NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

INTEGRATION OF MINI-UAVS AT THE TACTICAL OPERATIONS LEVEL: IMPLICATIONS OF OPERATIONS, IMPLEMENTATION, AND INFORMATION SHARING

by

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June 2005

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
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** June 2005	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Integration of Mini-UAVs at the Tactical Operations Level: Implications of Operations, Implementation, and Information Sharing			**5. FUNDING NUMBERS**
6. AUTHOR(S) Collier C. Crouch			
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)

Small units maneuvering on the battlefield have little time to establish data links and interface with the Global Information Grid (GIG) while trying to achieve an objective. The bandwidth and interface requirements necessary to receive live data from current strategic level systems limit the small unit operational user's ability to receive and act upon data and intelligence. Without the ability to interface with current strategic-level UAV assets, these small units are left without a comprehensive operational picture. Mini-UAVs offer the capability for the tactical user, in a variety of missions, to have direct control over the aerial asset without intervention from higher authority. Organic UAV assets can be used to collect data relevant to small units without the need for connecting to intelligence systems. This offers increased mobility and a dedicated collection platform; however, there are still drawbacks to this capability. This thesis examines mini-UAVs, and their integration into the Coalition Operating Area Surveillance and Targeting System (COASTS) network.

14. SUBJECT TERMS COASTS, Unmanned Aerial Vehicles, Mini-UAVs, Command and Control, Computers, Communications, Intelligence. Surveillance, Reconnaissance, C4ISR, COTS, Commercial-off-the-shelf technology, Local Persistence.			**15. NUMBER OF PAGES** 199
			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** UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY

from the

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Small units maneuvering on the battlefield have little time to establish data links and interface with the Global Information Grid (GIG) while trying to achieve an objective. The bandwidth and interface requirements necessary to receive live data from current strategic level systems limit the small unit operational user's ability to receive and act upon data and intelligence. Without the ability to interface with current strategic-level UAV assets, these small units are left without a comprehensive operational picture. Mini-UAVs offer the capability for the tactical user, in a variety of missions, to have direct control over the aerial asset without intervention from higher authority. Organic UAV assets can be used to collect data relevant to small units without the need for connecting to intelligence systems. This offers increased mobility and a dedicated collection platform; however, there are still drawbacks to this capability. This thesis examines mini-UAVs, and their integration into the Coalition Operating Area Surveillance and Targeting System (COASTS) network.

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LIST OF KEY WORDS, SYMBOLS, ACRONYMS AND ABBREVIATIONS

2D	Two Dimensional
ATO	Air Tasking Order
BDA	Battle Damage Assessment
C4I	Command and Control, Computers, Communications and Intelligence
CN	Counter Narcotics
CNO	Chief of Naval Operations
COASTS	Coalition Operating Area Surveillance and Targeting System
COTS	Commercial-off-the-shelf
CSAR	Combat Search and Rescue
DARPA	Defense Advanced Research Projects Agency
DCGS	Distributed Common Ground System
DOD	Department of Defense
DRDO	Thai Department of Research & Development Office
DTAC	Digital Training Access Center
EO	Electro-optical
FLIR	Forward Looking Infrared
FP	Force Protection
GCS	Ground-control Station
GHz	Gigahertz
GIG	Global Information Grid
GPS	Global Positioning System

IOC	Initial Operational Capability
IR	Infrared
ISR	Intelligence, Surveillance, and Reconnaissance
ISRT	Intelligence, Surveillance, Reconnaissance, and Target Acquisition
JPO-UAV	Joint Project Office for Unmanned Aerial Vehicles
JUSMAGTHAI	Joint U.S. Military Advisor's Group Thailand
LCE	Launch and Recovery Element
Li	Lithium
LOS	Line-of-sight
MCE	Mission Control Element
MCM	Mine Counter Measures
MCP	Mobile Command Post
METOC	Meteorology and Oceanography
MHz	Megahertz
Mini-UAVs	Miniature Unmanned Aerial Vehicles
MOE	Measures of Effectiveness
MOP	Measures of Performance
MSE	Mobile Subscriber Equipment
NiCd	Nickel Cadmium
NIMA	National Imagery and Mapping Agency
NPS	Naval Postgraduate School
OFDM	Orthogonal Frequency Division Multiplexing
OSD	Office of the Secretary of Defense

OTH	Over-the-Horizon
RATO	Rocket Assisted Take-off
RF	Radio Frequency
RTSC	Thailand Royal Thai Supreme Command
RTARF	Royal Thai Armed Forces
SA	Situational Awareness
SATCOM	Satellite Communications
SEAD	Suppression of Enemy Air Defenses
SIGINT	Signals Intelligence
TALD	Tactical Air Launched Decoys
TAMD	Theater Air and Missile Defense
TCS	Tactical Control System
TEMP	Test and Evaluation Master Plan
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle
USB	Universal Serial Bus
VLC	VideoLAN Client
WLAN	Wireless Local Area Network
WMD	Weapons of Mass Destruction
WOT	War on Terror

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ACKNOWLEDGMENTS

I would like to thank the following people: James Ehlert, Bill Kemple, Ed Fisher, Mike Clement, Ron Russell, Dwayne Lancaster, Chris Lee, and Rob Hochstedler. I would like to especially thank Alexis Wise and Kevin Barrett for their constant support and guidance.

I would also like to thank my parents for their enduring support.

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I. INTRODUCTION

A. INTRODUCTION

Since descending from the trees of the jungle to roam the plains, humankind has had to endure limited resources. In an effort to secure these resources for their survival, humans formed societies and initiated civilization and ownership. Yet as humans became more nomadic, they encountered other wandering tribes who were also eager to secure the limited resources for their own survival. As competition for these scarce resources increased, the dawn of warfare emerged.

Society developed tactics and techniques to outsmart the enemy and gain control of the resources necessary for survival. Technology has forced tactics to change; however, the need for information has increased. Information is pivotal to the success of any military campaign. With knowledge of the enemy, a commander can decide whether to attack or retreat. Information can enable a small force to overcome the advantages that a large adversary may possess. Liddell Hart's "indirect approach" relies on the attacking commander's ability to obtain superior knowledge of the enemy's forces in order to exploit the advantage.

Classical information gathering has both strategic and tactical implications. Strategy is the overarching concept that a commander employs in order to force a decision (with or without battle). If battle must be made, it is through tactical decisions that a battle may be won. The object of obtaining information (whether it be enemy unit locations, enemy force strength, enemy capabilities, or enemy intentions) has been to enable strategic decisions to be made for tactical implementation. Throughout military history this has long been a corollary of successful warfare. Today the wealth of information and the capabilities of existing systems are melding the lines between tactical and strategic decision-making. The speed of disseminating information is producing a battleground where tactical decisions can have immediate strategic implications. World opinion now plays a major role in military operations. “The CNN effect” can instantly inform both the world and the enemy of current operations and intentions, as well as influence the views of people all over the world. The result is that media outlets, enemy Command and Control, Computers, Communications and Intelligence (C4I) systems, and even individuals can affect public opinion in real-time, thus turning a tactical victory into a strategic loss.

One mechanism to address this phenomenon is to provide more information to the tactical commanders, enabling them to consider the consequences of their actions more effectively. Unmanned Aerial Vehicles (UAVs) uniquely broaden the operational picture of tactical commanders.

B. OVERVIEW

Unmanned Aerial Vehicles are defined in Department of Defense (DOD) Joint Publication 1-02 as:

> A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload. Ballistic or semi ballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles.

It is important to consider the differences between UAV systems and other unmanned weapons. "The key discriminates are (1) UAVs are equipped and employed for recovery at the end of their flight, and cruise missiles are not, and (2) munitions carried by UAVs are not tailored and integrated into their airframe whereas the cruise missile's warhead is" (Unmanned Aerial Vehicle Roadmap 2).

Unmanned Aerial Vehicles (UAVs) are increasing the wealth of information available to commanders at the strategic, operational, and tactical level, yet they cannot provide perfect information. Current UAV systems are deployed at the strategic and operational levels and provide very little real-time intelligence and feedback for tactical users. Moreover, the current systems are bulky and require a great deal of support structure. These systems are plagued by problems with reliability and integration. Larger units (battalion strength and larger) have little problem integrating UAV units into operations, but the control of these units is usually dedicated to fulfilling battalion level and higher tasking. Tactical users at the squad and platoon level, as well as special operations units, have little ability to obtain information from these strategic-level assets. The information from these strategic-level units is usually routed to a processing center and then sent to tactical units with a large delay. Tactical users are denied real-time and near-real-time data that are immediately applicable to operations as they engage the enemy.

Mini-UAVs can improve this situation by equipping the tactical commander with a man-portable system to obtain real-time intelligence that can be immediately exploited. These systems serve as locally controlled assets, providing crucial information to small unit commanders and further inhibiting interference at the tactical level.

These mini-UAVs generally have wingspans between six inches and ten feet and can fly between 20 to 50 miles per hour (Coffey 1), yet these mini-UAVs, of relatively simple design, yield a great deal of versatility and portability. Additionally, various control stations have been devised to interface with these vehicles. Therefore, once the data from the tactical units are integrated, the widespread distribution of mini-UAVs can furnish strategic-level commanders with more accurate details of individual unit operations.

The Chief of Naval Operations has recently underscored a need for a move from “reconnaissance to persistence,” implying that the Navy must have perfect information for all situations (CNO Guidance for 2005 18). Of course, the development of persistent information collection systems will take time and resources. The limits of the current systems and the inability of tactical users to interface with these systems constrain the flow of information to the tactical level.

In its After Action Report from Operation IRAQI FREEDOM the Third Infantry Division (Mechanized) stated that, "As a result of the division's fast-paced operations during the first several days of the war, the mobile subscriber equipment (MSE) network was not often established for the DTAC [Digital

Training Access Center] and the maneuver brigades." This and other networks are important in establishing communications with other units on the battlefield. The fast paced movement of troops inhibits and limits the ability of units to connect into intelligence dissemination systems.

Mini-UAVs can solve this problem by allowing tactical units to determine and fulfill their need for Intelligence, Surveillance, Reconnaissance, and Target Acquisition (ISRT) data without connecting to intelligence dissemination systems. However, the development of mini-UAVs through the traditional acquisition process will be costly and time consuming. This capability will require a great number of iterations and a vast number of new systems to be produced, resulting in a great delay, while the need for information will still grow. Commercial-off-the-shelf (COTS) technology can currently furnish a number of capabilities economically and rapidly.

One milestone on the path to persistence should be the development of a concept of “local persistence.” This capability will offer tactical users information directly applicable through organic ISRT units. Organic ISRT units reduce the need for information to flow to the tactical units by allowing them to collect their own information. Higher-level commanders can later access the information collected by these units.

By collecting ISRT data through organic units, tactical users can immediately assess potential actions that may neutralize the targets under their purview. An organic UAV capability can be fielded quite quickly due to the vast array of mini-UAV systems now available from the commercial world. COTS technology currently offers an affordable, mass-produced method for providing local persistence to the military.

C. THE EMERGENCE OF UAV TECHNOLOGY

Prior to FY1987, UAVs in the US inventory were built as experimental units, not intended for mass production and operational employment. FY1987 marked the first year that acquisition programs for UAVs were started, and

Operation DESERT STORM marked the first major operational use of UAVs by the U.S.

UAVs in Operation DESERT STORM were used for intelligence, surveillance, and reconnaissance missions. They were also utilized as Tactical Air Launched Decoys (TALD) as well as for Battle Damage Assessment (BDA) and targeting. The RQ-21 Pioneer was so successful at targeting and providing BDA in Operations DESERT SHIELD and DESERT STORM that Iraqi troops even surrendered to it as it flew overhead.

> The most famous incident occurred when *USS Missouri* (BB 63), using her *Pioneer* to spot 16 inch gunfire, devastated the defenses of Faylaka Island off the coast near Kuwait City. Shortly thereafter, while still over the horizon and invisible to the defenders, the *USS Wisconsin* (BB 64) sent her *Pioneer* over the island at low altitude. When the UAV came over the island, the defenders heard the obnoxious sound of the two-cycle engine since the air vehicle was intentionally flown low to let the Iraqis know that they were being targeted. Recognizing that with the "vulture" overhead, there would soon be more of those 2,000-pound naval gunfire rounds landing on their positions with the same accuracy, the Iraqis made the right choice and, using handkerchiefs, undershirts, and bedsheets, they signaled their desire to surrender. ("RQ-2A *Pioneer* Unmanned Aerial Vehicle (UAV)")

Today, UAVs are quickly assuming the role previously performed by manned intelligence gathering aircraft. UAVs are particularly good at replacing manned aircraft in areas that are considered too “dull, dirty, or dangerous." The products of UAV sensor data are becoming vital to the continued success of the United States Military. "The current architecture stresses the available bandwidth and results in less than desired distribution of data" (Defense Science Board, ix). The bandwidth required to distribute this data to tactical users is not available. Mechanisms to deliver large amounts of data to tactical users must be developed to increase the effectiveness of these units and allow them to interoperate with future systems.

In the National Defense Authorization Act for FY2001 Congress stated, “Within ten years, one-third of U.S. military operational deep strike aircraft will be unmanned" (Senate Committee on Armed Services 141). UAVs are already becoming the platform of choice for intelligence gathering operations. Projected increases in technology will spur development of more capable systems to replace manned aircraft. Clearly, the future of UAVs will extend into the realm of unmanned armed combat.

D. THE COASTS PROGRAM

The Coalition Operating Area Surveillance & Targeting System (COASTS) program is a joint project between the Naval Postgraduate School (NPS), U.S. Pacific Command (USPACOM), Joint U.S. Military Advisor's Group Thailand (JUSMAGTHAI), Royal Thai Armed Forces (RTARF), Thailand Royal Thai Supreme Command (RTSC), and the Thai Department of Research & Development Office (DRDO). The program researches emerging COTS technologies and their integration in order to find cost-effective solutions for theater security, host nation security, and the War on Terror (WOT).

The COASTS experiment seeks to integrate aerial nodes (UAVs, aerostats, balloons, and relay units), ground sensors, tactical users, tactical command and control centers, and strategic command and control centers. A common operational picture (COP) is distributed to all users through the network. The underlying network topology is created through wireless local area network (WLAN) technology.

The COASTS program is researching "low-cost, state-of-the-art, real-time threat warning and tactical communications equipment that is rapidly scaleable based on operational considerations" (Appendix A). The technologies being explored are

- 802.11b/g
    - Rajant Breadcrumbs™
    - 802.11b/g enabled computers
- 802.16 Orthogonal Frequency Division Multiplexing (OFDM)

    - Redline Communications AN-50e
- Satellite Communications (SATCOM)
- Wearable Computing Devices
    - Inter-4 Tacticomp PDAs
- Unattended Air and Ground Sensors
    - Crossbow Sensor Grid
- Mobile Command and Control Platforms
- Persistent Surveillance
- Shared Situational Awareness
    - TrakPointC2™
- Hastily Formed Networks
- Ultra Wideband Technologies
- GPS Tracking Technologies
    - TrakPointC2™
- GPS Denied Tracking Devises
    - TrakPointC2™
- Unmanned Aerial Vehicles (Micro, Mini, and others).
    - Cyber Defense Systems Inc. CyberBUG™

This thesis focuses on the operational considerations of mini-UAVs at the tactical level as demonstrated by the integration of mini-UAVs into the COASTS network.

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II. UAV OVERVIEW

A. INTRODUCTION

UAVs are organized into categories based upon their size and endurance. Traditionally, UAVs have been complex systems requiring a large footprint and a wide array of support staff to operate. All of the equipment, shelters, communications gear, personnel, and personnel support structures encompass the footprint that must be transported to the area of operations. The logistical requirements to transport and erect all of this gear grow exponentially as the size of the footprint grows. The size of these support structures has limited the ability for small units of maneuver (companies, platoons, squads) to obtain an organic UAV capability and remain mobile.

Small units rarely gain access to data from UAVs to support their operations. Access to data from strategic-level UAV systems requires heavily planned operations with a vast array of support structures to integrate battalion and larger systems into small-unit operations. To combat this problem, smaller systems with decreased size and endurance are currently being considered to support smaller forces.

B. UAV COMPONENTS

A UAV system is generally composed of a vehicle, a ground-control station, a tracking control station, and a data dissemination system. Some UAV systems can downlink data to remote terminals in order to exploit the data from the UAV immediately. Control systems have been designed to operate each specific type of UAV and are not generally interchangeable. The diversity of missions and equipment in different types of UAVs has led to the development of specific control systems to support individual systems.

Tactical users require mobile platforms capable of rapid deployment and possible control while moving. Strategic users require robust data links and large control stations to support the wide varieties of payloads usually found on these systems. Stovepipe development has limited the interoperability of UAV ground-control stations; however, the Tactical Control System (TCS) currently under development by the Joint Project Office for UAVs (JPO-UAV) will allow multiple types of UAVs to be controlled through a single control station ("UAV Tactical Control System").

The vehicle includes a number of subsystems, such as a propulsion source, a payload, avionics equipment, a power supply, and data link equipment. Larger UAVs use fuel-powered engines in order to attain flight. Smaller UAVs typically use either gasoline-powered engines or electrically powered engines. The payload is composed of Electro-optical (EO) cameras, Infrared (IR) cameras, signals collection packages, or a vast array of other packages that can be interchanged to support specific missions. The avionics equipment controls the direction of flight, the altitude and attitude of the aircraft, and its speed. The power supply powers the avionics system as well as the data link and the payload. The power may be supplied by a battery, or produced by an engine.

The data link is arguably the most important part of the system. The data link allows control from the control station as well as down linking of the collected data. Most data processing and storage must be performed on the ground to conserve space and weight on the UAV. Smaller systems have limited space for onboard processing. Additionally, smaller UAVs are used for providing real-time and near-real-time data that does not require storage and processing onboard the aircraft.

UAVs usually contain two data links, a control data link and a data link to transmit the payload data. The control data link and the payload data link are not always separate links. The control data link handles the vehicle telemetry data and the control signals from the ground control station in order to provide vehicle control. The payload data link generates video, IR, or other data from the UAV to the user for processing and dissemination. In some current systems, such as the

RQ-2 Pioneer, mobile users can interface with the payload of the UAV to receive data from overhead.

C. PLANNING INVOLVED IN UAV OPERATIONS

UAVs are considered to be either organic assets or non-organic assets. Organic assets are those that are under the direction of the commander of a specific unit, whether it be squad, brigade, battalion, or corps. The UAV is considered to be a part of that unit, and the commander has control over its tasking. Non-organic assets are assets that a commander does not control. Consider the case in which a battalion owns a UAV. The UAV is organic to the battalion, but it would be non-organic to a squad in that battalion. The squad leader would have no way to task the battalion level unit without using a non-organic procedure. The squad would be able to obtain data from this UAV, but it would not control the UAV directly, and it would not receive the data immediately.

UAVs can perform pre-planned missions, immediate missions, or can be dynamically retasked to support urgent data collection requirements. All UAV assets are susceptible to being diverted by a higher authority (Marine Corps Warfighting Publication 3-42.1: Unmanned Aerial Vehicle Operations 4-3).In a Marine Corps UAV squadron the commander controls organic UAV tasking. Organic mission planning procedures are similar to non-organic procedures, except they provide more control over the collection of data.

UAV planning and tasking requires a great deal of coordination in order to ensure safe vehicle operation and collection of relevant mission data. Planned missions involving organic assets are initiated through a Joint Tactical Air Strike (JTAR) request. The UAV is then assigned tasking and authorization through the Air Tasking Order (ATO) (4-4). This process is not immediate. The development of an ATO requires 72 hours for route planning, collection planning, and airspace coordination with other assets. Immediate organic missions “are supported via the fastest means” possible to meet the collection requirements (4-3). Immediate requests are met according to the availability of assets, the ATO, and other priorities. Dynamic retasking of organic assets, changing the route, altitude, or collection targets of a platform already aloft is also achieved through the fastest means possible. These changes must be coordinated with current air assets by either the Direct Air Support Center (DASC) or the Tactical Air Control Center (TACC) (4-4).

Tasking of non-organic assets is also accomplished via the JTAR, but the Joint Force Commander (JFC) J-2 determines prioritization. The lack of assets means that some requests will not be met in a timely fashion and will lack UAV support. Planned missions for non-organic units are received through the ATO. Immediate tasking is developed by the execution cell of the combat operations center and delivered to the UAV squadron for implementation.

D. CLASSES OF UAVS

UAVs are currently classified into Micro, Mini, Tactical, Medium Altitude, and High Altitude systems. Micro-air vehicles generally operate at low altitudes, weigh less than one pound, and have limited capabilities as individual units. They are currently in the experimental phase and have not been implemented under operational conditions. The small size of micro-UAVs, less than six inches, limits their ability to transit from the immediate area of launch. These UAVs have limited space for fuel and batteries to power their systems.

Mini-UAVs typically fly between 18 and 45 knots and weigh between 1 and 40 pounds. They have wingspans between 6 inches and 10 feet with maximum ranges being limited by the horizon. Mini-UAVs must maintain line-of-sight (LOS) between the aircraft and the ground station. The small size of these units inhibits the ability to carry satellite communications gear onboard for Over-the-Horizon (OTH) communications. Mini-UAVs are easily supportable with a small footprint and require very little logistical support. These systems are designed to provide an organic UAV capability to small forces such as Special Operations, company, platoon, and squad units.

Tactical UAVs are larger systems that require a great deal of support, maintenance and manpower. On the other hand, they provide farther range and longer loiter capabilities than smaller, less capable systems. These systems are typically between 60 to 1000-pounds and operate at low to medium altitudes. They are typically launched utilizing a runway, a catapult, or a rocket assisted launch system.

Medium and High Altitude UAVs are generally larger than 1,000-pounds. The Medium Altitude UAVs operate near the altitude of commercial airliners (18,000-45,000 ft) while High Altitude UAVs operate above the commercial airliner airspace, above approximately 50,000-feet. Figure 1 provides an overview of the relationship between weight, maximum altitude, and UAV classification.

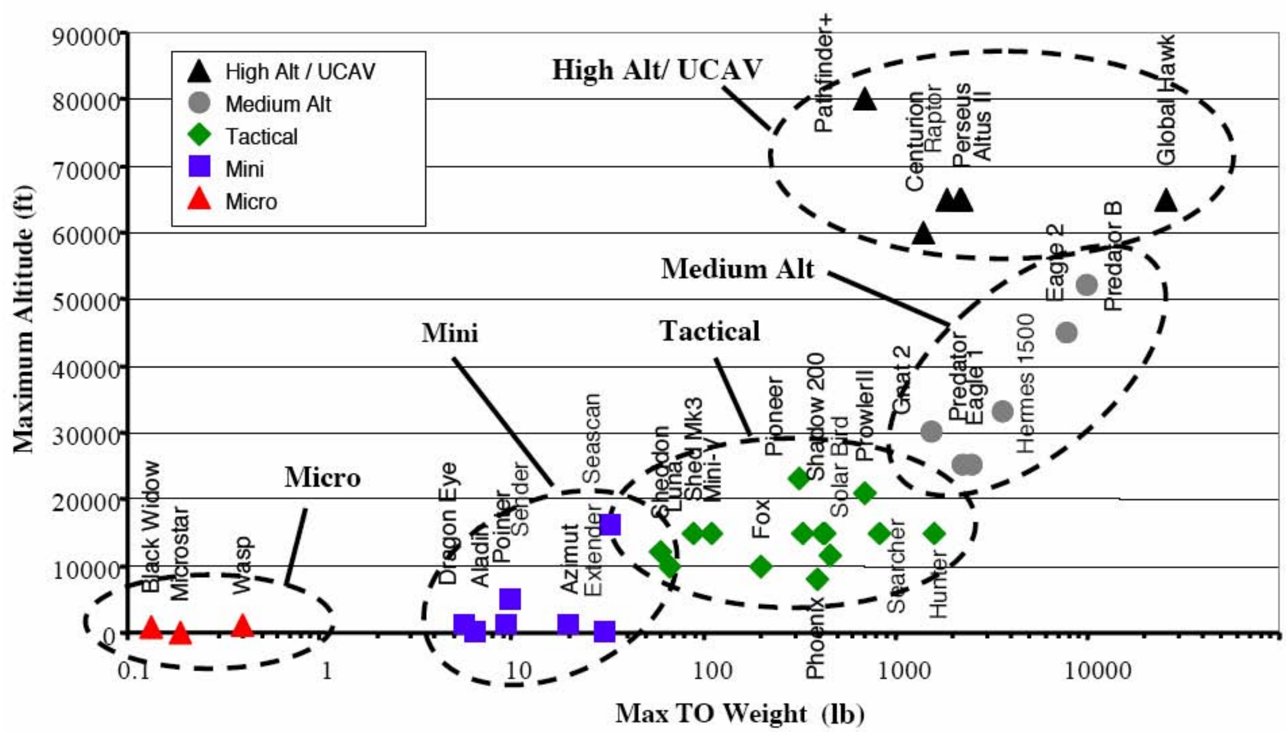

Figure 1. Altitude and Weight Classification of Current UAVs (From: Weibel)

Endurance, another factor discussed when describing different UAVs, is the amount of time that a UAV can remain aloft. Systems are classified as having low, medium, or high endurance. A low-endurance vehicle is generally considered to have a flight time less than six hours. These vehicles will usually be micro-and mini-UAVs, with some tactical UAVs included in this category. A medium endurance vehicle has a flight time between 6 and 24 hours. Tactical UAVs usually have medium endurance. A system with more than 24 hours of mission time is considered a high-endurance vehicle. Medium altitude and high altitude UAVs are commonly classified in this range.

