com/2007/06/04/world/middleeast/04surge.html> [Accessed October 2, 2007].
- [47] A.T. Ball and B.T. McCutchen Jr., "Task Force ODIN Using Innovative Technology To Support Ground Forces," *Blackanthem.com Military News*, September 20, 2007. [Online]. Available: http://www.blackanthem.com/News/Military_News_1/Task_Force_ODIN_Using_innovative_technology_to_support_ground_forces10239.shtml. [Accessed October 4, 2007].
- [48] The Columbia Electronic Encyclopedia. "http://www.infoplease.com/ce6/.html." © 1994, 2000-2006, on Infoplease. © 2000–2007 Pearson Education, publishing as Infoplease. 06 Nov. 2007 <<http://www.infoplease.com/ce6/world/A0857443.html>>.
- [49] E. Watkins, "Facing the Terrorist Threat in the Malacca Strait," *Terrorism Monitor*, vol. 2, issue 9, May 6, 2004. [Online]. Available: <http://www.jamestown.org/terrorism/news/article.php?articleid=236671> [Accessed November 5, 2007].

- [50] BBC News. “‘Deal reached’ at N Korea talks,” *BBC News*, February 13, 2007. [Online]. Available: <http://news.bbc.co.uk/2/hi/asia-pacific/6355681.stm> [Accessed October 2, 2007].
- [51] BBC News. “N Korea Closes More Nuclear Sites,” *BBC News*, July 18, 2007. [Online]. Available: <http://news.bbc.co.uk/2/hi/asia-pacific/6903894.stm> [Accessed October 2, 2007].
- [52] BBC News. “Rumsfeld Questions China Spending,” *BBC News*, October 18, 2005. [Online]. Available: <http://news.bbc.co.uk/2/hi/asia-pacific/4351422.stm> [Accessed October 2, 2007].
- [53] Space Daily. “Global Hawk Operating Base Selected,” *Space Daily*, July 27, 2001. [Online]. Available: <http://www.spacedaily.com/news/uav-01i.html> [Accessed October 2, 2007].
- [54] Strategy World. “Global Hawk Base in the Pacific,” *Strategy World*, May 8, 2007. [Online]. Available: <http://www.strategypage.com/htmw/htairfo/articles/20070508.aspx> [Accessed October 2, 2007].
- [55] Global Security. “Al Dhafra Air Base, UAE,” *Global Security*. [Online]. Available: <http://www.globalsecurity.org/military/facility/dhafra.htm> [Accessed October 4, 2007].
- [56] Google Earth Software, version 4.2.0198.2451 (Beta).
- [57] Central Intelligence Agency. *Political Map of the World*. The World Factbook, April 2006. [Online]. Available: https://www.cia.gov/library/publications/the-world-factbook/reference_maps/political_world.html [Accessed August 30, 2007].
- [58] J. Gates, “Introduction to Cost Analysis,” *Defense Acquisition University*. *DAU Teaching Note*, April 2006. [Online]. Available: <https://acc.dau.mil/CommunityBrowser.aspx?id=30372&lang=en-US> [Accessed October 12, 2007].
- [59] Flight International. “Aerovironment details new Global Observer variants,” *Flight International*, February 14, 2006. [Online]. Available: <http://www.flightglobal.com/articles/2006/02/14/204655/aerovironment-details-new-global-observer-variants.html> [Accessed October 12, 2007].
- [60] Defense Industry Daily. “\$143M for Global Hawk Cost Overruns,” *Defense Industry Daily*, April 25, 2005. [Online]. Available: <http://www.defenseindustrydaily.com/143m-for-global-hawk-cost-overruns-0408/> [Accessed October 12, 2007].

- [61] Defense Systems Daily. "\$500 million UAV EO sensor market by end of decade," *Defense Systems Daily*, June 18, 2003. [Online]. Available: <http://defence-data.com/paris2003/pagep147.htm> [Accessed November 5, 2007].
- [62] Defense Energy Support Center. *FY2008 DoD Standard Price of Fuel, effective September 2007*, September 2007. [Online]. Available: http://www.desc.dla.mil/DCM/Files/FY2008StandardPrices_092007.pdf [Accessed October 14, 2007].
- [63] Sinclair Oil Corporation. *Material Safety Data Sheet. Sinclair Jet Fuels. MSDS # F3*, December 2005. [Online]. Available: <http://www.sinclairoil.com/msds/Jet%20Fuels.pdf> [Accessed October 14, 2007].
- [64] Office of the Under Secretary of Defense for Acquisition, Technology and Logistics. *More Capable Warfighting Through Reduced Fuel Burden*, January 2001. [Online]. Available: <http://www.acq.osd.mil/dsb/reports/fuel.pdf> [Accessed October 14, 2007].
- [65] Defense Energy Support Center. *FY2008 DoD Standard Price of Missile Fuel, effective October 2007*, October 2007. [Online]. Available: http://www.desc.dla.mil/DCM/Files/MFSPFY08_071107.pdf [Accessed October 14, 2007].
- [66] Department of Energy. *DOE Announces New Hydrogen Cost Goal*, July 14, 2005. [Online]. Available: http://www1.eere.energy.gov/hydrogenandfuelcells/news_cost_goal.html [Accessed October 14, 2007].
- [67] Cost Analysis Improvement Group (CAIG). Air Force Total Ownership Cost (AFTOC) Global Hawk FY06Q4 Data.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
Ft. Belvoir, Virginia
2. Dudley Knox Library
Naval Postgraduate School
Monterey, California
3. Deputy Under Secretary of Defense for Advanced Systems and Concepts
Ms. Teresa Gayle
Washington, D.C.
4. Assistant Deputy Under Secretary of Defense for Advanced Systems and
Concepts
Deputy Director, ACTD/JCTD Program
Mr. Alexander Lovett
Washington, D.C.