Smaller UAVs typically have low endurance due to size and weight restrictions. These UAVs generate less lift due to smaller wingspans and less power output from motors. Trade-offs between avionics and payloads with fuel and energy cells can extend the range and endurance of these systems. Smaller cameras with fewer lines of resolution and less weight and bulk can be used in order to employ larger, heavier, more capable batteries or motors, which also extend the range of these UAVs. Larger motors provide greater speed and higher altitudes, but they require more space and power. Developments in technology will produce smaller, more capable subsystems that will further extend the range and endurance of these small systems.

Micro-UAVs are a class of UAVs currently being researched by the Defense Advanced Research Projects Agency (DARPA) in conjunction with a number of defense contractors. These UAVs have a short range; however, they are being researched for their ability to participate in swarming. Swarming would allow the individual units to act as one unit over a particular area. These small vehicles could be carried as a payload of a larger UAV and dropped in order to land and to loiter in a specific area. These small units would conduct a "perch and stare" mission in which they would place themselves in a location without the knowledge of the enemy in order to collect imagery, signals, or other types of intelligence. This intelligence could then be stored and later collected and sent back to headquarters through a second UAV. Naturally, the small size of these systems would limit the power of their transmitter and antenna gain, which in turn would limit the distance that they could transmit data.

E. MQ-1 / MQ-9 PREDATOR

Figure 2. MQ-1 Predator UAV (From: Globalsecurity.org)

	MQ-1	MQ-9
Gross Weight	2250 lb	10,000 lb
Length	28.7 ft	36.2 ft
Wingspan	48.7 ft	64 ft
Ceiling	25,000 ft	45,000 ft
Radius	400 NM	400 NM
Endurance	24 hrs	24 hrs
Payload	450 lbs	750 lb (internal) 3000 (external)
Cruise Speed	70 kts	220 kts
Aircraft Cost (w/out Sensors)	$2.4 M	$6 M
Sensors	EO/IR/SAR	EO/IR/SAR
System Cost (4 UAVs)	$26.5 M	$47 M

Table 1. MQ-1/MQ-9 Predator Data (From: UAV Reliability Study)

The MQ-1 Predator (Figure 2) is a General Atomics Aeronautical Systems, Inc. aircraft classified as a medium altitude and high-endurance UAV. It is primarily used for armed reconnaissance, airborne surveillance and target acquisition. Each Predator unit is optimally composed of four aircraft including the sensors and data links, one Ground-Control Station (GCS) and a Trojan Spirit II Satellite Communications (SATCOM) system used for data dissemination. The aircraft is controlled over a C-Band line-of-sight data link or a beyond line-of-sight KU-Band satellite. The aircraft is equipped with a nose camera for use by the operator during take-off and landing, an Electro-optic (EO) camera for daylight and well-lit night viewing, a variable aperture infrared (IR) camera, and synthetic aperture radar.

Figure 3 illustrates the synthetic aperture radar capabilities of the Predator. It also illustrates the various data links discussed above that are required for operation. Some units also include a VHF/UHF relay radio, along with a Mode 4 Identify Friend or Foe (IFF) transponder for coordination with manned-flight missions.

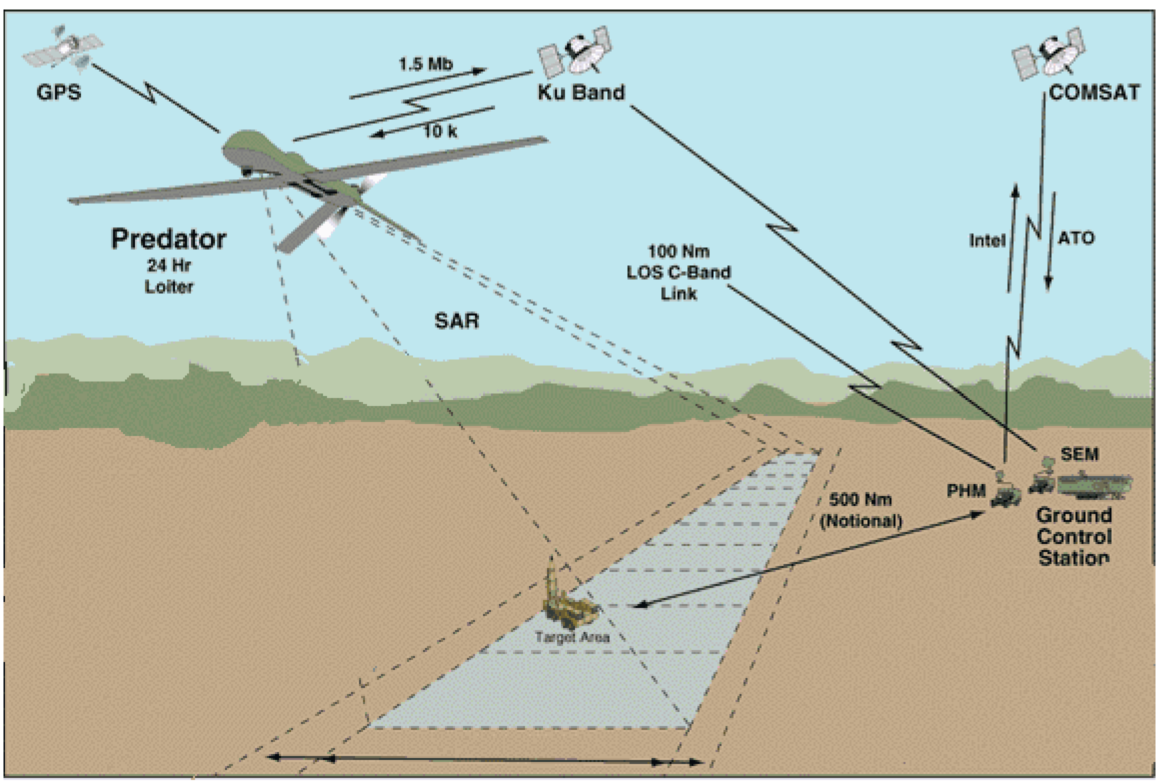

Figure 3. Links in the Predator System (After: Globalsecurity.org)

The MQ-1A and MQ-1B variants are based upon the original configuration of the predator system. However, the MQ-1B variant is capable of firing a Hellfire missile and carries laser-targeting equipment. The MQ-9 variant is a larger and more reliable system featuring increased redundancy of flight-control systems in addition to longer range, greater payload capacity, and extended loiter time. The Predator has been nearly continuously deployed since its initial advanced concept technology demonstration (ACTD). In order to support operations in Bosnia, Kosovo, Albania, Afghanistan, and Iraq, units designated specifically for testing and concept development were deployed to support operational needs (UAV Reliability Study 8).

The Predator is launched from an improved surface or a runway. According to the UAV Reliability Study the MQ-1 variant is 28.7-feet in length with a wingspan of 48.7-feet. It has a radius of 400 NM and a ceiling of 25,000 feet. The aircraft cost without sensors is $2.4 million. A total system with four aircraft and related control equipment is $26.5 million. The MQ-1 can cruise at 70-knots for over 24-hours with a 450-pounds payload. The MQ-9 variant is 36.2-feet in length with a wingspan of 64 feet. It has a radius of 400 NM with a ceiling of 45,000 feet. The aircraft cost is $6 million without sensors. A complete system of four aircraft costs $ 47 million. The MQ-9 is advertised to cruise at 220 knots for over 24-hours with a total payload of 3,750-pounds. (750-pounds internal, 3000-pounds external). The Air Force has lost 26 Predators since 2002 when Operation ENDURING FREEDOM began. The Air Force has lost a total of 46 aircraft out of a total of 114 Predators during the life of the program (Bigelow).

F. RQ-2 PIONEER

Figure 4. RQ-2 Pioneer (From: Globalsecurity.org)

	RQ-2B
Gross Weight	452 lb
Length	14 ft
Wingspan	17 ft
Ceiling	15,000 ft
Radius	100 NM
Endurance	5 hrs
Payload	75 lbs
Cruise Speed	80 kts
Aircraft Cost (w/out Sensors)	$650,000
Sensors	CCD/FLIR
System Cost (4 UAVs)	$7 M

Table 2. RQ-2B Pioneer Data (From: UAV Reliability Study)

The RQ-2 Pioneer (Figure 4) is a tactical, low-endurance UAV produced by Israeli Aircraft Industries. The United States Navy purchased it in 1985 to provide a reconnaissance and surveillance platform for amphibious forces. The other Service Components quickly obtained versions for use in the field. It was originally operated off Iowa class battleships but has since been operated by both the Army and the Marine Corps to provide tactical surveillance. The Pioneer system flew over 300 combat missions during Operations DESERT SHIELD and DESERT STORM. Six separate operational units in three different services used it for battle damage assessment, maritime interception operations, target selection, and intelligence gathering (Reid).

The Pioneer system is composed of four to five air vehicles, a GCS-2000 ground-control station, a tracking control unit, a C-band data link, a portable control station, and four remote receiving stations. The Pioneer is launched using a catapult system, traditional runways, or a rocket assisted shipboard system. The control link relies on a line-of-sight link limiting the range of the Pioneer to 100 NM. The cost of one RQ-2 is $650,000. The complete system of four aircraft and associated support equipment costs $ 7 million. It has a length of 14-feet, a wingspan of 17-feet, and it has an endurance of five hours at an altitude of 15,000-feet with a max payload capacity of 75-pounds. The cruise speed of the aircraft is 80-knots. The payload can be configured to carry EO/IR cameras as well as several different types of sensors. All data can be linked to the ground-control station through the C-band data link.

G. RQ-5 HUNTER

Figure 5. RQ-5 Hunter (From: Globalsecurity.org)

	RQ-5
Gross Weight	1,600 lb
Length	23 ft
Wingspan	29.2 ft
Ceiling	15,000 ft
Radius	144 NM
Endurance	11.6 hrs
Payload	200 lbs
Cruise Speed	100 kts
Aircraft Cost (w/out Sensors)	$1.2 M
Sensors	CCD/FLIR
System Cost (8 UAVs)	$24 M

Table 3. RQ-5 Hunter Data (From: UAV Reliability Study)

The RQ-5 Hunter (Figure 5) is a tactical, medium-endurance UAV, designed to meet the corps level requirement for reconnaissance, surveillance, and target acquisition. It has a ceiling of 15,000-ft with a range extending 144 NM over 11.6-hours carrying a 200-pound payload. The aircraft can cruise at 100 knots and has a length of 23-feet. and a wingspan of 29.2-feet. The aircraft can take-off from a runway or perform a Rocket Assisted Take-off (RATO). Landings can be performed in fields, on a runway, or utilizing an arresting cable.

("Hunter RQ-5A Tactical Unmanned Aerial Vehicle, USA/Israel"). Its basic link is a line-of-sight C-band data link. A second aircraft can act as a data and control link to extend the range of the system. The system has a large logistical footprint consisting of eight aircraft, two ground-control shelters, one mission planning shelter, one launch and recovery shelter, two ground-data terminals, eight modular mission payloads, and four air-data relays. Each system costs $ 24 million with each aircraft costing $ 1.2 million. The Hunter system, though plagued by multiple developmental problems, has proven to be a valuable asset to the United States Army in Iraq. It has flown over 3,100-hours since being deployed to Iraq in January of 2003 ("Northrop Grumman Hunter UAV Achieves 3,000 Combat Hours in Iraq").

H. RQ-7 SHADOW

Figure 6. RQ-7 Shadow (From: Globalsecurity.org)

	RQ-7
Gross Weight	327 lb
Length	11.2 ft
Wingspan	12.8 ft
Ceiling	15,000 ft
Radius	68 NM
Endurance	4 hrs
Payload	60 lbs
Cruise Speed	82 kts
Aircraft Cost (w/out Sensors)	$325,000
Sensors	EO/IR
System Cost (4 UAVs)	$6.2 M

Table 4. RQ-7 Shadow Data (From: UAV Reliability Study)

The RQ-7 Shadow (Figure 6), a tactical, low-endurance UAV, was designed to conduct brigade-level operations. Intended to provide reconnaissance, surveillance and target acquisition, it has a short radius of 68 NM with a 4-hour endurance and a 15,000-foot ceiling. The aircraft has a length of 11.2-feet and a wingspan of 12.8-feet. It is launched by rail and recovered by arresting gear. The RQ-7 is capable of carrying a 60-pound payload and is strictly operated line-of-sight, due to the C-band data link. It has been used in Iraq to support intelligence-gathering requirements (Chatwin). The system consists of four air vehicles along with the GCS, communications equipment, and the associated launch and recovery equipment. A complete system costs $ 6.2 million, with individual aircraft costing $ 325,000. The system is transportable in two High-Mobility Multi-Purpose Wheeled Vehicles (HMMWVs) along with two additional HMMWVs with trailers acting as troop carriers. The payload consists of an EO/IR camera and communications equipment.

I. RQ-4 GLOBAL HAWK

Figure 7. RQ-4 Global Hawk (From: Globalsecurity.org)

	RQ-4
Gross Weight	26,750 lb
Length	44.4 ft
Wingspan	116.2 ft
Ceiling	65,000 ft
Radius	5,400 NM
Endurance	32 hrs
Payload	1,950 lbs
Cruise Speed	345 kts
Aircraft Cost (w/out Sensors)	$20 M
Sensors	Radar/EO/IR
System Cost	$57 M

Table 5. RQ-4A Global Hawk Data (From: UAV Reliability Study)

The RQ-4 Global Hawk (Figure 7) is the largest UAV in the U.S. fleet. It is a high altitude, high-Endurance UAV manufactured by Northrop Grumman. It has a ceiling of 65,000-feet and a maximum endurance of 32-hours with a 5,400

NM range. The aircraft has a length of 44.4-feet and a wingspan of 116.2-feet. The Global Hawk can carry both radar and an electro-optical/infrared (EO/IO) payload at the same time. It can carry a total payload of 1,950-pounds. It is controlled through either line-of-sight or KU-band Satcom for beyond line-of-sight communications.

Although the Global Hawk has not yet reached Initial Operational Capability (IOC), it has been used to support Operation ENDURING FREEDOM. The Global Hawk aircraft costs $20 million, with a complete system costing a total of $57 million (OSD Reliability 18). The Global Hawk aircraft can be based in a theater or in the United States. The system requires a long runway for take-off and for recovery of the aircraft. The complete system is composed of air vehicles, the sensor and payload gear, avionics and data links, a ground-based Launch and Recovery Element (LCE), a Mission-control Element (MCE), a support element, and the personnel required to maintain and to operate the system. The MCE is not required to be in the area of the LCE, allowing the aircraft to be controlled from a distance. The Global Hawk can be controlled remotely from the United States while it is over a target in another hemisphere. The Global Hawk system is capable of linking with current and future planned intelligence systems in order to distribute data across the battlefield and back to the Continental United States.

J. FMQ-151 POINTER

Figure 8. FMQ-151 Pointer mini-UAV (From: Aerovironment.com)

	FMQ-151
Gross Weight	5 lb
Length	6 ft
Wingspan	9 ft
Ceiling	985 ft
Radius	4.3 NM
Endurance	1.5 hrs
Payload	2 lbs
Cruise Speed	16 kts
Aircraft Cost (w/out Sensors)	$50,000 (UAV Forum- Pointer)
Sensors	EO/FLIR
System Cost (3 UAVs)	$220,000 (UAV Forum- Pointer)

Table 6. FMQ-151 Pointer mini-UAV Data (From: Jane's Unmanned Aerial Vehicles and Targets 182)

The FMQ-151 Pointer (Figure 8) is a mini-UAV with low-endurance, which small forces can carry and operate in the field. It provides real-time images for force protection and intelligence, surveillance, reconnaissance, and target acquisition (ISRT). It has an 8-foot wingspan and weighs about 9-pounds. It can be operated in the dark with a Forward Looking Infrared (FLIR) camera and has a mission time of about 90-minutes. The system is composed of three vehicles and a ground-control station. It is a hand-launched vehicle that lands in a controlled crash, not unlike many mini-UAVs. It has a maximum altitude of 3,000-feet and a speed of 43-knots. It is powered by rechargeable Nickel Cadmium (NiCd) or Lithium (Li) batteries and can carry a payload of two pounds (UAV Forum- Pointer). It has a radius of 1 to 3 NM. The vehicle is priced at $50,000 dollars per aircraft. The system of three aircraft, the GCS, and supporting payloads costs $220,000.

This system has had extensive use with special operations forces over the course of Operation ENDURING FREEDOM ("MAV- Combat Lessons Learned"). The Pointer is used to support ground forces. These forces will require more than one flight to support the duration of their missions. The 90-minute endurance of the Pointer aircraft ensures that the three-man crew is constantly preparing, launching, and recovering one of the three aircraft to support the ground forces with persistent information.

K. DRAGON EYE

Figure 9. Dragon Eye mini-UAV (From: Globalsecurity.org)

	Dragon Eye
Gross Weight	4.5 lb
Length	2.4 ft
Wingspan	3.8 ft
Ceiling	1000 ft
Radius	2.5 NM
Endurance	.75 hrs
Payload	1 lbs
Cruise Speed	35 kts
Aircraft Cost (w/out Sensors)	$40,000
Sensors	EO
System Cost (3 UAVs)	$125,000

Table 7. Dragon Eye Data (From: UAV Reliability Study)

The Dragon Eye (Figure 9) was developed by the Marine Corps Warfighting Lab in Quantico, Virginia, to extend UAV operations to the company level and provide these units with an organic UAV capability. It is a mini-UAV designed for low-endurance operations. It was developed to provide "over-the-next-hill" and "around-the-corner" reconnaissance. Operation IRAQI FREEDOM found that higher-level commanders, battalion level and above, tasked the Dragon Eye more frequently than lower-level commanders.

> The majority of units kept Dragon Eye as a battalion asset with missions tasked by the battalion commander, intelligence officer, or higher command level. Only one unit used Dragon Eye at the company-level. This unit used Dragon Eye the least, as the company commander was too busy with his missions and did not have the staff and specialists to support UAV tasking plans. (Defense Update- MAV)

The system is composed of the fixed-wing air vehicle and a wearable GCS, which controls the vehicle and receives its intelligence. The system can be disassembled into five pieces and backpacked to an operational area. Composed of fiberglass and Kevlar, it has a range of about 5 NM, a top speed of 35-knots, and a maximum altitude of 1,000-feet. It usually operates between 45 and 60-minutes and is capable of autonomous operation. One aircraft costs $40,000 with a total system of three aircraft and related equipment costing

$125,000. The payloads can provide full motion color and low-light video. The aircraft requires a LOS data link to maintain control. Future payloads are planned to increase its capabilities.

L. DESERT HAWK

Figure 10. Desert Hawk mini-UAV (From: Globalsecurity.org)

	Desert Hawk
Gross Weight	5 lb
Length	2.25 ft
Wingspan	3.75 ft
Ceiling	1000 ft
Radius	5 NM
Endurance	1.5 hrs
Payload	1 lbs
Cruise Speed	50 kts
Aircraft Cost (w/out Sensors)	-
Sensors	EO/IR
System Cost (6 UAVs)	$300,000 (Kirsner)

Table 8. Desert Hawk Data (From: Jane's Unmanned Aerial Vehicles and Targets 244)

The Desert Hawk (Figure 10) is a mini-UAV with low-endurance used extensively during Operation ENDURING FREEDOM to protect forces via airborne surveillance. The aircraft has a 4-ft wingspan and can take off in a small field using a 300-ft bungee cord system that requires a two-man crew. The system transmits real-time video to a laptop operated by the controller up to a range of about three miles. The Desert Hawk can store waypoints and can update these waypoints during flight. Each kit comes with six aircraft, a GCS and a remote video terminal. The complete system costs $ 300,000 (Kirsner). The control system is limited to operating one aircraft at a time. The Desert Hawk incorporates an interchangeable payload allowing both day and night cameras as well as infrared capability. The system is powered by rechargeable batteries and can remain aloft for one hour, cruising between 35 and 52 knots at an altitude of about 500 feet.

M. UAV PRODUCT DISSEMINATION

UAVs are controlled through the GCS and MCE that can be located in the immediate vicinity, local area, local region, theater or even as far away as the United States depending on the system. Systems capable of being controlled through a KU-band satellite link and that have greater range, such as the Global Hawk, are usually operated from the United States. Information is passed from either the GCS or the MCE to the Service Distributed Common Ground System (DCGS) (<u>Unmanned Aerial Vehicle Roadmap</u> 166). The DCGS is a group of standards that address Tasking, Posting, Processing and Usage (TPPU) requirements in order to facilitate interoperability between the stovepipe systems of the individual services. The DCGS architecture integrates all of the data so that each service can use its legacy systems to access common data. The link to the DCGS commonly occurs at the control station of the UAV. The DCGS is a preliminary step to the Global Information Grid (GIG), the use of which will increase systems integration and throughput capacity.

The link to the DCGS allows the intelligence centers to collect the data and produce products for dissemination. Tactical users cannot always immediately exploit the intelligence they receive because some level of analysis must occur in order to decipher the information received. It would be useful for tactical users to be able to receive and interpret the data from a UAV immediately. Unfortunately, not all data can be accurately framed without an in-depth background in intelligence interpretation. Immediate exploitation of UAV data requires the user to interpret the data quickly and accurately. There is a high likelihood that some data transmitted directly to the tactical user may be misinterpreted, or that the user will have insufficient knowledge of the complete situation in order to interpret the data.

The tactical users at the company level and below are mostly concerned with real-time intelligence in their local area. Mini-UAVs provide the portability needed to support small units of operation with timely information, which intelligence experts can then interpret. Inexperienced commanders should not control some of the capabilities that are being researched because they will not be able to appropriately employ these assets. For example, a tactical unit should not operate an electronic warfare platform without the knowledge needed to use these assets properly. Tactical users should focus on collecting and interpreting any data and images that can be used immediately. Specialized units should collect any data that are not applicable to the tactical user and then forward the data to intelligence centers for interpretation and dissemination.

N. SUMMARY

UAVs offer a platform to perform “dull, dirty, and dangerous” missions (Unmanned Aerial Vehicle Roadmap 27). UAVs are less expensive to maintain and operate that most manned aircraft. They allow collection of vital intelligence data when it would be dangerous for a manned aircraft, but they are still susceptible to the same factors as any other type of aircraft. Wind, sand, icing and other environmental factors limit their ability to fly and to collect useful data.

There is a vast amount of information on UAV systems, however a great deal of this information is either incorrect or limited in its usefulness. Experience with UAVs develops the understanding needed to employ these assets properly. Each system is capable of performing different types of missions with varying degrees of success. Payloads vary in quality and complexity and some aircraft perform better than others. Experience reveals the capabilities and limitations of individual systems. This knowledge is necessary to optimizing the use of these limited resources.

The development of future UAV systems strives to increase the capabilities of these units and increase the reliability of these systems; however there will always be limitations. Each specific aircraft has its own unique set of limitations and capabilities. Attainment of this knowledge will increase the effectiveness of these assets through their correct employment.

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III. MINI-UAVS

A. INTRODUCTION

The 2002 Department of Defense (DOD) Unmanned Aerial Vehicle Roadmap considers a number of capabilities for larger UAV systems, however not all of these missions can be considered effective allocation of resources for mini-UAVs due to their limited capabilities and time aloft. Miniaturization of payloads will open up a wider variety of applications for mini-UAVs by allowing them to carry more than one type of sensor. The current level of technology limits payloads to performing one type of mission during a flight. Interchangeable payloads extend the mission range of these systems, but they must return to the ground to be replaced. Larger systems, such as the Global Hawk, currently provide the capability to equip the aircraft with a wide variety of sensors that allow multiple types of missions to be accomplished in one flight.

The 2002 DOD Unmanned Aerial Vehicle Roadmap identified seventeen areas in which UAVs have been employed either through concept demonstrations or operationally. Mini-UAVs cannot provide adequate support in some of these areas:

- Intelligence, Surveillance, & Reconnaissance (ISR)
- Command and Control (C2)/ Communications
- Force Protection (FP)
- Signals Intelligence (SIGINT)
- Weapons of Mass Destruction (WMD)
- Theater Air and Missile Defense (TAMD)
- Suppression of Enemy Air Defenses (SEAD)
- Combat Search and Rescue (CSAR)
- Mine Counter Measures (MCM)
- Meteorology and Oceanography (METOC)
- Counter Narcotics (CN)
- Psychological Operations

- All Weather/ Night Strike
- Exercise Support
- Counter Fire
- Anti-Submarine Warfare
- Navigation

B. MINI-UAV FACTORS

1. Mini-UAV Planning/ Preflight

Mini-UAVs are envisioned as being rapidly available to a commander, yet there are still considerations that must be taken into account before a mini-UAV mission. Thorough planning must be undertaken to ensure that the aircraft will be operated safely. Even though mini-UAVs are of low cost, and can be considered expendable, care must still be taken to bring as many back as possible. The possibility of mini-UAVs causing damage and loss of life to our own troops exists if they are not operated with caution.

Planning must be undertaken to ensure that the mini-UAV is operated with the best consideration of winds and other environmental factors, launch position, mission profile, mission objectives, integration into the airspace, and landing. This includes defining the separation of UAVs with manned aircraft and the entry and exit procedures over the target area. Mini-UAVs must be integrated into the airspace over a target area to provide time or altitude separation from other aircraft. The small size of these vehicles limits the ability of pilots of manned aircraft to maintain visual separation. Mini-UAVs offer little situational awareness to the operator, so it becomes hard for the UAV pilot to maintain visual separation. The possibility of installing a transponder system is unlikely for the foreseeable future due to the small payload size that these units are capable of carrying.

A thorough preflight must be performed to verify that all systems are working correctly. Mini-UAVs seldom include any system redundancy. Each system becomes a single point of failure and each must work in unison to ensure that the aircraft can fly and perform its mission. If the control link fails, the UAV will usually have a return-to-base feature guided by Global Positioning System (GPS) data; however, if the motor, electrical system, data link, or avionics/ control system fails then the aircraft will become unusable. Any problems in the preflight must be corrected before the aircraft can fly, or the mission will not succeed and the UAV will likely be lost or destroyed.

The planners must consider the entire mission before the aircraft has left the ground. While this planning may occur rapidly, it must be comprehensive in order to operate the aircraft safely. The planning must consider the full capabilities and limitations of these vehicles. Although they are designed to be expendable, treating them as such is not wise. The limits of these craft may be tested if it is of operational necessity; however, the commander must be willing to assess the costs and benefits of losing his "eye" in the sky.

2. Time Aloft/ Loiter Time

Larger UAV systems have significantly longer loiter times to survey a target area. The Global Hawk can remain aloft for over 32 hours. Larger UAVs also require improved areas for take-off and landing. The lack of runways in proximity of tactical units restricts the ability to locate UAVs nearby. Even if they can be located near the troops they are supporting, this is not a judicious option, as their logistical bases are not rapidly mobilized, and these systems are tied to runways. The probability of destruction by enemy fire increases as these units are stationed closer tactical units.

Mini-UAVs provide short times aloft, generally in the range of thirty minutes to one hour and thirty minutes. Surveillance using mini-UAVs cannot be conducted over the period of a lengthy operation without multiple UAVs and without a crew experienced at launching and recovering UAVs continuously. Time to reach the target area must be factored into the calculations of the UAV availability over the area.

The ability to support retasking of these assets is also minimal, for they might not have the capability to accomplish sustained operations. Mini-UAVs must be considered as platforms used to perform a specific mission at a specific time. These missions can be rapidly formed, but these platforms should not be seen as persistent surveillance platforms. They should be seen as platforms used to answer specific questions or address specific threats.

3. Ability to Launch

The ability to launch the UAV is vital to its employment. Most mini-UAVs do not require a runway or any type of improved surface for launching, but they do require an open field or drop-off in which to transition to flight. A general area about the size of a football field should be used. Mini-UAVs cannot be operated directly on the front lines safely. The requirements for launch of current systems require some isolation from direct fire. Soldiers must be able to stand up and launch the systems by hand. The Dragon Eye system requires at least two people and a long bungee cord to launch the system, leaving the launch crew exposed (Grimes). Therefore, this is not yet a system that can be launched in the direct vicinity of combat.

Instead of launching at the front, these units must be launched away from the rear of the combat area. The situation will dictate how far from the front lines mini-UAVs must be launched. Locating the UAV GCS away from the commander and troops intent on using data from the UAV introduces coordination issues. With the GCS in the rear it is hard to direct the UAV and obtain data from it.

4. Wind and Atmospheric Conditions

Moderate winds are a large hindrance to the operation of mini-UAVs due to their small design. In high winds, the aircraft will tend to become less stable and thus the cameras and sensors will lose effectiveness for live video feeds. Using still images under these conditions is possible.

Mini-UAVs are launched into the wind in order to supply the lift needed until their motors can provide the thrust necessary for flight. Light winds allow the user to choose a direction of flight in which to launch the UAV for optimal operational utility. Of course, moderate winds can drastically affect the ability of a Mini-UAV to launch in an optimal direction.

> We are only limited by the weather and battery life. The environment here [in Iraq] makes it tough to fly, especially (in) the wind. Getting the plane airborne, keeping it on track and (landing) in a safe place when it's done (are) probably the hardest (parts) of the (Desert Hawk) mission. (qtd. in Nelson)

Winds will also affect the direction of launch of the UAV, as well as its ability to maneuver around a target. Moderate to high winds with the target upwind of the launch point will hinder operations to reach the target site, as mini-UAVs typically have small motors and a limited top speed.

Moderate winds reduce the ground speed of the mini-UAV and may overpower the mini-UAV. In high winds, smaller control surfaces also have less ability to maintain the direction and stability required to fly the aircraft. The aircraft is more susceptible to wind gusts and other phenomenon that can wreak havoc on the aircraft.

Other environmental conditions impact the usefulness of these mini-UAVs during operations. Icing can cause control surfaces to loose effectiveness and add weight to the airplane causing a decrease in lift and possibly a loss-of-control situation. Mini-UAVs do not have the systems required to fly through conditions that might cause ice to form on lift and control surfaces. Systems that combat icing add complexity and cost to these units and are not necessary in most operational scenarios.

The use of mini-UAVs during rain and snow is not generally recommended. Moisture can damage the electrical systems and cause the UAV to crash. Mini-UAVs have few provisions for protection from the elements. Flight during light rain and snow might be possible, but is not recommended.

5. Density Altitude

Density altitude describes what the air feels like to an aircraft in relation to a standard atmospheric day (15°C and 29.92 in. of mercury at sea level). As temperature increases, the air molecules move fast and further apart. This creates a thinner, less dense atmosphere when compared to a lower temperature at the same altitude. Air density directly affects the lift that can be produced from an aircraft. As the air density decreases, the density altitude increases, and the ability to generate lift decreases. In mini-UAVS this can be a problem, as they are not designed to fly in extreme conditions. Mini-UAVs are generally not designed to fly at high altitudes. A high density altitude causes the aircraft to fly as if it were at that altitude. This can limit the availability and utility of mini-UAV operations.

6. Temperature

The temperature does not just affect the density altitude. Electrical components need to be cool to operate properly. Extreme environments affect all of the systems on-board the aircraft. Overheating can cause components to fail either before take-off or during flight. Generally failure will take place before the preflight. During flight components are cooled as air passes over them.

An operational fix for this deficiency might be the employment of small fans used to cool computers. These fans are light and draw very little amperage. They could easily be added internal to the UAV to cool components. The lack of an ability to operate in high temperatures means that operations in high temperature environments are affected. Individual systems are composed of different grades of components that can handle different temperatures. The effects of heat may vary between different models of mini-UAVs.

7. Operations in Dense Areas/ Over-the-Horizon

Mini-UAVs require direct line-of-sight between the ground-control station and the aircraft. Any objects in the way will absorb, scatter, or reflect the weak control signals and cause the UAV to become uncontrollable. The ground-control station antennas must be placed high above any obstruction. Buildings, dense forested areas, and other structures will not permit the weak control signals to reach the aircraft. Figure 11 illustrates the shadow zone that is created by obstructions. In the figure the obstruction limits the UAV from operating at low altitudes around the city and the factory. As the UAV goes further from the ground control station it must maintain a higher altitude to overcome the curvature of the earth and the shadow zone created by the obstruction.

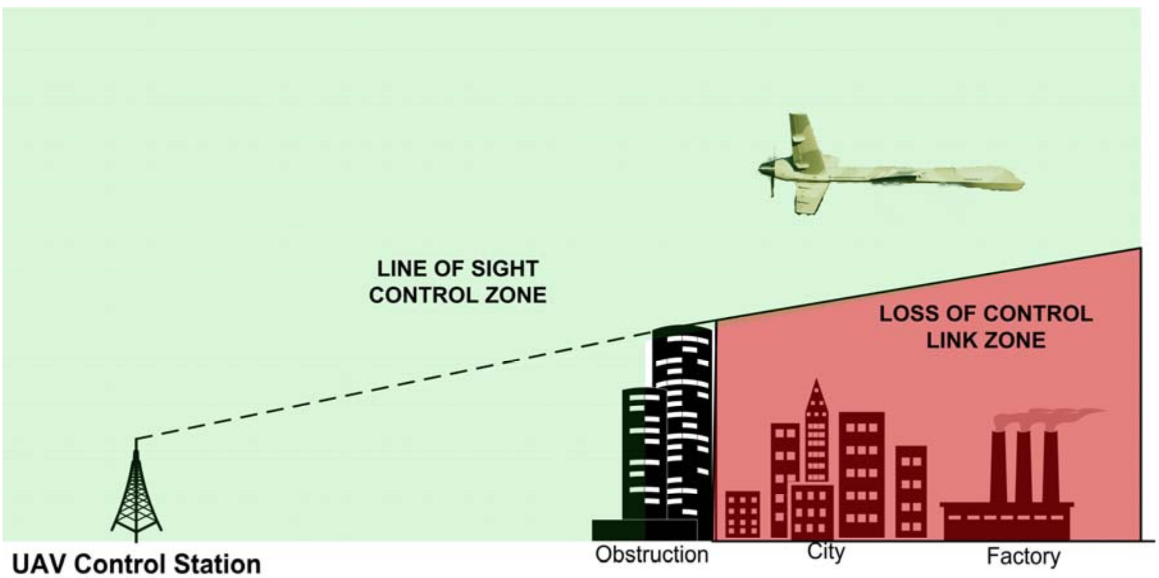

Figure 11. UAV Line-of-sight Control Link Limitations

The placement of the GCS is an important consideration. Mini-UAV GCS are integrated units that contain the mission-planning software and the transmission equipment necessary to interface with the mini-UAV under flight. Consideration of the operating area must be taken into account. The flight path of the aircraft must be considered before a site is chosen on which to erect the ground-control station and supporting equipment.

8. Number of People to Operate

Operating mini-UAVs typically requires one to two people. Launch and recovery may require more. The technology readiness level (TRL) of mini-UAVs is presently low, but future vehicles will be able to perform most missions on their own (<u>Unmanned Aerial Vehicle Roadmap</u> 131). The TRL is used to "assess the maturity of evolving technologies prior to incorporating that technology into a system or subsystem" ("Technology Readiness Level"). One component relating to an increase in the TRL is autonomy. Autonomy is the ability of a unit to operate without input from a human.

A UAV with some level of autonomy is in the near future; however, the utility that can be gained will be minimal. The required level of autonomy to allow a fighting troop to operate and to gain information from a mini-UAV will have to be very high. A troop must be able to task the UAV and receive information from the unit quickly and directly without the need to operate the UAV. At this point in time mini-UAVs must have dedicated crews to perform their mission. Keeping these people from danger is important, since they must concentrate on the operation of the UAV, rather traditional combat operations. Yet, they must still be located near the commander to relay pertinent information, or have a direct means of communication with the commander.

9. Communications Security

The nature of COTS technology defines the components as mostly COTS as well. Most mini-UAV manufacturers are technology integrators who purchase equipment from other vendors in order to develop a system. The components are mass-produced by these companies. Mass production drives down the cost of the individual components and the total system. Although lower cost is a benefit, the mass production of the components means they can be purchased and easily used to reverse engineer a system. Components can be of hobby-grade or of military-grade.

Hobby-grade components do not ensure security. If the adversary could obtain one of the systems it would be easy to reverse engineer the complete system. Since the components could easily be bought through COTS venders, specifications and parts to recreate the system could readily be obtained. It is possible that the enemy could reverse engineer the data link and the control link. The enemy would then have the opportunity to monitor the use of the mini-UAV or even take control of the unit. Subsequent development of mini-UAVs should concentrate on developing more secure control and data links between the ground-control station and the mini-UAV.

Commercial venders must accept the requirement for these secure data links and work to develop them. The military can refuse to buy any system that does not have a secure data link, but they must be willing to endure the increase in cost to obtain these systems.

10. Frequency Separation

A major concern with mini-UAVs is the loss of control link. If the control link is lost the aircraft cannot be controlled from the ground-control station. An aircraft operating in autonomous mode will continue upon its intended flight path, but if the control link and the data link are combined, the user will not be able to obtain any data from the aircraft. The lack of onboard storage will mean that the flight was unsuccessful. A larger problem will occur if the aircraft is in manual mode. Most systems will cause the aircraft to return to a defined point when the control-link is lost. The loss of the control-link still results in the mission being unsuccessful.

A major problem with the control link is interference with other systems on nearby frequencies, or interference due to flying through an area with too many transmitters. The radio frequencies (RF) in an area of operation must be considered and steps must be taken to keep the control and data link frequencies clear of other traffic. Mini-UAVs concentrate on the use of Commercial-off-the-Shelf integration in order to cut down costs. Most of these units use similar frequencies for control and data links. If adversaries were sufficiently prepared they could easily use other devices to jam these non-secure control and data links.

11. Tie-in to the Information Grid

The ability to tie into the information grid is a key component to passing data to the higher levels of command.

> At least 100 UAVs of 10 different types were used in OIF yet none of them allowed integrated direct data receipt. To date, individual Services have been reluctant to adopt common mission management systems or other interoperability approaches within similar types or classes of UAVs. Each Service has tended to initiate its own separate development program specifically tailored to its requirements rather than adopting an existing capability from another Service. (Defense Science Board x)

Video, still images, and other data collected from mini-UAVs can provide greater situational awareness to local users and higher-level commanders if they are shared with those higher-level commanders. Mini-UAV ground-control stations are not bound by any set of standards. The data and control links between different systems are not interoperable. The larger UAV systems are currently dealing with this problem, but most of these systems have been developed under some type of government contract so they incorporate some common standards (Unmanned Aerial Vehicle Roadmap 135). The standardization of the interfaces for these UAVs is a significant problem that is being examined.

COTS systems present a different problem when trying to deal with developing and enforcing standards. The components in these systems can be similar because they are obtained from other COTS manufacturers. Yet even if the components are similar, companies will have different interfaces with their units to attempt to distinguish their systems from competitors. These interfaces are not interoperable. Some COTS manufactures are not interested in developing systems that interface with other systems, instead they are interested in developing stand-alone systems and the impetus for integrating these systems into the intelligence networks must fall on the user.

This data sharing hinges on the ability of the UAV ground-control station to connect to military information systems. It also requires a great deal of bandwidth to support full-motion video and other live products. At this time, connection to the GIG may restrict the mobility of the GCS. It also requires the ground-control station be located near assets that are already connected to the global information grid. Distribution to users over the "last tactical mile" from GIG access points to soldiers on the ground is a problem that needs to be solved. The development of systems that allow individual users to connect to the global information grid will increase the mobility of soldiers. It will, in turn, increase the mobility of mini-UAV ground stations connected to the global information grid.

12. Landing

Due to the small size and mass of mini UAVs, these units do not possess a great deal of momentum at any point during their flight. Most mini-UAVs land in a controlled crash. The engine is shut down and the aircraft is allowed to glide into the ground. If this procedure is performed incorrectly, varying amounts of damage can occur, depending upon the surface and the speed of the UAV and the construction of the unit. Most damage can be repaired through the use of spare parts.

13. Field Support Requirements

Mini-UAV systems can be considered expendable due to their inexpensive cost, but they should not be treated as such. These units are often easily repaired by non-technical people through the use of spare components without any mechanical or technical training requirements. All of the components in these units must be operational before launch. A good preflight inspection and testing of the systems will ensure this is the case. When there is a problem the parts can quickly be interchanged from a small inventory of on hand parts. The simplicity of these systems even allows the use of duct-tape to hold together broken body parts. This inventory is not much of a burden on the individual soldier because the parts are small.

C. MINI-UAV SPECIFIC MISSIONS

A solid understanding of UAVs must underlie any decision to employ these assets. The 2002 Unmanned Aerial Vehicle Roadmap defines a wide range of missions in which UAVs can perform, but UAVs might not be the best option for some missions. A commander must consider all of his assets before selecting a particular course of action. The tendency is to call on UAVs before considering other solutions. The “wow” factor involved in UAV operations has created a syndrome in which inexperienced people believe that flying a UAV above any area will bestow “everything to everyone.” The limitations of these assets are not considered.

Mini-UAVs are prone to this phenomenon. Operational experience with these UAVs leads to better understanding and employment of these assets. The Defense Science Board Task Force on UAVs found that, "operational experience with Predator, Global Hawk, Hunter, and special purpose UAV systems during recent conflicts demonstrated that, once employed by warfighters, the value of UAVs becomes immediately evident, ideas for new operational concepts are spawned, a constituency is formed, and strong advocacy begins to build" (9). Mini-UAVs are still under development and most commanders do not have a clear understanding of their limitations. In the future it will be possible for mini-UAVs to participate in all the missions defined by the 2002 Unmanned Aerial Vehicle Roadmap, but like all aircraft they will still have constraints on their operation.

Miniaturization of current technology will give mini-UAVs robust capabilities. The ability to perform electronic warfare and information operations will be available in the future. Other developments will greatly enhance the ability to collect and to disseminate intelligence data. The DOD must ensure that it does not lose sight of the employment limitations of these vehicles. Some capabilities that are implemented in larger UAVs have no place in the smaller, mini-UAV systems. The basic factors of their employment must be considered. Technology must not dictate the mission. Conversely, the mission should dictate the appropriate technologies that should be developed for these units. Small tactical units, devoid of specialized training, should not employ mini-UAVs with capabilities beyond EO and IR.

Mini-UAVs should be treated the same as larger manned systems they intend to replace. Signals intelligence, anti-submarine warfare, and detection of weapons of mass destruction are all areas in which specially trained personnel are needed to manage collection and interpretation of data. Typical military units do not have the training or manpower to process and disseminate this data accurately. Units dedicated to these areas of expertise must be used if there is to be any gain from the use of these mini-UAVs. With this in mind, the greatest utility for mini-UAVs is in furnishing regular unit commanders with intelligence data that require rudimentary analysis and simple missions. These missions include: Intelligence, surveillance, and reconnaissance, C2/ communications, force protection, combat search and rescue, and navigation. Still, the limitations of these units must be considered in relation to other available assets before they are used.

1. Intelligence, Surveillance, and Reconnaissance (ISR)

Intelligence, Surveillance, and Reconnaissance (ISR) is the classic mission associated with UAVs. A variety of different payloads support this capability and all current UAVs have some form of ISR capability. ISR collection and distribution can include EO/IR full motion and still imagery. Smaller UAVs are readily capable of ISR collection for immediate exploitation by ground troops. This is a vital asset for small forces allowing an "Over-the-Hill" or "Around-the-Corner" capability.

ISR is arguably the most valuable type of information that mini-UAVs can collect. Due to their small size and limited range, they are well situated to operate in and around a small force. They don't require higher headquarters tasking, and can be launched immediately, whereas larger systems need to coordinate with other air assets. Despite their relative ease of use, a surveillance technician must constantly monitor the data feed from these units so that intelligence can be gleaned from the raw feed. There is a tendency to believe that anyone can interpret data from a UAV, but skilled interpreters must be available to interpret any obscure or confusing information.

The military is being asked to participate in situations that are not usually in the realm of pure military operations. These operations Other Than War require background knowledge for the interpretation of the data to be collected. Interpretation of situations without the knowledge of an experienced intelligence analyst could lead to fatal or faulty decisions. Trained intelligence analysts must be in the vicinity of the data feed to ensure that the information gained from mini-UAVs is interpreted correctly, unless it is possible to pass the data quickly to a remote-site analyst and receive rapid feedback on the information being collected. This would rely on a secure and robust connection to the global information grid.

2. Force Protection

Force protection is a primary mission for mini-UAVs. All of the current mini-UAVs are being used for this mission. Force protection includes perimeter patrol of bases as well as scouting out convoy routes prior to troop/vehicle passage. Mini-UAVs provide an excellent capability because it is not difficult to schedule these aircraft or prepare them for flight. One drawback is that very little automation of detection technologies exists onboard mini-UAVs. Operators must monitor video and sensor feeds to ensure that the appropriate data are captured, intelligence derived, and that the commander can be alerted.

3. C2/ Communications

UAVs have been shown to be capable of linking ground forces where LOS bands do not reach. A UAV with a relay radio inside is able to act as a repeater station. If both units can see the UAV, but not each other then they can talk through the UAV with this repeater capability.

> Use of a weaker source RF signal and then a UAV to boost the signal and overcome LOS restrictions can help to reduce an enemy's ability to use the direction of arrival of an intercepted signal to locate the position of a ground unit, command post, etc. This can increase the security of our communications, but more significantly, the physical security of the communicator. (Fisher)

The use of UAVs as communications nodes for extending communications distances is better left for larger systems. While mini-UAVs are able to provide repeater communications over a small area, they cannot power transmissions to connect distant units. Mini-UAVs do not currently have the ability to lift and transport radios large enough to fill the necessary capability gap to fill a vital mission role in this area. The size of the radios necessary to link communications would limit the mini-UAVs ability to carry other equipment and would reduce its time aloft. Power requirements would also limit the total time aloft, reducing the effectiveness of this capability and making it more of a hindrance to operations than a force enabler. Miniaturization of electronics will expand the capability of mini-UAVs to perform this mission in the future. The Special Operations Forces believe that this capability will enable them to operate more effectively in the field (Howard 53).

4. Navigation

Mini-UAVs could determine reference points for navigation. The ability to obtain a bird’s eye view of the current location of forces as well as the rivers, mountains, road intersections, and enemy forces can help one decipher locations on maps as well as provide directions and distance. The GPS signal requires at least three satellites for a two dimensional (2D) fix. The latitude and the longitude are reported in a 2D fix; however, altitude data is not reported. Canyons, mountains, and atmospheric disturbances can degrade a GPS receiver's accuracy. UAVs might obtain GPS through their avionics systems by rising above the terrain or elemental restrictions of a particular area. This is a particularly good mission for mini-UAVs because it can be accomplished while the mini-UAV is conducting other missions and does not require a special payload.

5. Combat Search and Rescue (CSAR)

Mini-UAVs are well suited for conducting Combat Search and Rescue (CSAR). They could be used to search for units isolated from the rest of the platoon or squad. They could also be used to locate downed pilots. These units are uniquely qualified to loiter over hostile areas and search for missing personnel. Mini-UAVs remove humans from the danger of flying over a hostile area while providing an aerial asset to search for missing personnel.

Once these personnel are located, the UAV can support rescue operations. These unmanned, expendable units can even be used to search the most dangerous areas. Their small size makes them difficult for the enemy to target. These units allow personnel on the ground coverage over large area in a short amount of time. The speed of the mini-UAV allows it to cover more distance than a human on the ground. The aerial viewpoint also makes it easy to locate wreckage that might be missed on foot. The use of multiple, coordinated UAVs could offer effective CSAR over an area.

D. LOCAL PERSISTENCE

The problem with current large UAV systems and the policy that governs their use is that data and intelligence rarely make it to the tactical users in time for them to use. This is not only a problem related to UAV systems. Tactical users have trouble interacting with any type of intelligence system due to their high mobility and the lack of robust systems to support them while mobile.

The ability to collect and to interpret their own data allows the tactical user to obtain the information that they need without relying on a connection to other intelligence systems. As the GIG becomes a reality, the tactical user will have the ability to interface with the rest of the force and receive up-to-date information in a timely manner.

As has been described previously, mini-UAVs can provide commanders disconnected from information dissemination systems with real-time intelligence. The future will concentrate on building systems to connect units to C4I systems over the "last tactical mile." A continuous connection will allow information to flow to-and-from the tactical users, enhancing their situational awareness. The integration of this information will be the most important aspect of the system.

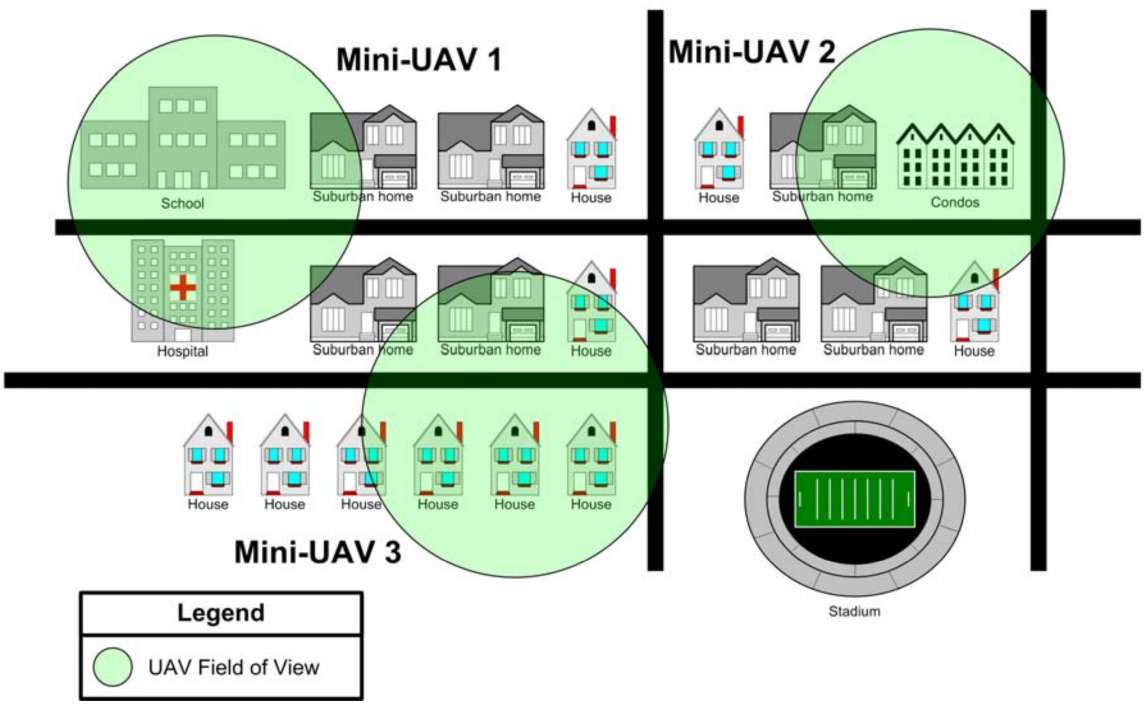

Figure 12. Local Persistence of Information

Local persistence is the continuous availability of intelligence data in the surrounding area of the local user. Local persistence gives the user a complete understanding of the intelligence history of his local area, as well as the current threats and any available intelligence on future threats. Considering the capabilities of current mini-UAVs, they do not meet the requirement for continuous surveillance.

Figure 12 depicts the current state of awareness of a commander using a mini-UAV. In this case, each commander has awareness of his individual area, depicted by the circles. As information sharing increases due to the development of better communications systems each commander will share his or her knowledge with the other units. This will expand situational awareness, but gaps may still exist.

When the battlefield communication and information systems develop further, mini-UAVs will be able to fully integrate into the system. Higher echelon commanders will be able to access the intelligence collected by tactical users. Units will also be able to share data with the other units at the same or possibly lower command levels.

The mini-UAVs will act as focused point-intelligence gathering units while battalion and corps level systems will survey wide areas. Mini-UAVs will be used to locate targets of interest to the individual units, with higher-level commanders retaining the ability to receive this information feed. Tactical units will have better situational awareness because they will control their own units and will also have the ability to observe the areas surrounding them through the GIG (Figure 13).

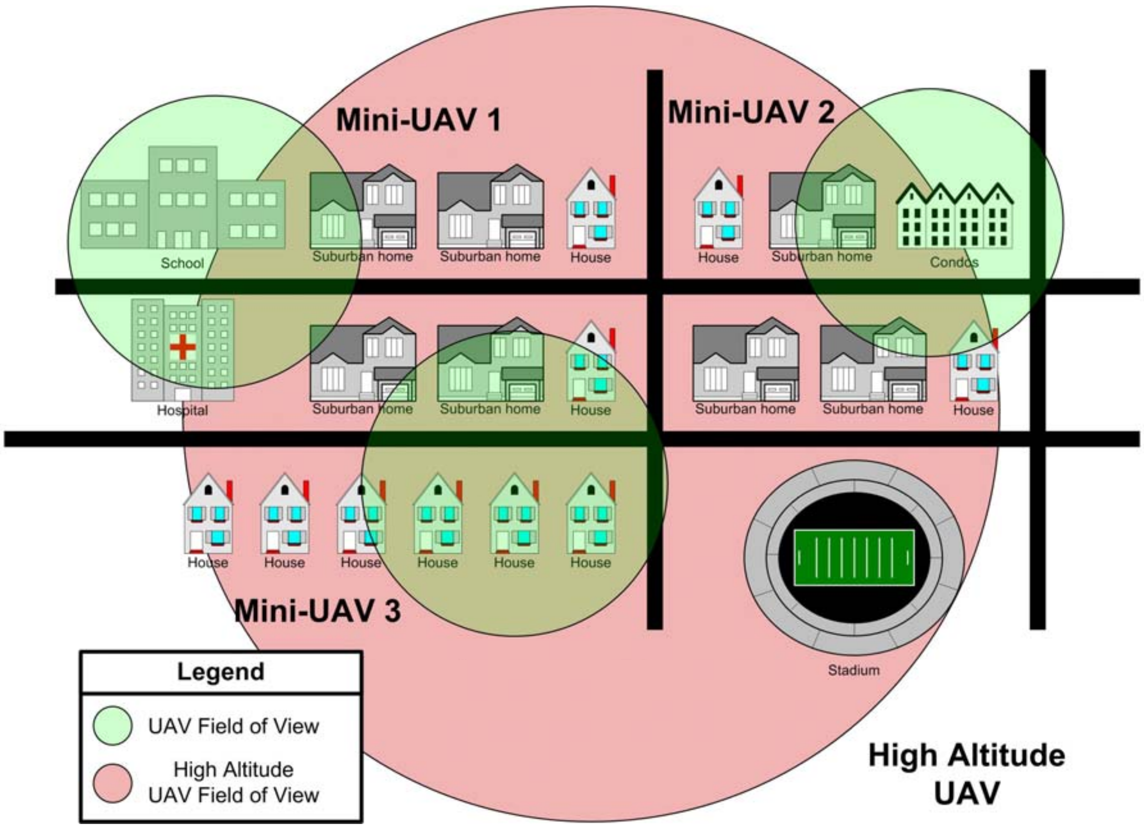

Figure 13. Effects of Combining Intelligence from mini-UAVs and High Altitude UAVs

E. SUMMARY

This chapter discussed the general operational issues involved with mini-UAVs. The limitations of these units inhibit their operation in some missions. As technology grows and the limitations are overcome, these vehicles will provide even more utility to units in the field in a wide range of roles.

Environmental factors impose significant limitations on the implementation of mini-UAVs. Environmental factors cannot be controlled and thus must play a major part in the considerations of UAV planning. Wind, temperature, humidity, and the landscape will play a major role in the effectiveness of UAV operations. There will be some cases in which the environment will preclude the use of mini-UAVs. In this case, commanders must be willing to forego the use of these vehicles less they risk the vehicle and waist valuable resources.

Missions to support tactical users are the primary use for mini-UAVs. While these units are capable of SIGINT, COMINT, ELINT and other specialized missions, average users do not easily employ them in this realm. Mini-UAVs should be used for immediate surveillance applications. Little to no analysis should be required to use the data collected from these units.

As the TRL increases mini-UAVs will become more valuable to tactical users. The number of people required to operate the system will eventually be reduced to support staff only. As mini-UAVs become autonomous users will only need to input missions and then utilize the data collected by these units. The user will not be required to control any function of the UAV, allowing him or her to focus on fighting. Eventually, mini-UAVs might be able to determine their own tasking. This capability is beyond the considerations of this paper, but one can imagine a scenario in which mini-UAVs would provide persistent surveillance across the battlefield and automatically provide targets to users.

Local persistence is a step toward global persistent ISR. Bandwidth increases to tactical users resulting from development of the GIG will enable local users to share ISR data and access intelligence databases. Information can be the key to warfare. The military with perfect information can, and likely will, dominate the battlefield.

The goal of mini-UAVs is to increase the amount of information available to commanders at the tactical level. While persistent ISR is a ways off, the concept of local persistence can be implemented in the near term. The next couple of chapters will consider information sharing at the tactical level using the COASTS network.

IV. COASTS PROGRAM OVERVIEW

A. INTRODUCTION

The Coalition Operating Area Surveillance and Targeting System (COASTS) program served as a test bed for integrating mini-UAVs into a rapidly deployable network based on Commercial-off-the-shelf (COTS) technology. The COASTS program is a model for integration of data from tactical users into the Global Information Grid (GIG). The COASTS program provides capabilities for individuals and small units to tie into strategic databases through a rapidly deployable network.

B. COASTS OVERVIEW

The COASTS program is researching rapidly scaleable and deployable wireless surveillance networks based on COTS technology. The program integrates UAVs, air balloons, portable and fixed ground-based sensors, as well as technologies to provide situational awareness to local and strategic users. The program is primarily concerned with supporting Direct Action, Tactical Reconnaissance, Foreign Internal Defense, Combating Terrorism, Civil Affairs, Counter-proliferation of Weapons of Mass Destruction, and Information Operations (Appendix A).

The COASTS program focuses on integrating all of the data at a Mobile Command Post (MCP) and then linking it to higher headquarters through this node. The MCP serves as a collation point for all data arriving from the deployed network architecture. The deployed network architecture is established through self-meshing wireless technology that serves as an access point for users and other assets, such as UAVs. The nodes and users connect to the deployed access points (Breadcrumbs™) and receive a link to the integration center, the MCP. Long-haul wireless technologies integrate other Mobile Command Posts and link these integration centers back to higher headquarters.

Breadcrumbs™, a product from Rajant, provide local access from the field to the MCP. These units use the 802.11b wireless standard protocol to create self-meshing access points. These Breadcrumbs™ are spread over the surveillance area and provide a wireless 2.4 GHz 802.11b access point for any wireless device capable of employing the 802.11b standard. Each device is self-contained and can be powered by a battery for approximately 8 hours. These access points connect the user to other users on the breadcrumbs network. The infrastructure is transparent to the user, as the Breadcrumb™ system handles all of the lower level connection details.

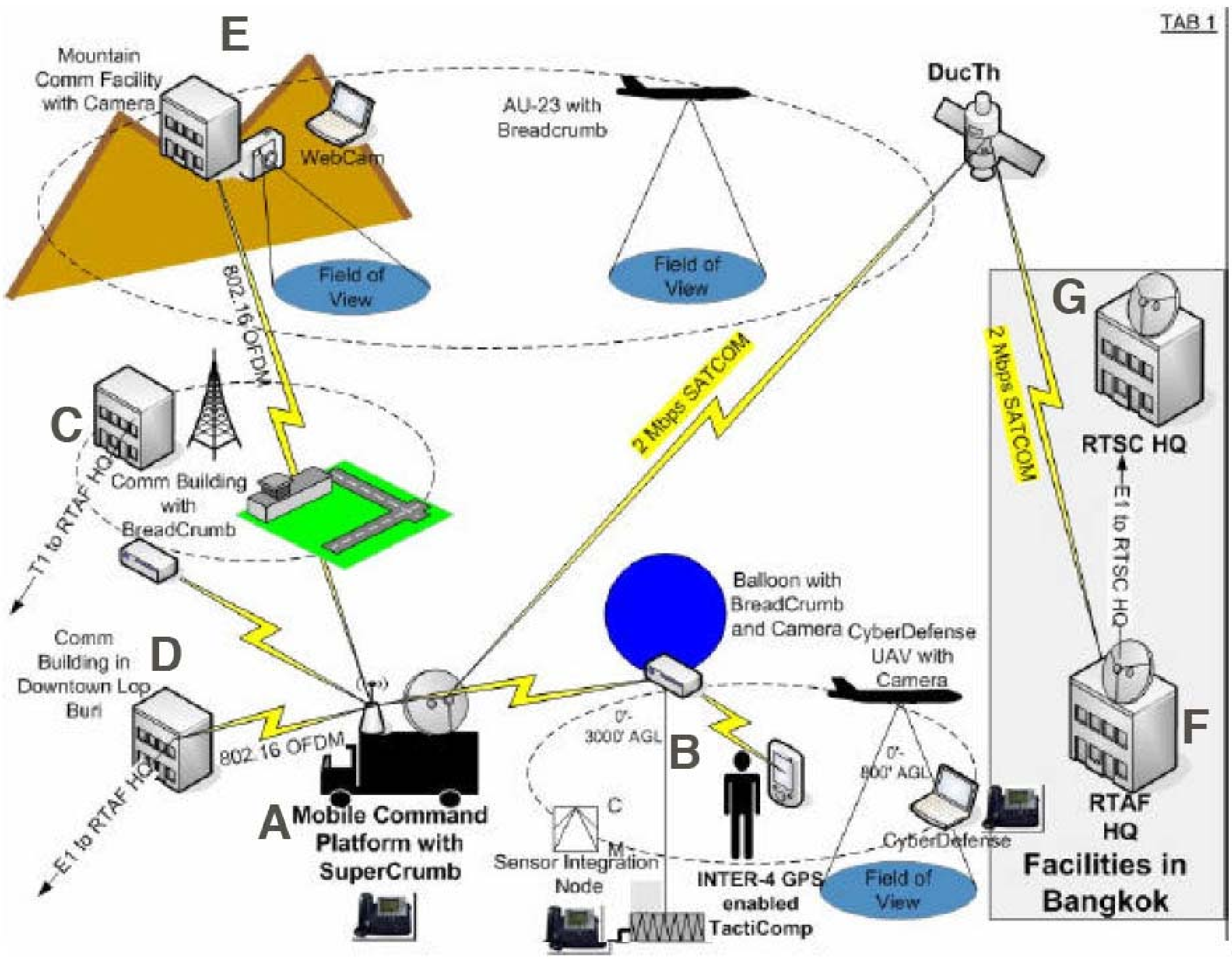

Figure 14. COASTS Architecture (From: Appendix)

Figure 14 provides a detailed diagram of the COASTS network. The MCP (A) and local area components (C, B) were located at the Royal Thai Air Force (RTAF) base in Lop Buri, Thailand. In this first iteration of the COASTS project the MCP served as the network control center, the data fusion center, and the location from which the local are network, created by the Breadcrumb™ mesh, connected to Bangkok (F, G). The Breadcrumbs™ connected tactically deployed users to the MCP across the airbase. Breadcrumbs were located at the MCP (A), the balloon node (B), and at the Wing Two communications building (C).

The link between Lop Buri and Bangkok utilized both an E-1 and a T-1 line. The MCP was linked to a communications building in downtown Lop Buri (D) utilizing Redline Communications 802.16 Orthogonal Frequency Division Multiplexing (OFDM) technology. An E-1 connection linked the downtown Lop Buri communications facility to the RTAF Headquarters in Bangkok (F). The second connection to Bangkok was established through a T-1 line located at the Wing Two communications building (C) to RTAF headquarters (F). The data passing over the T-1 was first transmitted to the Wing Two communications building through the Breadcrumb™ network before being relayed to Bangkok. RTAF headquarters connected to the Royal Thai Supreme Command (RTSC) headquarters (G) utilizing an E-1 line.

The connections from Lop Buri to Bangkok permitted remote, strategic users access to the local situational awareness picture. Users in Bangkok, at both RTAF and RTSC headquarters, were able to manipulate cameras, receive video feeds, and communicate with users in the field.

TrakPointC2™ co-developed by Mercury Data Systems and NPS (Figure 15) is the shared situational awareness software that provided a common operational picture to all of the users. It is based on client-server architecture and allows clients to access the TrakPointC2™ database running on a server in the MCP. TrakPointC2™ provides chat, unit tracking through GPS, moving map display, and access to video and data supplied by the nodes. Video cameras, sensor data, users on the ground, UAVs, and other units are integrated into the

TrakPointC2™ system. Raw sensor data feeds, such as video feeds can be accessed and controlled through the system. TrakPointC2™ is the center of the data-fusion process that occurs at the MCP. It also allows users outside the local area to share the situational awareness picture. TrakPointC2™ can be run by any computer connected to the network, as well as Personal Digital Assistants (PDAs) connected to the network. PDAs connected tactical users to the TrakPointC2™ server through the deployed Breadcrumb™ network.

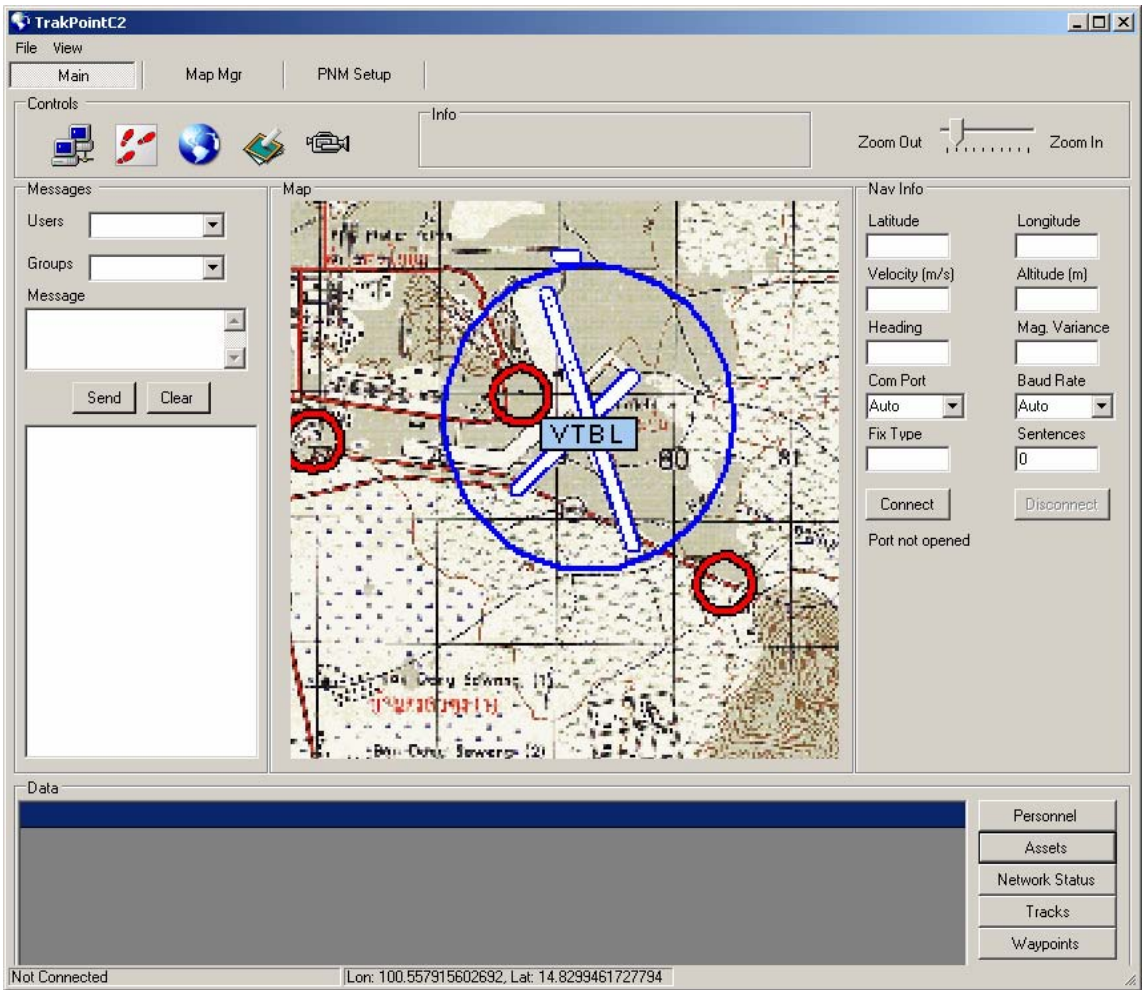

Figure 15.   TrakPointC2™ User Interface

UAVs in the COASTS network collected near real-time intelligence for local and remote users. The goal was to show that users could call for intelligence and retrieve the data via the COASTS network.

C. CYBER DEFENSE SYSTEMS INC. UAV OVERVIEW

The Cyber Defense Systems Inc. vehicle is a COTS system designed for military and law enforcement use. The CyberBUG™ served as the COASTS program UAV. The entire system is built using commercial products that are mass-produced and thus relatively inexpensive and easy to obtain and integrate. The user is paying for the systems integration, rather than for complete development of each individual subsystem in the UAV. The cost of the total system is kept low by removing the cost of developing the individual subsystems.

The CyberBUG™ system is composed of the vehicle and the GCS. It is a standalone system with low-endurance. Like most mini-UAV systems, it is not designed to operate with theater or global intelligence distribution systems. The integration of data from mini-UAVs is critical to closing the gap between our current intelligence systems and the long-term goal for persistent information. The COASTS program focused on integrating the data from the payload of this UAV into its network for distribution to local and regional users.

1. CDUAV Vehicle

The Cyber Defense Systems Inc. CyberBUG™ mini-UAV (Figure 16) used in this experiment is 4 feet long and has a wingspan of 4 feet with a weigh of 12 pounds. The CyberBUG™ vehicle is unique in that it uses a kite wing. It is powered by batteries and can carry a maximum payload of five pounds. The motor is electric and is powered by the same batteries as the avionics system. The single payload is interchangeable and can be selected by the user.

Figure 16. Cyber Defense Systems Inc. CyberBUG™

The COASTS program used a low-light camera with tilt and rotate capability to capture video and transport it across the network. The video was captured at the GCS and sent through the breadcrumb network for distribution. The tilt and rotate feature of the camera helps collect video from different areas and ensures that the vehicle does not need to fly directly over the target. Some mini-UAVs do not have the ability to tilt and rotate their cameras, making it more difficult to obtain usable video and data.

2. Control and Data Links

The UAV has one control link and one data link. The control link provides GPS and avionics data from the aircraft using a 900 MHz radio serial data modem. Control signals from the ground station to the aircraft are also sent over this link. The control link has a range of 12 to 17 miles, limited to LOS. The data link is a 2.4 GHz radio transmitter that transmits analog video to the ground-control station. The antenna at the ground control station determines the range of the data link. The smaller 8-dBi antenna has a range of 2 to 3 miles, also limited to LOS. A more focused directional antenna could potentially increase the range.

The control and data link transceivers are housed in a small, weather resistant box that generates analog video and two RS-232 serial data outputs. The box contains two serial radio modems (control link) for redundancy and one video receiver (data link). The GCS requires power for the laptop and the transceivers. This power can be generated by a battery at the GCS or by connection to 120V AC power. The serial modems use omni-directional antennas. The video receiver uses an 8.5 dBi flat panel antenna.

3. GCS

Figure 17. CyberBUG™ Control Station (From: Cyber Defense Systems Inc.)

The GCS (Figure 17) is composed of a laptop computer, a battery, a joystick, and the data and control link equipment. The computer runs the Windows operating system and the UAV control programs. The data and control link equipment interfaces with the laptop through a video capture device and a RS-232 serial connection to the radio serial data modem. The joystick directs the video camera on the UAV and is also able to control the UAV. The battery powers the laptop and the control and data link equipment. In this experiment the GCS also contained a wireless network card for integration into the mesh network. The wireless network card associated to the Breadcrumb™ network to provide access to the TrakPointC2™ server located at the MCP.

4. GCS software

Figure 18. UAV Ground-control Station Software

The GCS computer runs four programs to operate the UAV. TrakPointC2™, VideoLAN Client (VLC), the UAV control software, and Microsoft NetMeeting are all hosted on the computer.

TrakPointC2™ was used for chat functionality, displaying the location of the UAV on a map and distributing GPS coordinates to other users on the network. VLC, a cross-platform media player, was used to display the video collected from the UAV through the capture device. Microsoft NetMeeting was run to allow users to receive the UAV video.

The ground-control station transmits National Imagery and Mapping Agency (NIMA) GPS data that can map the position of the UAV on a mapping product, such as TrakPointC2™ or FalconView™. TrakPointC2™ collected the GPS information from the laptops com1 serial port and displayed this location on the map. TrakPointC2™ was configured as a client to the TrakPointC2™ server running at the MCP. The chat function was used to coordinate UAV operations over the network.

The UAV control software (Figure 18) allows control of the UAV in either a manual or an autonomous control mode. The control software manipulates the camera in addition to the UAV system. Detailed control inputs include heading, altitude, and camera orientation information. The motor speed and control surface orientation are depicted as well.

The autonomous mode utilizes GPS and waypoints which can be set for the aircraft to follow. There is a return-to-base function that provides for the aircraft to return to the ground-control station with the loss of the control link. There is also a function that flies the aircraft to wherever the camera is pointed. If an object of interest is found, the aircraft can be told to circle over that particular area. In the event the operator wishes to override the autonomous operation, there is a function to allow manual control of the aircraft using either the joystick or buttons in the control software.

VLC is an open-source program that can be obtained from http://www.videolan.org/vlc/. This program is used to display video from the UAV as well as to record the data for later review. This program is also capable of streaming video across a network; however, it was not used to perform this function during the COASTS demonstration. VLC integration TrakPointC2™ was not fully developed in time for the COASTS demonstration. Microsoft NetMeeting was used to stream video as a substitute for VLC.

D. UAVS IN THE COASTS PROGRAM

The mini-UAV in the COASTS program was intended to research general parameters in which COTS mini-UAVS could be used in the field and integrated into a surveillance network. The primary goal of this demonstration was to integrate video from the UAV into the COASTS network. The following goals were set from which to evaluate the UAV.

- Effectively setup computer to digitize data from UAV RF link
- Transmit digitized video feed onto network through 802.11 Breadcrumb™ network
- Effectively view the transmitted data with a high degree of resolution and reliability at the MCP
- Effectively provide GPS coordinates of the UAV and UAV control station to the MCP
- Test and maintain connectivity to the CyberBUG™ UAV
- Explore and capture techniques, tactics and procedures, which can be leveraged in further testing
- Explore range limitations of the RF link

Not all of the goals could be met. The UAV was flown only three times. In each of these flights the UAV was difficult to control for reasons described below which resulted in uncontrolled landings. The third flight left the UAV inoperable after it crashed. The factors involved in these crashes yielded valuable data to leverage in future tests. RF link limitations, connectivity, and certain techniques, tactics and procedures could not be captured due to the UAV mishap. The video was captured and transmitted through the network, but the video was not seen with a high degree of resolution or a fast frame-rate.

The UAV was pushed to its operational limits in Thailand. During these flights the conditions were above the design parameters for the UAV, which resulted in problems with each of the three flights. The high heat and humidity produced a situation in which the altitude (98 feet) of the airfield had a density altitude of 3,700 feet. The effect was as though the aircraft was flying at 3,700 ft higher than the actual altitude. The high winds also created control issues. The aircraft could not be effectively flown into the wind. The high winds, 15 to 20 knots, when combined with the effects of the high temperature and humidity, pushed the aircraft beyond its operational envelope. This is an important limitation that must be corrected for future operations in areas of high heat and humidity.

E. CYBER DEFENSE SYSTEMS INCUAV VIDEO INTEGRATION

The untimely mishap of the UAV meant that the video integration became the most important part of the UAV operations. Analog video was received from the output of the data link. This video was then integrated into the network using a Dazzle™ video capture card from Pinnacle Systems (Figure 19). This video-capture device digitized the analog signal sent by the data link. It works over Universal Serial Bus (USB) and supplies live video digitization from the source.

Figure 19. Dazzle Video-capture Device

VLC received the digitized video from the source and displayed it on the laptop screen while the video feed was recorded. Microsoft NetMeeting used the same video-capture device to obtain the video for distribution over the network.

Figure 20. Microsoft NetMeeting

Microsoft NetMeeting (Figure 20) was configured to distribute video to any user that connected to it. Clients wishing to receive UAV video connected to the UAV laptop using NetMeeting. The UAV laptop was configured to automatically accept any attempts to connect to it through NetMeeting.

The connection through NetMeeting was slow and required considerable bandwidth. Frame-rates of 3 to 5 frames per second were typical during average usage of the COASTS network. Frame-rates dropped below 1 frame per second when multiple users were connected through NetMeeting. Video resolution was low and not clear.

F. SUMMARY

The first iteration of COASTS offered an opportunity to develop relationships with COTS UAV vendors that should prove beneficial in the future. The mishap involving the UAV reduced the number of goals that could be attained; however, the three flights provided good data on the effects of wind and high density altitude on mini-UAVs. The density altitude of 3,700 feet coupled with the high winds forced the UAV to operate outside of its envelope. This is an issue of mini-UAV systems that warrants future research.

The wind limited the direction of flight of the UAV and pushed it off course. The UAV could not be controlled without consideration of the winds. Awkward patterns had to be flown to reduce the effects of wind while trying to survey a target. In some circumstances, the strong wind prevented the UAV from even reaching the target area, as it could not maintain its heading into the wind.

The dissemination of video from the GCS leaves much to be desired. The transmitted video required considerable bandwidth that degraded the other video feeds on the network. Low frame-rates limited the usefulness of the video and made it hard to concentrate on analyzing the feed. Higher frame rates and better quality video are needed to support fast decision-making. Data compression technologies need to be explored to reduce bandwidth requirements and provide high quality video.

This chapter was a direct product of the experiences from this exercise. The next iteration of COASTS will include a greater number of UAVs of varying sizes, technology, and capability.

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V. COASTS CASE STUDY

A. INTRODUCTION

Up to this point, each node was able to perform individually; this scenario was developed to showcase the functionality of the COASTS system as a whole.

In cooperation with the Thai government, the NPS COASTS team developed a scenario to demonstrate the utility of the COASTS network. A number of trial runs were performed on 16 May 2005 in preparation for the 17 May demonstration. The scenario was executed at the Wing Two airfield in Lop Buri, Thailand.

The loss of the mini-UAV left the COASTS program without a UAV capability for demonstration; therefore only intended use of the mini-UAV in this scenario can be presented.

B. SCENARIO

1. General Information

The scenario developed by the COASTS team focused on utilizing the network during a counter-drug operation. In the scenario an intelligence tip was received that warranted the deployment of the Coalition Operating Area Surveillance and Targeting System to support the surveillance and apprehension of drug traffickers. The tip stated the time and location of a drug transfer from a storage facility to a van for transportation and distribution. It also included the make and model of the van being used to pick-up and transfer the drugs and a description of the drug traffickers.

A team of Thai commandos and a member of the NPS staff composed the interdiction team. An NPS student and a contract van driver played the role of the drug traffickers. NPS students and faculty manned the MCP and provided Command and Control of the various sensors and units in the field.

The scenario was run at 1030 local time on 17 May under clear skies. The winds were blowing at 5 knots from the southeast. The temperature was around 90°F with a density altitude of about 3,500 feet.

2. Network Description

The network consisted of cameras, sensors, and wireless data relays, deployed specifically to support the surveillance and apprehension of the drug traffickers. Figure 21 depicts the network set-up and movement of the drug traffickers. The network centered around the MCP which was located in the control tower of the Wing Two airfield.

One function of the MCP was to host the TrakPointC2™ server for local and remote access to real-time Situational Awareness (SA). Remote users connected to the server over the E-1 and T-1 links described in the previous chapter. The Breadcrumbs™ provided the tactical connection to the MCP. The UAV node, the interdiction team, all of the cameras, and the sensor grid were connected to the network through the Breadcrumbs™.

The interdiction team was equipped with a Tacticomp™ PDA device that connected to the network and allowed access to the TrakPoint™ server. The client running on this PDA passed GPS data to the server and acted as a tracking device for the interdiction team.

Multiple radio frequencies were utilized during this demonstration. The UAV used a 900 MHz control link and a 2.4 GHz data link. The Breadcrumbs™ operated at 2.4 GHz. The Redline Communications gear for linking remote users to the MCP operated at 5.4 and 5.8 GHz

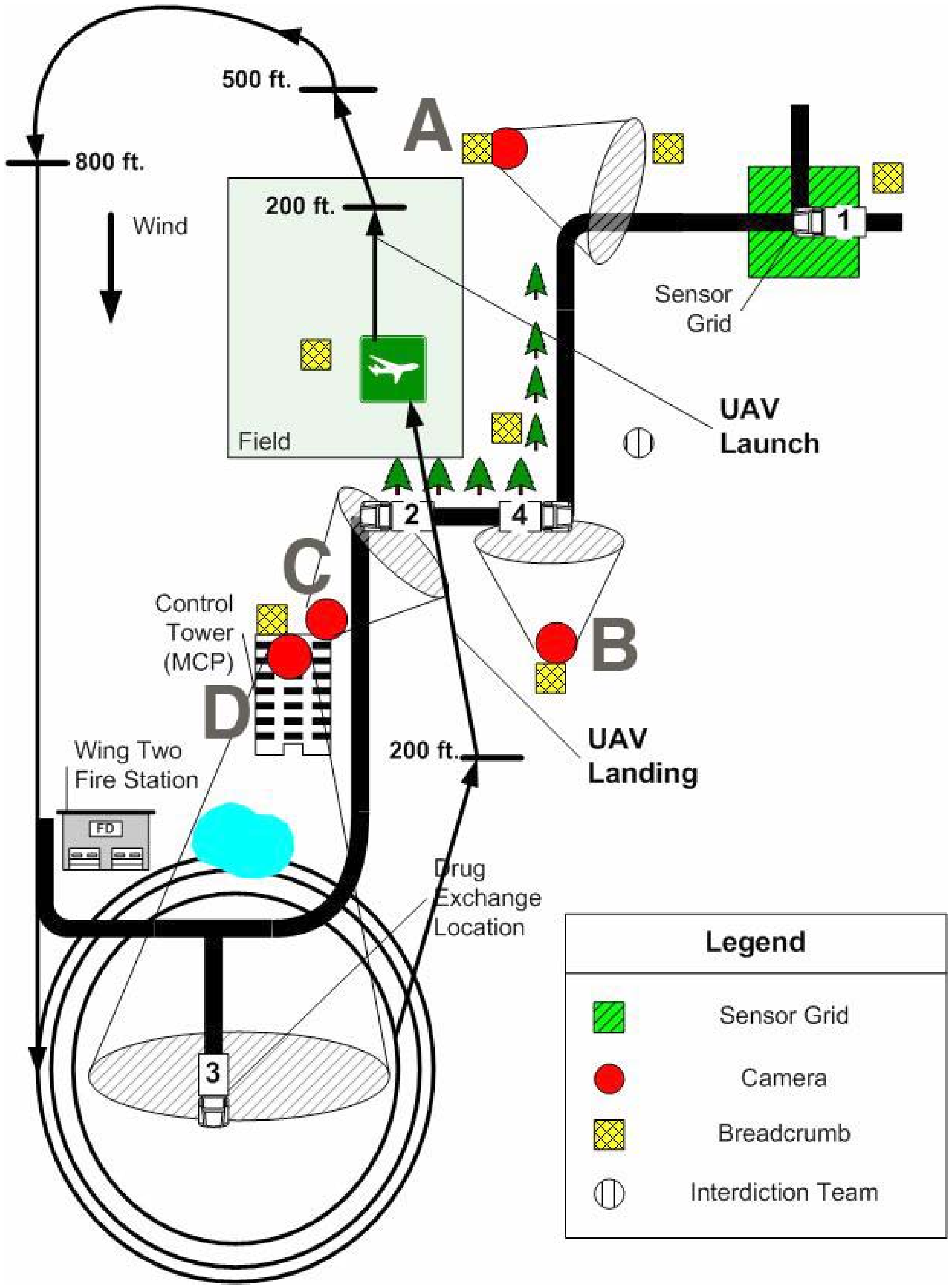

Figure 21. COASTS Scenario

3. Detailed Scenario Description

Figure 21 depicts the movement of the drug traffickers through the scenario. At point 1 the van crosses the sensor grid, which registers through the TrakPointC2™ software. This alerts the surveillance team in the MCP via the TrakPointC2™ interface to the presence of a vehicle. The team then accesses the video feed from camera A to determine the make and model of the vehicle. The surveillance team determines that this is a vehicle of interest and begins tracking the vehicle utilizing camera A and camera B. Once the surveillance team verifies that this is the reported suspect vehicle, it notifies the interdiction team to prepare to arrest the drug traffickers. The interdiction team communicates with the MCP via the chat function of TrakPointC2™. The COASTS network continues to use cameras C and D to track the van to the drug exchange location.

Once the van reaches the drug transfer location (point 3) camera D is used to monitor the drug transfer and confirm the identity of the drug traffickers. The members of the interdiction team access live video of the van and the drug traffickers through the Tacticomp to assist in apprehension. Video of the transfer allows confirmation of the drug transfer and provides justification for the interdiction team to arrest both the suppliers and the drug traffickers.

Once the van leaves point 3 with the drugs the surveillance team at the MCP notifies the interdiction team and instructs them to prepare to apprehend the van. The MCP continues to monitor the van as it travels to point 4. The MCP is able to track the interdiction team using the GPS tracking functionality of TrakPointC2™. Before the van reaches point 4 the MCP notifies the interdiction team to apprehend the van and arrest the suspects using chat.

The MCP monitors the drug traffickers as they travel through the surveillance area. It also provides all of the monitored feeds to remote users. Specific goals were set for the scenario and are described below.

4. Measures of Effectiveness/ Measures of Performance

The COASTS team developed a number of Measures of Effectiveness (MOE) from which to gauge the success of the operation. MOEs are based upon qualitative attributes. Conversely, Measures of Performance (MOP) are based upon meeting quantitative objectives. The "Benchmarks for success in COASTS were not based upon numerical data, they were based upon success or failure of the scenario" (Clement). This first iteration of the COASTS project focused on meeting MOEs and collecting data to facilitate creating MOEs and MOPs for the next iteration. The first iteration of the COASTS project was more concerned with what can be done, rather than how well we can do it. Results from this iteration of the COASTS project will feed future development of MOEs and MOPs.

The MOEs for this scenario were:

- Does the sensor event register in TrakPointC2™?
- Can the video from the cameras be viewed at the MCP via the breadcrumb network?
- Can the cameras be controlled at the MCP via the breadcrumb network?
- Did the video feed facilitate identification of the van (e.g. make, model, color, license plate)?
- Did the video feed provide positive identification of the drug traffickers?
- Was continuous surveillance of the van and drug traffickers maintained?
- Were users able to use chat through TrakPointC2™?
- Was the interdiction team able to be tracked through TrakPointC2™?
- Was the interdiction team able to be tasked through TrakPointC2™?
- Was the interdiction team able to access video on the Tacticomp in order to identify the suspects?

C. RESULTS

1. Measures of Effectiveness

a. Sensor Event

The sensor events were not able to register in TrakPointC2™. This was due to a problem with the integration of the Crossbow sensors into the TrakPointC2™ software and limitations of the sensors employed. The development and integration process took longer than expected and the sensor grid was not directly integrated into the situational awareness software. The sensors purchased provided a limited ability to detect vehicles. A human had to take the place of the sensor grid and report the arrival of the van to the MCP using a cellular phone.

b. Camera Viewing

The operation and viewing of the cameras through the breadcrumb network worked well. The cameras could be controlled from the local area network for the demonstration.

c. ID Van

The video feed facilitated the identification of the van. The cameras provided enough resolution and control to obtain the make, model, color, and license plate of the van. If this had been a scenario involving multiple vehicles it would have been easy to track this vehicle utilizing this information.

d. ID Traffickers

The video feed facilitated positive identification of the drug traffickers. Video of the drug transfer allowed the identification of the drug traffickers through recognition and comparison.

e. Continuous Surveillance

Continuous surveillance of the van was not possible due to obstructions to the camera view. This gap in coverage only lasted approximately 10 seconds. If the UAV had been flying it might have been able to fill this coverage gap.

f. TrackPointC2™ Chat

Users were able to chat using TrakPointC2™. This provided an excellent resource for C2 of deployed units from the MCP to the field. The Tacticomp user in the field had a hard time sending messages to the MCP due to problems with the interface design. The Tacticomp user was required to use a stylus to type in letters one at a time in order to write a message. This limited his ability to respond to queries and introduced delay when the interdiction team needed to make statements or call for support.

g. TrackPointC2™ Tracking

The interdiction team could be tracked through TrakPointC2™. The Tacticomp collected GPS coordinates and forwarded them to the server at the MCP. This allowed all users running TrakPointC2™ to track the interdiction team.

h. TrackPointC2™ Tasking

The interdiction team was effectively tasked through TrakPointC2™. The messages to the interdiction team were clear and full of detail. The interdiction team was tasked to stop and arrest the drug traffickers in the van through the network.

j. Tacticomp Video Access

The interdiction team was not able to access the video utilizing the Tacticomp. While technically feasible, the software to access and play the video was not installed. The Tacticomp required a Java runtime installed on the PDA, however it was not possible to install this software in the field.

2. Observations

The use of the COASTS network provided support to the interdiction team in the field. Utilizing the surveillance functions of the network, the MCP was able to positively identify the vehicle and collect evidence of the drug transfer without alerting the drug traffickers. By starting surveillance early, the MCP was able to positively identify the van and passengers, providing the interdiction team with

SA and advanced notice so that it could concentrate on intercepting and detaining the target. The COASTS network removed the responsibility of identifying the target from the interdiction team.

While not all of the MOEs were met, the interdiction team was still able to utilize the network and the expertise of the people in the MCP to reduce the burden of identification. By distributing the identification phase through the network all members of the interdiction team could focus on stopping and capturing the drug traffickers rather than using team members to identify the drug traffickers. The COASTS network reduced the manpower that needed to be distributed by substituting cameras and equipment for personnel.

3. Limitations

The COASTS network required a long time to deploy. Once units were deployed to their locations the network setup was fast; however, the unknown limitations with the wireless network forced the team to adjust the density of breadcrumbs in the operational area, which cost the team valuable time.

The number of people required to set-up the network also offset the decreased number of people needed during the entire operation. While the COASTS network decreased the required manpower onsite to successfully complete the scenarios, the manpower needed to fix network issues offset this.

The bandwidth available on the reach-back network could not support the large number of users that wanted to access the video feeds. An attempt was made to implement multicasting of the video, but the Breadcrumbs™ did not support this bandwidth saving technology. The number of frames-per-second decreased as more users simultaneously accessed the video feeds. This issue must be dealt with, as it is difficult to use choppy and fuzzy video to make identifications. Bandwidth issues were minimized in the demonstration by limiting the number of people requesting video feeds from cameras.

The sensors need to be improved and fully integrated with TrakPointC2™. The sensors were not able to detect the van as it passed through the sensor grid.

This is a major limitation as the network depends on the sensor grid as a first-alert mechanism to potential activity.

The chat function on the Tacticomps was hard to use and required a great deal of time for the user to enter simple messages. Individual characters had to be entered into the unit with the stylus. In order to report the status of the interdiction unit it was necessary for the NPS faculty member on the interdiction team to be solely focused on operating the Tacticomp.

There was no testing of distributing SA to remote users in this demonstration. While earlier tests showed that it was possible to stream video to remote users in Bangkok, this was not done during the scenario.

The density of cameras was greater than it would be in an actual deployment. In the demonstration the cameras provided nearly full coverage; however, an actual deployment would require cameras, sensors, and nodes to be deployed over a larger area. The same amount of resources deployed over a larger area could reduce the coverage of the vehicle, resulting in windows in which the vehicle was not being tracked.

The cameras in this demonstration were static. The route and intentions of the drug traffickers were known a priori; this allowed the network to be setup easily, but if the tip was incorrect it might result watching the wrong area.

4. Follow-on Suggestions

The COASTS network just completed its first iteration. There are lessons to be captured and taken into consideration for future evolutions. Future demonstrations should focus on MOPs as well as MOEs. Robust data collection procedures will be needed to support MOPs. A detailed Test and Evaluation Master Plan (TEMP) should be developed to support collection and analysis of results.

The COASTS program should focus on creating a more rapidly deployable network that does not need detailed configuration during setup. Future scenarios, based on real-world requirements, must be developed before the operation so that proper equipment can be integrated into the network. The scalability of the COASTS network should be explored in detail. Increasing the number of integrated components in the system will allow judicious selection of components to meet a variety of missions, rather than relying on a limited selection of components that will only fulfill the mission requirements partially.

It is evident from the results of the first iteration that the COASTS network must be able to adapt to the situation. Detailed information on adversary movements is not usually available thus, it is important to be able to adapt to their movements. Stationary cameras have limited a field-of-view due to obstructions, their placement, and the design of the cameras. Mobile units that can rapidly adapt to cover areas out of view of the stationary sensors should be integrated into the network. The mini-UAV was supposed to provide adaptable coverage, however the crash precluded its use in this scenario. The next section presents the intended use of the mini-UAV.

D. UAV USE

The UAV was anticipated to provide continuous surveillance of the van and drug traffickers throughout the scenario. This continuous surveillance could not be provided by stationary units due to obstructions of their views and limitations of the cameras. Specific MOEs were developed for the mini-UAV in the scenario, but it was not possible to test these MOEs because the UAV was not capable of being employed in the demonstration. The mini-UAV MOEs are presented below for general analysis and consideration. The MOEs for the UAV were as follows:

- Could the UAV be tasked through TrakPointC2™?
- Was the UAV able to take-off?
- Was the UAV able to climb and maintain its altitude?

- Was the UAV able to be effectively operated to maintain surveillance of the target vehicle?
- Was the vehicle able to land?

1. Intended Use

Planning and setup of the network indicated that the best location for the UAV was in the field adjacent to the road along which the target would be traveling. The open area of the field permitted the UAV plenty of room for take-off and landing.

The UAV was to be used for continuous surveillance of the van and drug traffickers during the demonstration. When the sensor grid detected the presence of the van (point 1) the UAV was to be launched by a command from the MCP through the TrakPointC2™ chat function.

After launch the UAV was to climb to an altitude of 800 feet while in a downwind turn. The requirement was to track the target as soon as possible while transiting to the drug exchange location (point 3). At the drug exchange location the UAV was to circle the area and relay real-time video through the COASTS network.

After capturing the transfer of the drugs the UAV was to descend and land in the field from which it launched.

2. Observations

Even though the UAV did not fly, the order to take-off was sent through TrakPointC2™ and received at the GCS. Unfortunately several of the MOPs were not met due to the inoperability of the UAV.

Planning was a big factor in employment of the UAV. Launch of the UAV could not be immediately accomplished without a great deal of forethought and planning. Mission planning and the UAV preflight checks had to be completed before the arrival of the target. Factors such as wind direction, location of the unit in relation to obstructions, and the intended time aloft were considered. No other aerial assets were to be employed during the scenario, so coordination was not a large issue. The demonstration took place around an airport and all air operations were coordinated with the control tower. In the even that a plane did stray into the area or attempt to land the UAV was to be immediately crashed into the ground upon notification from the control tower.

Winds were minimal during the demonstration, so control of the UAV would not have been a problem. The high temperature and humidity might have been a problem for the UAV if combined with the wind, but a clear determination of the effects of just the high temperature and humidity cannot be made without more testing.

A map of the area was beneficial to plan the route and use of the UAV, however it was possible to deviate from this plan if the target decided to deviate from the intelligence provided. The stationary units in the demonstration were not able to simultaneously adapt to large changes in location of the drug exchange, however the UAV would have been able to follow and track the van through gaps in coverage of the stationary cameras.

Endurance would have been a large factor during the operation. The low-endurance of the mini-UAV (45 minutes) limited the time aloft. The UAV could not loiter in the area until the target arrived because it might not have had enough battery power to maintain surveillance of the target throughout the operation. The launch of the UAV upon arrival of the van at the sensor grid allowed the UAV to spend all of its available time tracking and monitoring the target.

Landing was another area that could have been a problem for the UAV. During the descent the UAV would have been required to avoid numerous trees around the field. It would have been important to line the UAV up with the field and start the descent at the perfect time to make sure the UAV did not overshoot or undershoot the field.

Maintaining LOS during the entire operation would have been important. If LOS was lost due to the UAV flying behind a building then the control link would have been lost and the UAV might have crashed. LOS would also have been a consideration during the landing phase due to the potential interference of trees surrounding the landing area.

3. Limitations

The limitations of employment of the UAV were not completely captured due to the lack of a flight during the demonstration. The previously mentioned factors would likely have played a role. Environmental factors such as temperature, humidity, and wind would have presented the largest obstacles to employment of the UAV.

E. SUMMARY

Though the UAV did not fly in the demonstration scenario, extrapolations could be made to illustrate the utility of a mobile surveillance platform. The entire COASTS network focuses on the ability of the network to be rapidly deployed to collect intelligence and support operations. This network should not be viewed as a persistent entity. It should be viewed as a temporary system designed to support individual operations.

The use of a UAV in the demonstration could have increased the adaptability of the network by allowing the UAV to follow the van and drug traffickers if they had deviated from their plan for the drug transfer. UAVs also have the potential to provide coverage in situations where intelligence is inaccurate.

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VI. CONCLUSIONS

A. CONCLUSIONS

This thesis has considered the use of mini-UAVs at the tactical operations level. Currently, squad, platoon, and company units of maneuver have difficulty obtaining intelligence from higher-level C4I systems. This problem is compounded when these units are on the move. Systems to connect and interact with intelligence databases do not allow these tactical units the mobility they require to wage war. These mobile interfaces are usually located with battalion-sized units and larger.

This thesis has explored the use of mini-UAVs as an organic asset for intelligence gathering. Instead of requiring connection to C4I systems, these mini-UAV equipped units can determine their own requirements for intelligence collection. The implications of mini-UAVs at the tactical operations level were explored through field experiments and literature review.

Mini-UAVs, despite their small size, must still have a plan for operation. Environmental considerations in the tactical operations area must be considered before employment. The short loiter times limit the ability for one unit to provide persistent surveillance. Mini-UAVs are best employed to accomplish specific objectives such as clearing an area, or searching for a target in a known location. Each mission must be planned in detail to gain the most utility. Mini-UAVs cannot loiter in an area to provide immediate surveillance like high-endurance systems.

The level of technology incorporated into these units is not currently to the point that they can be expected to operate autonomously. Human interface is required during launch and operation of the UAV. Multiple personnel are required to launch the UAV, and these units are not capable of being launched in all conditions. At the tactical level this means that one or more members of the squad, platoon, or company will not be available for direct combat. This creates a deficiency of direct combat power for small units, as some of the members must operate the UAV; however, the information garnered through these mini-UAVs may allow the unit to be employed more efficiently and result in more effective combat power.

While mini-UAVs are capable of many different missions, the most effective missions involve the use of these units as an "eye in the sky." These missions are used to quickly provide a picture of what is "around-the-corner" or "over-the-hill." Missions that require detailed analysis of imagery or data from the payload require specially trained operators experienced with the tactics of employing these units. Typical ground units do not require the need for specialized payloads that would require expert analysis. Tactical units are mostly concerned with obtaining real-time intelligence to support ongoing operations.

The security of mini-UAV systems is an additional concern. The tendency for them to crash is high. While there is little data on the reliability of mini-UAVs, it is generally thought that they fail more often than larger UAV systems. This is due in part to the design of the components in these systems, but also due to the lack of redundant systems. Since COTS components are mainly used, if a UAV is recovered by an enemy it can easily be backwards engineered to allow the enemy to collect data from friendly units and possibly even control the UAV.

The future will require mini-UAVs to be more closely integrated with other intelligence systems. COTS mini-UAV systems are not designed for interoperability with current or planned intelligence systems. Stovepipe development cuts down the costs, but it also inhibits higher-level commanders from accessing the local intelligence data collected by mini-UAVs. The integration of mini-UAVs into intelligence networks will bring the military closer to a concept of persistent intelligence. The distribution of mini-UAVs will provide redundancy and increased detail of tactical operations.

The COASTS program illustrated the utility of providing a tactical integrated intelligence collection system. The ability to view what tactical units are seeing allows commanders to better consider the tactical maneuvers that can have strategic implications. While this is no substitute for ground truth, it increases the accuracy with which strategic commanders can understand the tactical picture.

B. RECOMMENDATIONS

Based upon the work of this thesis there are several recommendations pertaining to mini-UAVs.

The autonomy of mini-UAVs must be increased so that users can task and forget about these units until they report back to the user with the requested information. This autonomy would remove most planning, launch, transit, and recovery considerations from the user. The reduction of human input would allow the user to concentrate on other tasks and utilize the data from the UAV without having to devote personnel to operating the UAV.

UAVs need to be developed that are available for use in adverse weather conditions. UAVs should be developed that can fly in conditions of high heat and humidity combined with moderate wind conditions. These units should use weather to their advantage and should provide a stable platform for any sensor or camera.

Sensors and cameras need to be developed that provide high-resolution images and data. In addition, more advanced payloads should be produced, but these should only be employed by appropriately trained personnel.

The security of systems needs to be increased so that adversaries do not exploit friendly assets. Data and control links should be encrypted to prevent adversaries from obtaining our data. While it might not be possible to destroy mini-UAVs if they crash, it is important to minimize crashes that would place the technology into the hands of an adversary. This will become more important as UAVs become more capable. SIGINT mini-UAV systems will require robust security so that the enemy cannot determine our capabilities or examine what we are collecting.

The DOD should push for interoperable systems that can rapidly integrate into current and future intelligence and data dissemination systems. Users must be able to share information. Integration of mini-UAVs into intelligence systems has the potential to broaden the perspective of higher-level commanders.

C. FOLLOW-ON WORK

Mini-UAVs are developmental. While there are a number of systems available, there is room for future improvements in design and operation of these systems. Follow-on work should consider the limitations and gaps in knowledge presented by this thesis. The following is a list of follow-on work:

- A study of the weather limitations of various systems
- Development of tactics for mini-UAVs
- Collection and analysis of data on mini-UAV reliability and operational availability
- Continued development of protocols and mechanisms to integrate mini-UAV sensor data into intelligence networks
- Development of standard procedures for planning and integrating mini-UAVs into the ATO rapidly when necessary
- A study on the use of mini-UAVs for targeting and battle damage assessment
- Development of standards for when it is permissible to use mini-UAVs without ATO coordination

The author would suggest the development of an NPS sponsored UAV for the COASTS project. This would allow greater control over the internal components and the ability to integrate technologies from other venders without major legal issues.

APPENDIX A

COASTS
Thailand Demo (May 2005)
Concept of Operations

NAVAL
POSTGRADUATE
SCHOOL

MONTEREY, CALIFORNIA

11 Mar 2005

I

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LIST OF ACRONYMS

AUV	Autonomous (Unmanned) Underwater Vehicle
BKK	Bangkok
CAC	Crisis Action Center
COASTS	Coalition Operating Area Surveillance and Targeting System
COTS	Commercial off the Shelf
DRDO	Department of Research and Development Office
FCC	Federal Communications Commission
GPS	Global Positioning System
ISR	Intelligence, Surveillance, and Reconnaissance Mission (ISR)
JUSMAGTHAI	Joint US Military Advisory Group Thailand
KIAS	Knot Indicated Air Speed
MCP	Mobile Command Post
MOSP	Multi-Mission Optronic Stabilized Payload
MOE	Measures of Effectiveness
MOP	Measures of Performance
NOC	Network Operations Center
NOTAMS	Notice to Air Mariners
NMC	Network Management Center
NPS	Naval Postgraduate School
PDAs	Personal Data Assistant
RF	Radio Frequency
RTA	Royal Thai Army
RTAF	Royal Thai Air Force
RTARF	Royal Thai Armed Forces
RTSC	Royal Thai Supreme Command
SATCOM	Satellite Communications
SSA	Shared Situational Awareness
STAN	Surveillance and Targeting Network
TNT FE	Tactical Network Topology Field Experiment
TOC	Tactical Operations Center

UAV	Unmanned Aerial Vehicle
WLAN	Wireless Local Area Network
WOT	War on Terror

1.0 PURPOSE.

This document describes the Concept of Operations (CONOPS) for the development and implementation of a Naval Postgraduate School (NPS) research program entitled Coalition Operating Area Surveillance & Targeting System (COASTS). COASTS support U.S. Pacific Command (USPACOM), Joint U.S. Military Advisor's Group Thailand (JUSMAGTHAI), Naval Postgraduate School, and Thailand Royal Thai Supreme Command (RTSC), Royal Thai Armed Forces (RTARF), and the Thai Department of Research & Development Office (DRDO) science and technology research requirements relating to theater security, host nation security, and the War On Terror (WOT). This CONOPS is primarily intended for use by the Naval Postgraduate School and USPACOM management team and participating contractors and coalition partners. However, it may also be used by other Department of Defense (DoD) organizations when applicable. The research and development of COASTS is described in this document as well as the proposed timetable for a cap-stone demonstration in May 2005 in Thailand.

1.1 BACKGROUND.

The COASTS proposed coalition field experimentation concept is modeled after a very successful ongoing NPS-driven field experimentation program previously known as Surveillance and Targeting Network (STAN) and now called the Tactical Network Topology Field Experiment (TNT FE). NPS, in cooperation with U.S. Special Operations Command (USSOCOM) and several contractors, has been engaged in a Research and Development (R&D) program entitled STAN since FY2002. The program was initiated in support of a USSOCOM requirement for integrating emerging wireless local area network (WLAN) technologies with surveillance and targeting hardware/software systems to augment Special Operations Forces missions. TNT FE has grown significantly since inception to include 10-12 private sector companies demonstrating new hardware/software capabilities, several DoD organizations (led by NPS) introducing operational and tactical surveillance and targeting requirements, as well as other universities contributing solutions.

1.1.1 TNT FE Specifics.

TNT FE occurs quarterly as a 1-2 week long complex experiment comprising 8-10 NPS faculty members, 20-30 NPS students, and representatives from multiple private companies, DoD and US government agencies. Major TNT FE objectives are as follows:

- Provide an opportunity for NPS students and faculty to experiment/evaluate with the latest technologies which have potential near-term application to the warfighter.
- Leverage operational experience of NPS students and faculty
- Provide military, national laboratories, contractors, and civilian universities an opportunity to test and evaluate new technologies in operational environments
- Utilize small, focused field experiments with well-defined measures of performance for both the technologies and the operator using the technologies

- Implement self-forming / self-healing, multi-path, ad-hoc network w/sensor cell, ground, air, SATCOM network components

1.1.2 TNT FE Limitations.

1.1.2.1 Sensitivities with Foreign Observers/Participants.

Certain hardware, software, and tools/tactics/procedures (TTP's) implemented at TNT FE are classified or operationally sensitive, and as a result TNT FE sponsors have not agreed to foreign military partnerships. Despite DOD requirements to operate in coalition environments, to strengthen relationships with foreign military partners, and to execute operations globally, TNT FE remains primarily a US-only event.

1.1.2.2 Meteorological, Hydrographic, & Geographic Considerations.

All TNT FE have been conducted at NPS's facilities in the Monterey California area. This vegetation and climate is not representative of the Pacific Area of Responsibility (AOR)—a likely deployment location for these tactical or operational WLAN and surveillance/targeting technologies. Higher temperatures and humidity, as well as denser vegetation in areas like Thailand and Singapore, will likely create WLAN and sensor performance problems.

1.1.3 COASTS.

1.1.3.1 Purpose.

COASTS will leverage and integrate the technological expertise of NPS's education and research resources with the science and technology (and potential operational requirements) of the RTSC using WLAN technologies to fuse and display information from air and ground sensors to a real-time, tactical, coalition enabled command and control center. The timeline for the planning and execution of this demonstration is provide in greater detail later in this document. An additional benefit of the COASTS project will be to demonstrate USPACOM commitment to foster stronger multi-lateral relations in the area of technology development and coalition warfare with key Pacific AOR allies in the WOT, as the May 2005 demonstration will have observers from Australia, Singapore, Thailand, U.S., and Japan.

1.1.3.2 Strategy.

The Thailand based COASTS demonstration will serve as a mobile field test bed environment for R&D, integration, operational testing, and field validation of several emerging wireless technologies and equipment suites. The demonstration will provide key Thai military leadership an opportunity to observe potential capabilities to support ongoing RTARF missions along the Mynamar border or in peacekeeping missions in Southern Thailand.

1.2 REFERENCES.

- Joint Doctrine for Information Operations, Joint Pub 3-13, 9 October 1998

- Joint Doctrine for Command and Control Warfare (C2W), Joint Pub 3-13, 7 February 1996
- Joint Doctrine for Operations Security, Joint Pub 3-54, 24 January 1997
- Joint Doctrine for Command, Control, Communications, and Computer (C4) Systems Support to Joint Operations, Joint Pub 6-0, 30 May 1995
- CG05 CDC briefs
- CG05 JUSMAG brief
- Brief to RTSC J7
- COASTS Concept of Operations

1.3 SCOPE.

This CONOPS applies to all aspects of the COASTS project specific to the May 2005 Thailand-based demonstration. This document provides all relevant information regarding the planning and execution relative to the above. Additionally, this CONOPS provides a technical and tactical framework for complex system demonstrations used in coalition environments. This CONOPS will cover the use of COASTS as a stand-alone or networked capability focused on security mission profiles that can be enhanced by the employment of COASTS technologies.

2.0 OVERVIEW.

2.1 CURRENT SITUATION.

As reflected by the increasing number of requests to NPS from foreign partners, there is an operational requirement for low-cost, state-of-the-art, real-time threat warning and tactical communication equipment that is rapidly scaleable based on operational considerations. Unlike TNT FE technologies, most current tactical systems lack the capability to rapidly enable a common operating picture amongst air, surface, and sub-surface entities via a self-forming, self-authenticating, autonomous network. Although commercial-off-the-shelf (COTS) technologies exist that can satisfy some of these requirements, they typically do not meet all of the DoD and coalition partner requirements associated with WOT and other security missions. The objective of COASTS is to demonstrate that NPS and coalition R&D, in concert with COTS capabilities currently available, can satisfy all technical and tactical requirements.

2.2 SYSTEM SUMMARY.

COASTS is an individual and small unit network-capable communication and threat warning system using an open, plug-and-play architecture, which is user-configurable, employing air balloons, UAVs, and portable and fixed ground-based sensors, i.e. soldiers equipped with Tacticomp or similar PDAs, all communicating via wireless network technology.

2.3 CAPABILITIES.

COASTS provides a mobile field test bed environment for U.S. and Thailand in support of R&D, integration, operational testing, and field validation of several emerging wireless technologies and equipment suites as follows:

- 802.11b
- 802.16 Orthogonal Frequency Division Multiplexing (OFDM)
- Satellite Communications (SATCOM)
- Situational Awareness Overlay Software
- Wearable Computing Devices
- Air and Ground Sensors
- Mobile Command and Control Platforms
- Persistent Surveillance
- Shared Situational Awareness
- Hastily Formed Networks
- Ultra Wideband Technologies
- GPS Tracking Technologies
- GPS Denied Tracking Devices
- Unmanned Aerial Vehicles (Micro, Mini, and other)

2.4 MAJOR COMPONENTS.

While the final configuration of the COASTS system may evolve further, the following core components represent the major system components:

- Supplied by Thailand:
  - RTA Searcher MK 1 Unmanned Aerial Vehicles (UAV's)
  - Au-23 fixed wing aircraft (manned)
  - RTSC Network Management Center (NMC)
  - RTSC Crisis Action Center (CAC)
  - Mobile Command Platform (MCP)
  - Facilities at Lob Buri Range
  - Satellite link between MCP and NMC
  - E1 (2.04 Mbps) point-to-point link between downtown Lob Buri communication facility and RTAF HQ.
  - T1 (1.44 Mbps) point-to-point link between Wing 2 and RTAF HQ.

Figure 1. Thai Mobile Command Platform

- Supplied by NPS:
  - Shared Situational awareness common operating picture (SA COP) systems
  - Tethered balloon and associated hardware
  - Wearable Computing Devices (INTER-4 Tacticomp)
  - Airborne camera system for balloon and/or UAV

- Numerous laptops for use in the NMC
- 802.11b network devices
- 802.16 OFDM network devices
- Unmanned Aerial Vehicles
- Sensor Network Grid (Crossbow)

Figure 2. Tethered Balloon

Figure 3. INTER-4 Tacticomp Handheld GPS Enabled Networked Situational Awareness Tools

2.5 CONFIGURATIONS.

The May 2005 COASTS demonstration will have three basic configurations: (1) as a command, control, collection, and communication suite; (2) a threat warning system; and (3) as an intelligence collection system.

3.0 CONCEPT OF OPERATIONS.

3.1 USERS.

The users of COASTS will focus on creating an international interaction mechanism for U.S. military forces, to include NPS, to collaborate with Thailand research & development organizations and military forces to support War on Terror (WOT) objectives and internal/external Thai security requirements.

The primary users during the May 2005 demonstration will be the military and civilian NPS students and faculty, JUSMAGTHAI personnel, and various members of the RTARF. Secondary users will be members of the Singapore Armed Forces (SAF), Japanese Self Defense Force (JSDF), Philippine Army, and Australian Army. Tertiary users will be the various vendors providing equipment and technical expertise to include Cisco Systems Inc., Rajant, Redline Communications, CyberDefense Systems, Remote Reality, INTER-4, and Mercury Data Systems. Specific vendor contributions shall be discussed in the Appendix section of this document. The NPS, RTARF, and vendor team will integrate COASTS into a system to facilitate surveillance and monitoring of simulated "areas of interest".

3.2 COASTS SUPPORT FOR PRINCIPAL MISSION AREAS.

As per Joint Doctrine, COASTS will directly support organizing training, and equipping U.S. military forces and the RTARF in seven principal mission areas:

Direct Action (DA): The primary function of COASTS during DA missions is to provide Force Protection. DA missions are typically short-duration, offensive, high-tempo operations that require real-time threat information presented with little or no operator interface. COASTS will augment other capabilities in direct support of the DA from an overwatch position. COASTS in support of the DA will target collection to support threat warnings relevant to that specific operation and provide automated reporting to the Tactical Operations Center (TOC) for potential threats relevant to a specific mission. COASTS may also be used as the primary source of threat information in the absence of other capabilities. Threat information presented by COASTS is intended to be relevant, real-time or near real-time, and within its area of operation.

Tactical Reconnaissance (TR): The primary purpose of a TR mission is to collect information. COASTS will augment other capabilities to obtain or verify information concerning the capabilities, intentions, locations, and activities of an actual or potential enemy. COASTS will support the full range of information and communication functions. COASTS will support operators to collect, process, analyze, and disseminate information rapidly. COASTS performance in this mission will be affected by meteorological, hydrographic, or geographic considerations; in these scenarios, COASTS will primarily support Force Protection.

Foreign Internal Defense (FID): COASTS will assist Host Nation (HN) military and paramilitary forces with the goal to enable these forces to maintain the HN's internal stability.

Combating Terrorism (CT): COASTS will support CBT activities to include anti-terrorism (defensive measures taken to reduce vulnerability to terrorist acts) and counterterrorism (offensive measures taken to prevent, deter, and respond to terrorism), taken to oppose terrorism throughout the entire threat spectrum.

Civil Affairs (CA): COASTS will assist CA activities in peacetime to preclude grievances from flaring into war and during hostilities to help ensure that civilians do not interfere with operations and that they are protected and cared for if in a combat zone.

Counter-proliferation of Weapons of Mass Destruction (WMD): COASTS will assist traditional capabilities to seize, destroy, render safe, capture, or recover WMD. COASTS can provide information to assist U.S. Military Forces and coalition partners to operate against threats posed by WMD and their delivery systems.

Information Operations (IO): COASTS can augment actions taken to affect adversary information and information systems while defending one's own information and information systems. IO applies across all phases of an operation and the spectrum of military operations.

3.2.1 Thailand Requirements.

3.2.1.1 Thailand Requirement Overview.

Thailand has a 2400 kilometer border with Myanmar that requires its military assets to patrol, as well as to provide surveillance, monitoring and targeting to combat drug and human slave operators from entering the country via Myanmar. This illicit drug trafficking/human slave problem is significant for both Thailand and the U.S. as these activities may potentially support financing and operations of international terrorist organizations.

In addition, some of the illegal drugs that successfully avoid Thailand's security infrastructure are ultimately taken to the U.S. via container shipping through the Straits of Malacca and Singapore Straits. The Royal Thai Air Force (RTAF) has been assigned the responsibility of patrolling the Thailand/Myanmar border areas by the RTARF

Likewise, the recent difficulties in the southern regions of Thailand pose potential serious security concerns. In an attempt to de-escalate tensions RTARF assets, most specifically the Royal Thai Army 4th Army, have been deployed to the region. Continued difficulty, or an escalation in unrest, might lead to instability in the region as well as to impact stability postures of other areas of interest within the Pacific Theater.

Finally, Thailand has been engaged in efforts, primarily in the Gulf of Thailand and surrounding territorial waters, to mitigate small boat activity involved in the illegal distribution of weapons and ammunition.

3.2.1.2 COASTS Support to Thai Requirements.

The RTARF has previously approached NPS for collaboration using UAVs and related surveillance/targeting technologies to augment their land and maritime border patrolling resources. The RTARF has been considering using UAV's and sensor meshes to patrol their northern and southern borders and is aware of NPS's TNT FE program. COASTS appears to be suitable as a technology collaboration vehicle, but also as a demonstration and field test environment with Thailand to develop the capability for real-world information gathering and dissemination on their illegal drug and human slave trafficking problems. This was further confirmed during conversations at the exercise COBRA GOLD 2005 Concept Development Conference during 04 Oct 2004 – 08 OCT 04.

3.3 COASTS IMPLEMENTATION AND OBJECTIVES.

3.3.1 Phased Approach.

The overall COASTS program uses a phased spiral development to implement the Thailand-based demonstration.

Phase I: This initial phase will consist of Thai (and Singapore) observation of the next TNT FE, occurring on 15-20 November 2004 at NPS and Camp Roberts, California. RTARF participation shall include approximately 7 members representing the RTAF and RTSC organizations. The primary focus of their visit will be to observe an UAV and air/ground sensor system connected via a wireless network similar to the topology of the COASTS network. The secondary focus of their visit will be to exchange operational and technical details and information to support detailed planning of the COASTS Thailand-based demonstration.

Phase II: This second phase will culminate with the complete COASTS system deployment from NPS to Thailand, and subsequent set-up and testing, occurring 19-31 March 2005. The primary focus of this phase will be to identify and mitigate any shortfalls relating to administration, deployment, and operation of the COASTS network. Upon completion of successful testing and operation the COASTS network will be disassembled and stored at Wing 6 near Lop Buri, Thailand.

Phase III: This third and final phase will consist of the actual operational demonstration, occurring 9-20 May 2005. Since the timing of the COASTS demonstration is parallel with the exercise COBRA GOLD 2005 Command Post Exercise (CPX), senior RTARF leadership will be available to receive the COASTS executive summary and actual system demonstration. Both of these events is scheduled to occur at the RTSC Crisis Action Center.

3.3.2 Phase I - Work Up.

Phase I consists of multiple events leading up to the May 2005 demonstration, the first major transnational demonstration of the COASTS project.

Milestones Completed:

- Participated at the exercise COBRA GOLD 2005 (CG05) Concept Development Conference (04-08 OCT 04). Informational COASTS briefings provided to U.S. and RTARF leadership, specifically the USPACOM Science Advisor, USPACOM J7 leadership, JUSMAGTHAI, and the RTSC J7 (MG Nopparat) and his staff.

- Conducted a Thailand site survey on 27-29 OCT 04 of RTARF assets to include Chandy Air Field, RTSC Crisis Action Center and Network Management Center, and the RTSC Mobile Command Platform with JUSMAGTHAI and RTARF personnel present.
- Participated at the exercise CG05 Planning Conference I (01 - 06 NOV 04). Informational COASTS briefings provided to U.S. and RTARF leadership, specifically the RTSC J3 (LTG Kemerat) and his staff.
- Conducted COASTS Planning Conference II (4-11 JAN 05) in Thailand. Refined this CONOPS and finalized the overall concept and design for demonstrations that support USPACOM, RTARF, and NPS. Key personnel were identified and final planning conducted. Planning estimates for future demonstrations began.
- Conducted operational rehearsal of COASTS network topology at Fort Ord in Monterey, California (1-3 FEB 05) with NPS personnel.
- Conducted detailed COASTS planning in Thailand (5-21 FEB 05) to develop detailed Warning Order (WARNORD) and initial Operations Order (OPORD). Lessons learned from February rehearsal were incorporated into the planning.
- OPORD 02-05 Thailand Rehearsal published 28 FEB 05.

Major Issues Remaining:

- Administrative coordination with CG05 Combined Forces Air Component Commander (CFACC) and RTAF personnel to de-conflict Wing 2 Range airspace for UAV and balloon operations.
- Administrative coordination with RTAF personnel to de-conflict the frequency spectrum in the 2.4 and 5.8 GHz frequency range at Wing 2 Range.

3.3.3 Phase II – Movement to Site

Phase II continues the planning and preparation for the May 2005 demonstration to include movement of personnel and equipment to on-site Thailand locations designated for the demonstration. Further, on site testing will be accomplished during Phase II prior to beginning the Phase III demonstration.

3.3.4 Phase III – May 2005 Demonstration.

The actual COASTS project demonstration will attempt to prove a low-cost, state of the art, rapidly deployable, scalable tactical system to monitor a land/sea border region using air and ground sensors connected via wireless network technologies. Since this will be the first iteration of the COASTS project, the management team specifically opted to keep the scope of the demonstration small and tightly focused. There are four main areas associated with the demonstration.

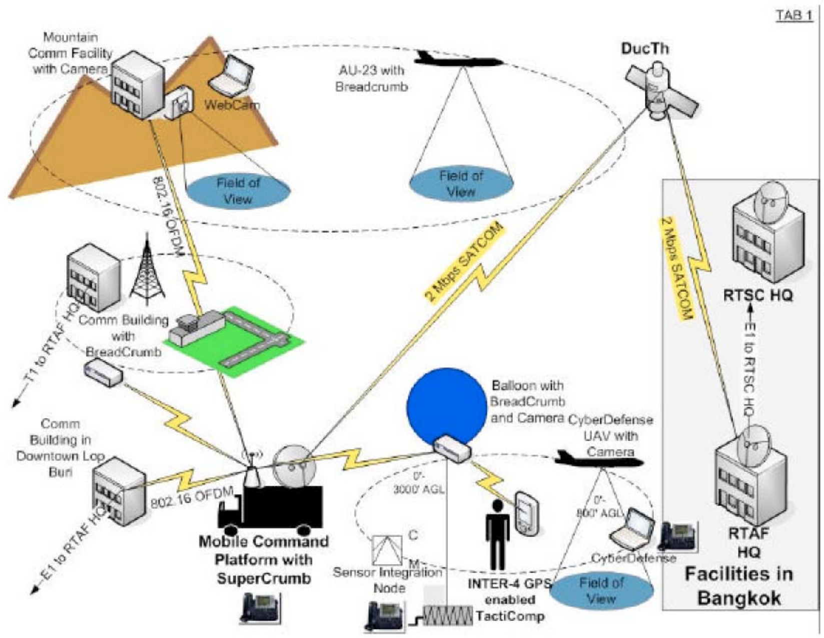

Figure 4. COASTS Demonstration Configuration

3.3.4.1 802.11 (2.4 GHz) End-user Tactical Network.

This local area network will comprise of an 802.11 footprint established via Breadcrumb wireless devices. Access points will be located in various ground positions (MCP, Communications Building, Foot Mobile) and on various air platforms (tethered balloon, AU-23). This network facilitates the situational agents end nodes and will connect to a local Mobile Command Post (RTA supplied 10-ton truck equipped with a variety of communication equipment) which will be co-located with air assets at the Wing 2 Range.

3.3.4.2 802.16 (5.8 GHz) Backbone.

A single, yet highly scalable, 802.16 OFDM link will be established between the Mobile Command Platform (MCP) and a communications facility located in downtown Lop Buri as well as a distant mountain top communications facility. The purpose of these connections is to (1) demonstrate the broadband, non-line-of-site, long range capable of 802.16 and (2) establish a primary communications link between the end-user tactical network and, via a point-to-point E1 line (2.04 Mbps) between Wing 2, and RTSC, provide real-time, information display for Command and Control (C2) purposes.

3.3.4.3 Satcom link.

A satellite communication link provided by Swe Dish between the MCP and RTAF HQ shall be utilized to provide for an entirely wireless, large coverage area network, as well as a secondary communications link for the real-time information display to RTAF (and the RTSC). This secondary communications link is expected to have a bandwidth of 2 Megabits per second (MBps).

3.3.4.4 Wearable Computing.

NPS and RTARF personnel shall be equipped with wearable networked computing devices manufactured and supplied by INTER-4. These devices will serve as nodes on the network and personnel will deploy to the jungle areas at Wing 2 Range to ascertain vegetation effects on signal performance.

3.3.4.5 Cyber Defense UAV.

Cyber Defense will supply two variants of a small, lightweight UAV and associated Command and Control platform to support the COASTS project. The UAV will operate at Wing 2 Range (orbiting in the vicinity of the balloon) and will be equipped with a camera and an 802.11 network connection. The UAV will provide a live video feed to the UAV ground station which will then be ported to the COASTS network.

3.3.4.6 Thai AU-23.

The RTAF will supply an Au-23 fixed wing aircraft and pilot to support the COASTS project. The Au-23 will operate at Wing 2 Range (orbiting in the vicinity of the balloon) and will be equipped with different payloads consisting of various video and wireless networking. The Au-23 will provide an opportunity to test the different payloads under different conditions and altitudes and also to serve as a back-up aerial node in the COASTS network topology.

3.3.4.7 Shared Situational Awareness (SSA) Agents.

These are the nodes and software associated with unmanned sensors such as seismic monitors, sound sensors, and streaming ground or balloon originating video feeds some with GPS enabled systems. The SA Agent will be displayed onboard the MCP, the RTAF, and the RTSC Crisis Action Center (CAC).

3.3.4.8 Tactical Operations Center / Network Operations Center (NOC)

The Tactical Operations Center (TOC) and Network Operations Center (NOC) collect and display the data feeds from the various nodes across the network. This is the center of the Command and Control capabilities of the COASTS program and where the deployed technology fuses and the force multiplying effects of the technology is leveraged. The MCP shall function as a TOC. In addition, the RTAF Air Operations Center and the Air Force Operations Center (both of which are co-located at RTAF HQ in Bangkok) will function as a NOC.

3.3.5 Future Items and Other Capabilities

3.3.5.1 Network Defense. A survey of the network from a defensive point of view using open source, and COTS products may be conducted on a not-to-interfere basis.

3.3.5.2 Modeling and Simulation. Using modeling and simulation techniques, results from the demonstration may be compared to predicted results in order to enhance our modeling capabilities and reducing the need to establish a network for testing.

An additional set of relatively simple tests, modeled after an experiment proposed for the NPS TNT Field Experiment 05-1, could be conducted as "littorals operations" setting up a point-to-point 802.16 access point enabled WLAN on the coast in Thailand with a ship positioned to access the network. A Test Plan could be developed with the ship moving further and further away from the access point while collecting network performance data (throughput measuring performance with different types of data such as voice, video, data – all at varying distances). This experiment could also focus on meteorological information as it effects network performance (throughput and sensor performance), as the much higher levels of moisture in the Gulf of Thailand will significantly impact performance of networks and sensors.

3.3.5.3 Micro/Mini UAVs. Both the RTA and U.S. military forces are interested in tactical application of UAVs, specifically with respect to the implementation and operationalizing of micro and mini-UAVs. These extremely small form factor UAVs, using swarming technologies or other process, can augment and/or potentially replace the larger, point target of larger, traditional UAVs.

3.3.5.4 High-Altitude Balloons. Again, both the RTA and U.S. military forces are pursuing the application of high-altitude, steerable, non-tethered airships. The Thai Department of Research and Development Office (DRDO) has already begun experimentation in this technology area and is seeking to partner with NPS to provide better, more capable, solutions.

3.3.5.5 Maritime Missions. The Thai DRDO has previously conducted ship-to-shore wireless network experiments in the Gulf of Thailand and is seeking to link information collected from seaborne sensors with a surface search radar system deployed to the Royal Thai Navy Base at Sattihip. Ultimately this information will be fused and passed to the newly created Maritime Operations Facility for Intelligence Collection (MOFIC).

In 2006, COASTS operation will be conducted in Sattahip area, RTN will be the host for this area. COASTS will be conducted both ground and maritime, to simulate as the southern Thailand. RTN will support the U-taphao airfield for AU-23A, and UAV searcher, also the transportation within the area. In the case that COASTS will operate in the sea, RTN will provide the ships upon the requested.

3.3.6 COASTS Critical Event Schedule.

The table below depicts a high level of schedule of critical events projected for the COASTS project. Included are the critical development and demonstration milestones.

The following table is a summary of the work-up dates and events.

Date:	Event:
26 October	JUSMAGTHAI Brief (Thailand)
27-28 October	Initial Site Survey (Thailand)
28 October	RTSC J3 Brief (Thailand)
01-04 November	COASTS Initial Planning Session (Thailand)
01-02 November	Sing visit to NPS
15-20 November	TNT FE 05-1 (Thai and Sing observers)
4-11 January	COASTS Mid-Planning Session (Thailand)
21-28 February	TNT FE 05-2/COASTS (Thai & Sing observers)
5-21 February	COASTS Final Planning Session (Thailand)
19-31 March	Set-up/test of COASTS (Thailand)
9-20 May	COASTS demo (Thailand)
TBD June	COASTS After Action Review (Thailand)

Figure 5. Critical Events Schedule.

3.4 CRITICAL OPERATIONAL ISSUES (COIS),

- The COASTS project demonstration in Thailand has three primary overarching COIs:
  - Does COASTS provide threat warning information as part of a wireless LAN/WAN?
  - Does COASTS meet performance requirements when deployed to Thailand (ground/jungle scenario)?
  - Does COASTS provide a research opportunity for NPS and Thai R&D assets?

The COASTS Oversight Group will refine and finalize the supporting MOEs and MOPs, linked to specific operational tasks, Standards and conditions, based on the evolving CONOPS for each specific demonstration. The assessment strategy and the final assessment criteria will be clearly delineated in the appendix of the final demonstration CONOPS.

3.5 MEASURES OF EFFECTIVENESS (MOE) AND MEASURES OF PERFORMANCE (MOP).

The MOEs and MOPs for the COASTs demonstration in Thailand are as follows:

- Establish plan of action that may act as a guideline for future refinements and develop a dialogue for further participation.

  Specifically,
  - Establish Points of Contact within the Thai military and Research & Development community.
  - Establish effective communication flow with Thai counterparts in regards to:
    - Administration infrastructure (procedures)
    - Training
    - Planning
    - Logistics
    - Establish operationally feasible plan of action for the May 2005 demonstration.
    - Aerial Access Point:
    - UAV
    - balloon
    - NOC/TOC

This Concept of Operation will act as a framework to add on specific experimental MOEs, MOPs, and other details in the appendix.

4.0 MANAGEMENT STRATEGY.

4.1 PARTICIPATING ORGANIZATIONS, ROLES, AND RESPONSIBILITIES.

4.1.1 COASTS Oversight Group.

- Chair: NPS Dean of Research
- Members: NPS Principal Investigators (PIs) consisting of the Thailand and Singapore PIs, NPS Operational Manager, and NPS Technical Manager

4.1.2 NPS Principal Investigator (PI).

Lead element of the COASTS project; responsible for project oversight, coordination between NPS, DOD, foreign partners, and commercial vendors; responsible for all fiduciary reports and contractual agreements.

- PI Thailand: Mr. James Ehlert
- PI Singapore: Mr. Brian Steckler

4.1.3 NPS Operational Manager (OM).

The OM is responsible for developing all demonstrations, plans, collection and dissemination of data, site surveys, Measures of Effectiveness (MOE), Measures of Performance (MOP), NPS resource allocation, internal NPS coordination, and support to the PI.

The OM plans, coordinates and directs all user activities related to the COASTS project. The OM will develop and provide the CONOPS, TTPs, operational mission scenarios, and the overall utility assessment. Additionally, the OM will coordinate administrative tasks for user participants, equipment and facilities supporting demonstration events.

- OM: Captain David Cooper, USMC

4.1.4 NPS Technical Manager (TM).

The TM is responsible for technical management including program management, engineering, and acquisition of technologies to integrate and demonstrate. The TM will provide technical support to the OM and manage all funding and technology development efforts related to the COASTS project. The TM has the overall responsibility for establishing criteria for technical performance evaluations.

- TM: Mr. Brian Steckler

4.1.5 The table outlines team functionality for the COASTS project.

COASTS TEAM LEADER						
Mr. Jim Ehlert COASTS Technical Manager	Program Manager					
Mr. Brian Steckler	Technical Manager					
COASTS FACULTY						
Mr. Mike Clement	Software Integration	MCP		MCP		
COASTS Students						
Capt. David Cooper	802.11	VOIP / Gunscope	Base Order, Annex A, D, H, Node Input	MCP, RTSC	Rajant	
Capt. Gary Thomason	802.11	VOIP	SSO, Orders, Hotel/Air Resv., Annex W	MCP, AU-23		Y
Capt. Francisco Caceres	802.16	Handheld	Annex K, Node Input	Mtn Node, PDA	Redline / Tacticomp	Y
LT Robert Hochstedler	802.16	Handheld	ORM Matrix, Node Input	Comm Facil Downtown		Y
LT Scott Cone	Sensors		Annex B, FP Plan, Node Input	Comm Fac. Lop Buri	Crossbow	Y
Capt Al Valentine	Liaison, Balloon	UAV / HNS Linguist	Language, HNS, Thai Liaison, Node Input	RTAF UAV		Y
LT Chris Lee	Balloon		Balloon Node Input	Balloon		Y
ENS Collier Crouch	UAV		Embarkation Plan, CD UAV Input	CD UAV	Cyber Defense	Y
Cpt. Chayutra Pailom	Software Integration					
Flt.Lt. Sunyaruk Prasert	Liaison					
Capt. Dwain Lancaster				Rear		Y
ENS Kevin Barrett			Purchase Orders	Rear	Mercury	
COASTS Vendor Support						
Rajant - Mr. Barry McElroy - Mr. Jim Washington	802.11					
Red Line - Mr. Andy Eu	802.16					
Inter-4 - N/A	PDA					
Cyber Defense - N/A	UAV					
Mercury Data Systems - Mr. Clayton Kane - Mr. Stefan Gefotz - Mr. Ryan Hale - Rich Guarino	Software Integration					

Crossbow - N/A	Sensor					

4.1.6 Participating Test Organizations.

The primary organization for assessment for the COASTS demonstration in Thailand is the Naval Postgraduate School. Other participating organizations are as follows:

U.S. Pacific Command (USPACOM)
Royal Thai Armed Forces (RTARF)
Thai Department of Research & Development Office (DRDO)
Royal Thai Supreme Command (RTSC)

4.2 RISK ASSESSMENT, MANAGEMENT AND MITIGATION.

Overall risk is estimated to be low to medium for the COASTS May 2005 Thailand demonstration. Risks can be mitigated by either reducing or adding additional experiments as appropriate. Table 2 depicts the NPS developed risk matrix:

Risk Area	Rating	Mitigation Approaches
Technology	Low Medium	- leverage TNT FE technology - early/continuous coordination with partners - early prototyping - multiple data collection events - modeling and simulation - in-process reviews
Schedule - Technical	Low Medium	- schedule estimates based on technology provider agreements - schedule estimates incorporate TNT FE lessons learned
Schedule - Demos	Low Medium	- incremental demonstrations - identify/leverage existing events
Assessment	Low	- Individual researchers develop MOEs and MOPs for their components of the demonstration.
Funding	Low	- significant funding confirmed, additional sponsors contacted

Figure 6. Risk Matrix

4.3 DEVELOPMENT STRATEGY.

The appendices of this document will provide specific guidance on each particular area, element, and component under study during the demonstration.

5.0 TRAINING, LOGISTIC AND SAFETY.

5.1 TRAINING.

A primary goal of the COASTS project in Thailand is to execute operational demonstrations in conjunction with U.S. and coalition warfighters. Accordingly, appropriate training materials will be developed for each demonstration and operator training will be conducted prior to each demonstration. Training will be performed by a combination of contractor and government personnel. There are also significant hands-on educational opportunities for NPS students, and it is expected that multiple NPS masters theses will be generated by participating US and foreign NPS students.

5.2 LOGISTICS.

Maintenance and logistics support will be conducted using a combination of contractor support and in-house NPS expertise and facilities. This includes the development and distribution of maintenance, training, and operating manuals, instructions, or materials. During the demonstrations, reliability, availability, and maintainability information will be collected for later analysis and review.

5.2.1 COASTS Set-Up and Demo.

The RTAF will conduct daily logistical movements via air/ground means between Bangkok and the Wing 2 Range for the NPS team during the March and May 2005 set-up and demonstration time periods. Transportation will primarily be on RTAF supplied C-130 and UH-1 aircraft or buses. The departure and return schedule are currently undetermined but will be based on operational and administrative requirements during each set-up or demonstration time period. An Air Tasking Order will be co-managed by the RTAF and NPS Air Marshalls for all aviation lift and operational requirements. The Host Nation Support Liaison will be responsible for managing all ground transportation requirements.

5.2.2 COASTS Equipment Shipping and Storage.

The NPS will provide JUSMAGTHAI with a list of equipment to be shipped in support of the March set-up and the May demonstration. RTSC J7 and the US Embassy will help facilitate the arrival of the equipment in Thailand and getting the equipment through Thailand Customs without delay.

The equipment will be stored at Wing 2 Range in, as of yet, an unidentified RTAF facility. The minimum requirements for this facility will be controlled access (lock and key) to prevent the loss of equipment and air-conditioning to preserve the material condition of electronic devices.

5.3 SAFETY.

There could be safety or potential environmental hazards associated with technologies being considered. As needed a safety analysis will be performed to identify potential safety hazards and risks and determine appropriate controls to preclude mishaps and reduce risks. The OM will coordinate all safety efforts associated with demonstrations.

6.0 MODIFICATIONS.

This CONOP is intended to be a living document. It will be updated as required to reflect changes to the COASTS project as it pertains to the Thailand demonstration. Most modifications will be at the discretion of the COASTS Oversight Group who will approve any substantive alterations to include changes in objectives, funding, schedule, and scope. Any changes, which materially affect commitments made by Thailand, will be approved by the affected organizations.

For major events, separate Warning Orders (WARNORD) and Operations Orders (OPORD) will be published. Interested parties should refer to these documents for the most up to date and detailed information relating to a specific event.

7.0 POINTS OF CONTACT

7.1 NAVAL POSTGRADUATE SCHOOL

Mr. Brian Steckler, Information Sciences Department Faculty

Phone: (831) 656-3837

Email: steckler@nps.edu

Mr. James Ehlert, NPS Cryptologic Research Chair

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Email: jfehlert@nps.edu

Captain David Cooper, Information Sciences Department Student

Phone: (831) 663-1536

Email: decooper@nps.edu

Captain Gary Thomason, Information Sciences Department Student

Phone: (831) 917-2892

Email: gthomaso@nps.edu

Mr. Mike Clement, Information Sciences Department Research Associate

Phone: (831) 656-7803

Email: mrclemen@nps.edu

7.2 JUSMAGTHAI

Major Marc Anderson, Asst. Chief of Policy and Plans

Phone: 011-661-636-1663

Email: manderson@san.osd.mil

7.3 US PACIFIC COMMAND

Mr. Chris Vogt, Science Advisor (J006)

Phone: (808) 477-0812

Email: chris.vogt@pacom.mil

7.4 ROYAL THAI ARMED FORCES

Major General Noporat Yodvimol, RTARF J7

Phone: 011-669-969-4747

Email: yodvimol@hotmail.com

Wing Commander Thanan Prateeptong, combat R&D, Directorate of Operations, RTAF HQ

Phone: 011-662-534-2219

Email: tprateeptong@yahoo.com

Wing Commander Ayuth (Air Marshall)

RTAF HQ

Phone: 011-661-653-0565

Email: a_yuth@yahoo.com

Flight Lieutenant Surapong Srivanich, Combat R&D, Directorate of Operations, RTAF HQ

Phone: 011-662-534-1446

Email: s_srivanich@hotmail.com

Flight Lieutenant Ruth, Communications Officer

RTAF HQ

Phone: 011-66-9-199-1254

Email: ruj42@hotmail.com

APPENDIX A. NETWORK TOPOLOGY

A. GUIDING PRINCIPLES

1. The development and integration of a new system requires all participants to capture and document system variables during testing in order to allow test to be repeated and return same results. To that end participants must capture variables such as equipment used during testing, software load, applications installed, and system configurations.

2. To allow for a rigorous analysis of test results participants must develop step by step scheme of maneuver (SOM) which outlines all the elements to be executed during network operations. This SOM should list Step to be executed, expected test result, comment and whether the step met expectations or not (i.e. Pass/Fail).

3. To best execute an exercise of this scope a controlled methodical installation and testing plan will be choreographed from the Mobile Command Post (MCP). See Appendix 2 (Test Execution Matrix).

4. Radio is the primary means of communications; cellular phone will be utilized when radio connectivity via the Rino 110 by Garmin can not be established. Mylar balloons may be utilized as visual signals.

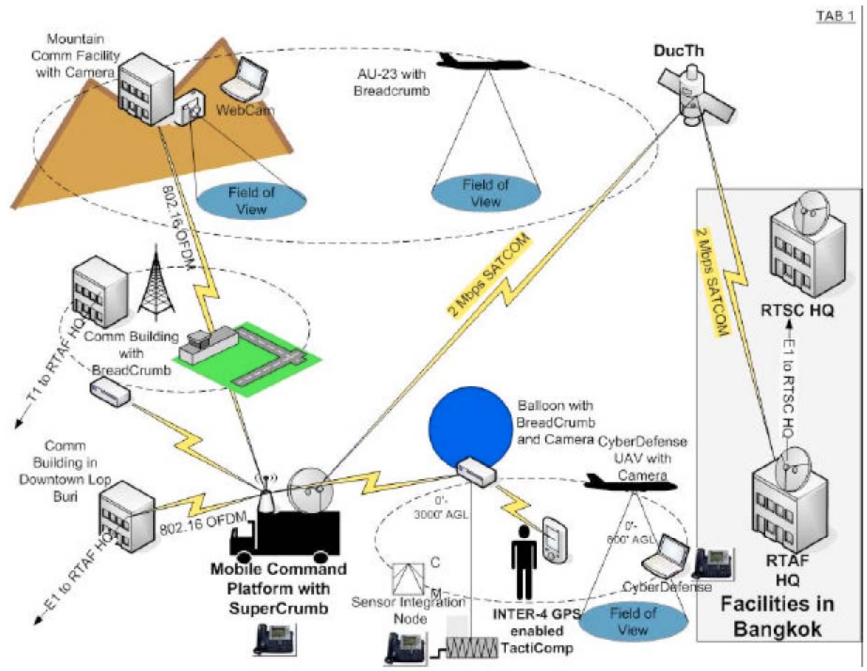
5. James Ehlert and Brian Steckler will be the point of contact on establishing priority of link establishment and system testing.

B. OPERATIONAL CONCEPT

1. Operational checks of all equipment will be conducted prior to departure from the Assemble Area at Wing 2. RTSC HQ has been proposed at a potential site for back to back operational checks.

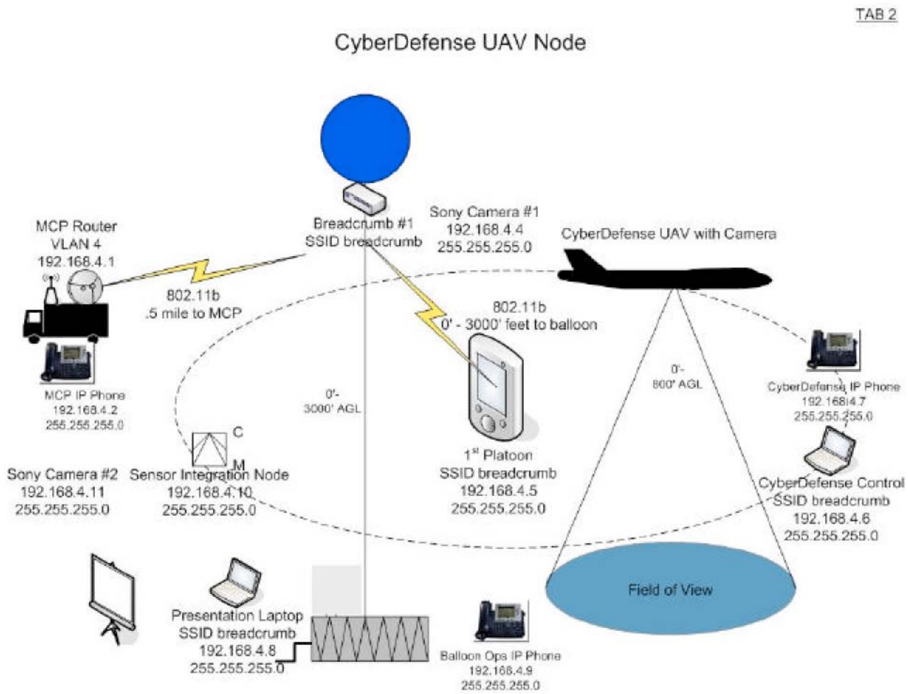
2. Functional Specialty Team Leaders are responsible for the installation, operation, and maintenance of their respective nodes; and must advise James Ehlert or Brian Steckler of situations, actual, or potential that could adversely affect system deployment as quickly as possible.

C. HIGH LEVEL TOPOLOGY



A-2

D. CYBER DEFENSE TOPOLOGY

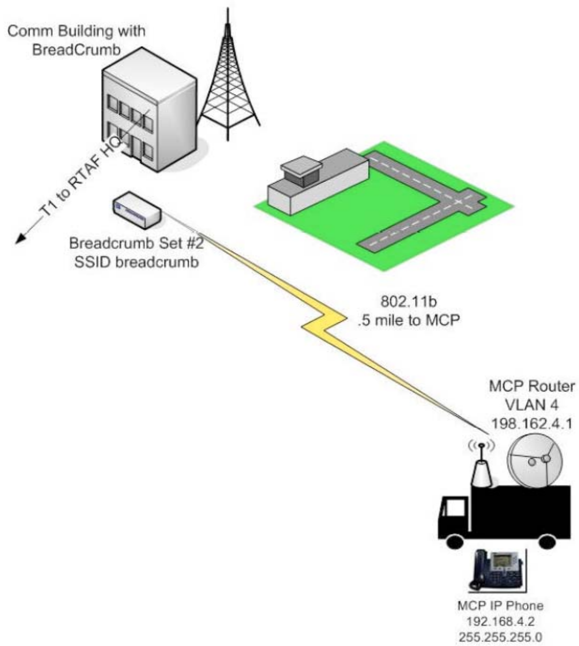


A-3

E. WING 2 COMMUNICATIONS BUILDING

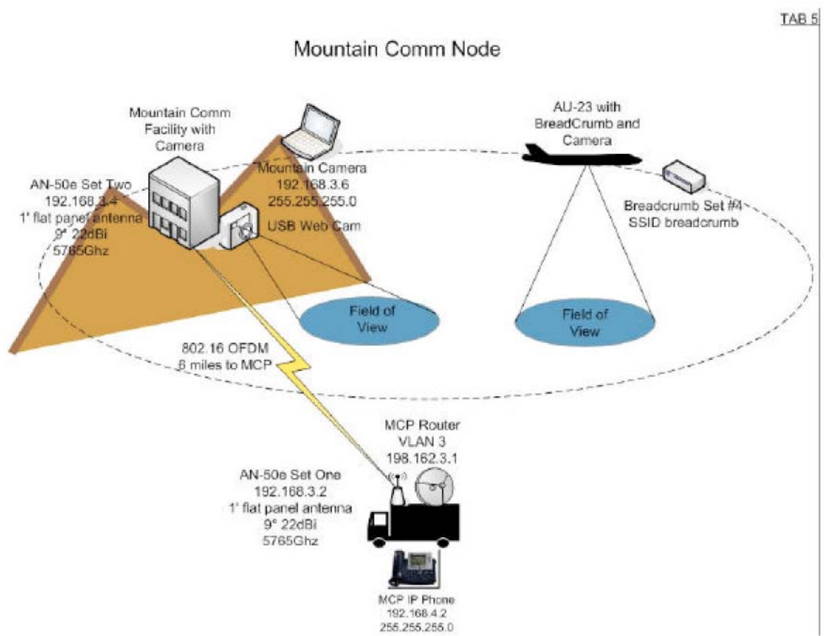
TAB 4

Wing 2 Comm Bldg Node



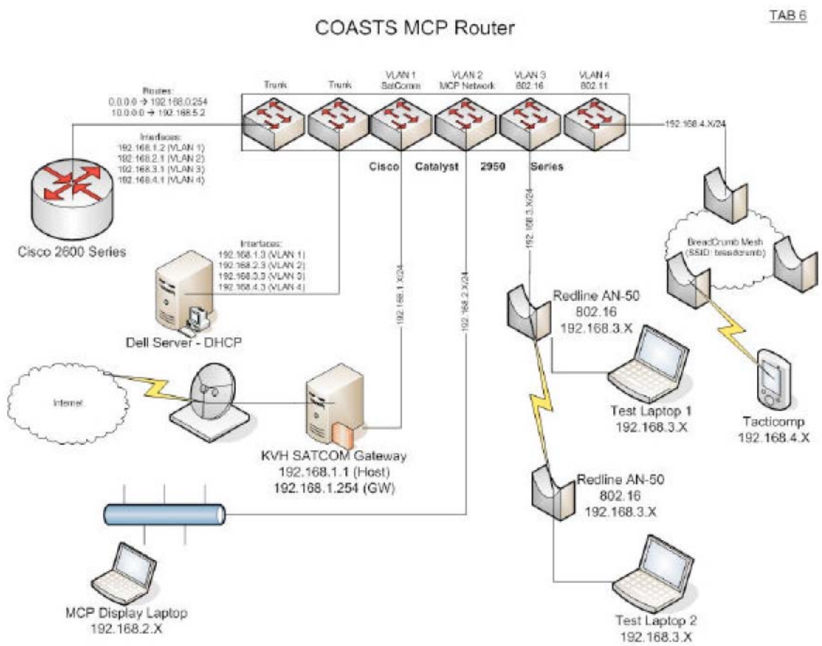
A-4

F. MOUNTAIN COMMUNICATIONS FACILITY



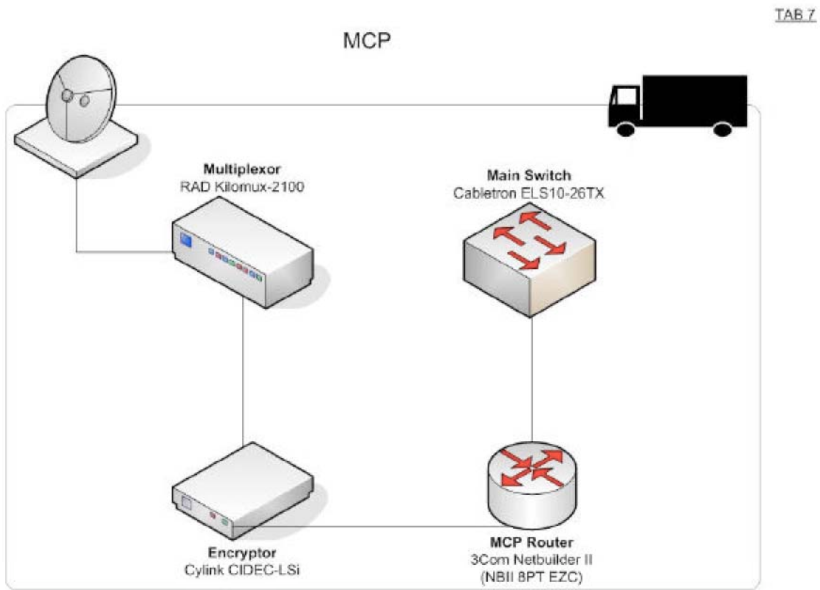
A-5

G. COASTS MOBILE COMMAND POST ROUTER



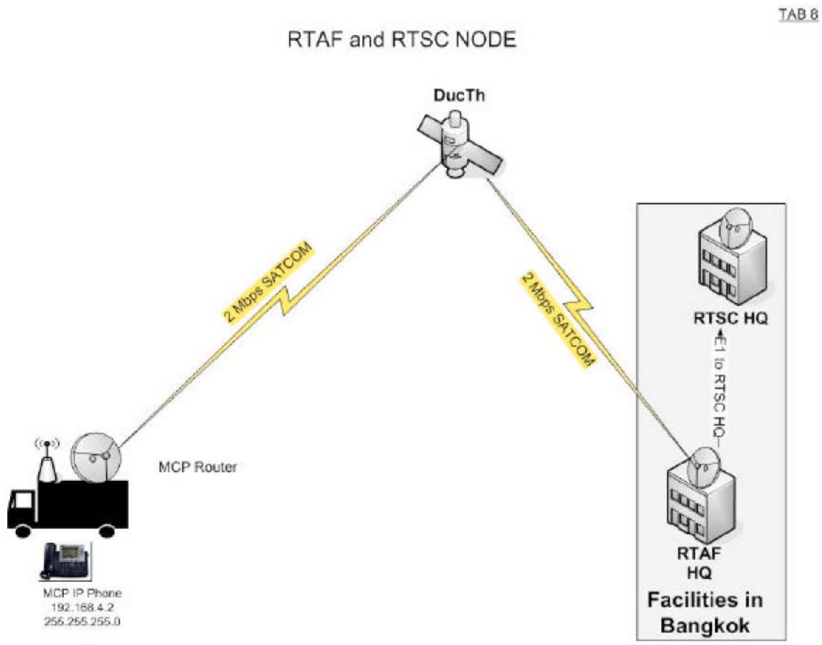
A-6

H. MOBILE COMMAND POST



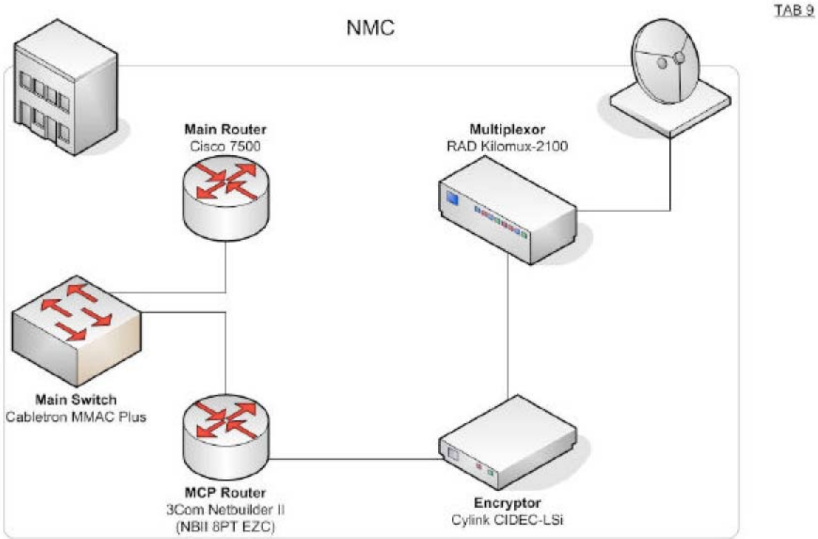
A-7

I. BANGKOK LINK



A-8

J. NMC


TAB 9
NMC
Main Router
Cisco 7500
Multiplexor
RAD Kilomux-2100
Main Switch
Cabletron MMAC Plus
MCP Router
3Com Netbuilder II
(NBII 8PT EZC)
Encryptor
Cylink CIDEC-LSi

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APPENDIX B. WIRELESS 802.11 NETWORK (BREADCRUMBS)

NPS does not endorse or recommend any of these commercial products/services. This information was downloaded from the Rajant website.

A. INTRODUCTION.

The mesh network is tied together with the 802.11 wireless network. All of the sensors, both airborne and ground based, are attached to the network via an 802.11 gateway. Once on the system, users can access and route information in the local area via the BreadCrumb mesh, or over longer distances via gateways to 802.16 long-haul links, sitcom links, or wired E-1 and T-1 lines. The breadcrumbs are at the heart of allowing sensors, users, and nodes to have access to a wireless network in an expeditionary and austere environment.

B. XL BREADCRUMB MODEL

1. BreadCrumb® XL is available with SEC NET 11. There is also a BreadCrumb® XLV designed to run off of your vehicle's power. We have developed a portable, self-configuring, standards-based, non-line-of-sight, completely wireless, broadband network system. Each BreadCrumb® Wireless LAN is a small battery-operated unit capable of instantly establishing a wireless meshed digital network in adverse environments.

Size	**11" L x 10" W x 6.25" H**
Weight	**10 lbs.**
Bandwidth	**Up to 22 Mb/s shared b/w nodes**
Frequency	**2.4 GHz**
Range	**10 Miles**

C. SE BREADCRUMB MODEL

1. BreadCrumb® SE is available with SEC NET 11. We have developed a portable, self-configuring, standards-based, non-line-of-sight, completely wireless, broadband network system. Each BreadCrumb® Wireless LAN is a small battery-operated unit capable of instantly establishing a wireless meshed digital network in adverse environments.

Size	**8.5" L x 7.25" W x 3.75" D**
Weight	**2.3 lbs.**
Bandwidth	**Up to 22 Mb/s shared b/w nodes**
Frequency	**2.4 GHz**
Range	**.2 - .5 Miles**

D. ME BREADCRUMB MODEL

1. We have developed a portable, self-configuring, standards-based, non-line-of-sight, completely wireless, broadband network system. Each BreadCrumb® Wireless LAN is a small battery-operated unit capable of instantly establishing a wireless meshed digital network in adverse environments.

Size	**6.25" L x 4" W x 1.5" H**
Weight	**1.5 lbs.**
Bandwidth	**Up to 22 Mb/s shared b/w nodes**
Frequency	**2.4 GHz**
Range	**.5 Miles**

E. WE BREADCRUMB MODEL

1. **We have developed a portable, self-configuring, standards-based, non-line-of-sight, completely wireless, broadband network system. Each BreadCrumb® Wireless LAN is a small battery-operated unit capable of instantly establishing a wireless meshed digital network in adverse environments.**

Size	**6.25" L x 4" W x 1.5" H**
Weight	**1.5 lbs.**
Bandwidth	**Up to 22 Mb/s shared b/w nodes**
Frequency	**2.4 GHz**
Range	**.5 Miles**

APPENDIX C. WIRELESS 802.16 NETWORK (OFDM)

NPS does not endorse or recommend any of these commercial products/services. This information was downloaded from the Redline website (www.redlinecommunications.com).

A. 802.16 EQUIPMENT. The purpose of the 802.16 link is to achieve greater distance capability on the network (up to 10 miles).

1. AN-50E. Redline's award-winning AN-50e is the world's first high-performance, low-cost multi-service solution for carriers and service providers looking to expand their networks and provide high quality access to customers. Operating in the 5.4 and 5.8 GHz unlicensed bands, Redline's AN-50e delivers an industry-leading 72 Mbps and supports long-range links exceeding 80 km (50 mi) in clear line of sight (LOS) conditions. The AN-50e provides cost-effective site-to-site connectivity for demanding PTP and PMP applications including transparent LANs and VoIP.

2. Features.

- Up to 72 Mbps raw/49 Mbps net Ethernet throughput
- Lowest end-to-end latency in its class
- Bi-directional dynamic adaptive modulation
- Dynamic time division duplex (TDD) transmission
- 2002 SUPERQuest award: "Most Promising Network Transport Technology"
- DFS and ATPC

B. TECHNOLOGY. Redline's core technical differentiation combines more than ten patented enhancements with current orthogonal frequency division multiplexing (OFDM) implementations resulting in a state-of-the-art, cost-effective solution that will immediately give service providers momentum and a leadership role in deploying their broadband strategy. These differentiators include:

1. Three interlocking techniques, including the OFDM data engine, MAC and RF, when combined, increase the efficiency of the OFDM engine in addressing NLOS deployments, multipath distortion effects and interference.
2. Streamlining the processing requirements of the medium access control (MAC) layer, further increasing efficiency and decreasing cost.
3. Implementing several groundbreaking RF enhancements, resulting in an optimized operation of the radio and OFDM data engine for greater range and dynamic response to propagation effects.
4. Utilization of network layer software to automatically adjust system characteristics to deliver optimal performance in the face of co-channel and adjacent-channel interference.

APPENDIX D. AVIATION OPERATIONS

A. AIR MARSHALL. NPS will designate an Air Marshall to coordinate all aviation related activities for COASTS. A Thai counterpart is requested to act as a counterpart for all coordination with the Royal Thai Air Force.

B. SUPPORTING DOCUMENTS. A detailed Airspace Control Measures document and Flight Schedule document with special instructions (SPINS) will be published by the Air Marshall for all COAST related aviation operations. Refer to these documents for the most up to date information for a particular COASTS event.

C. AIRSPACE CONTROL MEASURES. The following airspace control measures will be used during COASTS demonstration in order to coordinate safe and effective use of available assets. All airspace corridors are referenced from the reported position of the NPS Balloon. The proposed initial NPS Balloon location is a soccer field southeast of the approach end of RWY 34 at Wing 2 Lop Buri.

D. COORDINATION.

1. Initial Briefing:

A confirmation brief will be held from 1000-1600, 22 March at RTAF HQ in Bangkok. During this time it is imperative that appropriate NPS and Thai air operations representatives are present in order to complete and solidify operating rules and timelines.

2. Daily air operations briefings:

Prior to each day's activity and upon arrival at the Wing 2 site, a group meeting will be held in order to communicate the plan of day for operations. This will include NPS COASTS demonstration flights and required logistical support flights for operations in the Thai Mountain Facility and for the Searcher Mk 1 UAV. This is intended to supplement the confirmation brief only. All requirements and conflicts are to be completed at the initial confirmation brief on 22 March.

Items to be discussed at Daily Air Ops Brief include:
Weather
Expected Daily Schedule
Airspace Control Measures
Communications Plan:
- POCs
- Frequencies

Flight Schedule:

COASTS air operations will follow the timeline set out in the COASTS Air Operations document.

3. Radio Communications:

Daily coordination will be conducted using an airport service vehicle equipped with a radio set to TWR frequency provided by the Thai airfield at Wing 2. This vehicle may also serve as a runner vehicle for the MCP node of the COASTS demonstration. A PRC-117 will be available at the COASTS primary site with UHF frequency capability.

E. AIRSPACE RESTRICTIONS FOR AIRCRAFT ATTACHED TO COASTS.

1. Au-23 Peacemaker

   Minimum Altitude: 7000 ft AGL
   Maximum Altitude: 10000 ft AGL for operating with COASTS Network
   Lateral Distance around balloon position: within 2500 meters of Balloon Pos

2. Mk1 Searcher:

   Minimum Altitude: 3500 ft AGL
   Maximum Altitude: 6500 ft AGL for operating with COASTS Network
   Lateral Distance around balloon position: within 2500 meters of Balloon Pos

3. Balloon

   Minimum Altitude: SFC
   Maximum Altitude: 3000 ft AGL

4. Helicopter UAV:

   Minimum Altitude: SFC
   Maximum Altitude: 800 ft AGL
   Lateral Distance around balloon position: within 750 meters or Balloon Pos

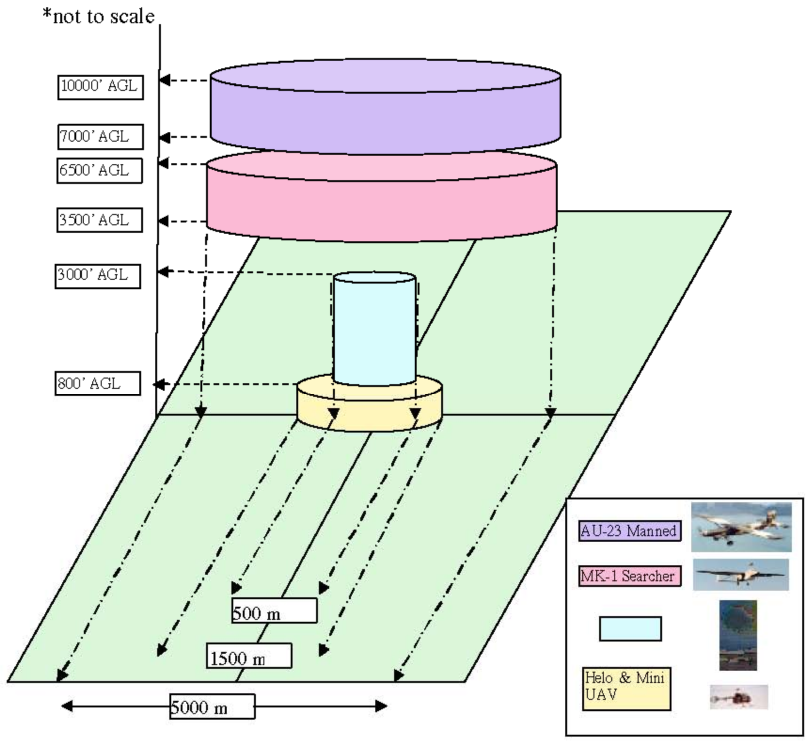
5. Mini-UAV

   Minimum Altitude: SFC
   Maximum Altitude: 800 ft AGL
   Lateral Distance around balloon position: within 750 meters or Balloon Pos

6. All Others:

All other Fixed wing and Rotor wing Operations will remain clear of the balloon operating area as directed by the airfield operations, tower, ground, and appropriate NOTAMS issued by the Thai airfield.

F. **AIRSPACE DIAGRAM**:



D-3

G. REQUESTED HOST NATION SUPPORT FOR AIR OPERATIONS:

1. Thailand Airfield:

    1. Provide one vehicle equipped with airfield radios capable of communication with tower and capable of accessing Balloon operating area. (light 4x4)
    2. Issue appropriate NOTAMS for COASTS demonstration.
    3. Attend initial Confirmation brief on 22 March.
    4. Attend daily air operations briefing upon COASTS team daily arrival to Wing 2 operating area.
    5. Clear airspace as appropriate for COASTS Air Operations.

2. Thai UAV squadron:

    1. Attend initial Confirmation brief on 22 March.
    2. Attend daily air operations briefing upon COASTS team daily arrival to Wing 2 operating area for those days requiring Searcher Mk1 support.
    3. Issue any NOTAMS specific to Searcher Mk1 UAV operations in the vicinity of the Wing 2 Airfield.

3. Thai Helicopter Squadron:

    1. Attend initial Confirmation brief on 22 March.
    2. Attend daily air operations briefing upon COASTS team daily arrival to Wing 2 operating area for those days requiring helicopter support.
    3. Provide logistical support to/from Mountain Facility.
       Thai C-130 Squadron:

    1. Attend initial Confirmation brief on 22 March.
    2. Provide logistical support to/from BKK and Wing 2 Airfield.
    3. Notify NPS Air Marshall, Capt Thomason, of any conflicts or problems with daily transportation flights to Wing 2 Airfield.

H. NPS TASKS:

1. Using provided radio com vehicle, notify airfield tower of NPS Balloon and UAV Deployment
2. Conduct initial confirmation brief on 22 March in order to complete and solidify operating rules and timelines.
3. Conduct daily confirmation briefing for all air operations scheduled for that day in order to communicate the plan of day for operations

I. OPERATING AIRFIELD INFORMATION:

KHOK KATHIAM TWR 122.6 Mhz/238.6 Mhz

KHOK KATHIAM, VTBL
N 14.87460° E 100.66335° (47P PS 78949 45123) 98

ID: TH25973
Name: KHOK KATHIAM
Country: Thailand
Location: N 14.87460° E 100.66335° (WGS84)
Elevation: 98 ft
Longest Usable Runway Length: 7252 ft
ICAO Code: VTBL
FAAID: N
Type: Active Military Airport
Magnetic Var: 0.5W

Runway Information:

ID	Displd Thresh	Dim(LxW ft)	Mag Hdg	Latitude	Longitude
05	0	4435x148	047	N 14.86938°	E 100.65763°
23	0	4435x148	227	N 14.87774°	E 100.66679°
10	0	600x64	96.5	N 14.88634°	E 100.66083°
28	0	600x64	276.5	N 14.88617°	E 100.66254°
16	467	7252x148	161	N 14.88390°	E 100.65993°
34	0	7252x148	341	N 14.86509	

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APPENDIX E. THAI AU-23 FIXED WING AIRCRAFT

A. CHARACTERISTICS.

1. The Au-23 is considered a mini- gunship.
2. Nicknamed "Credible Chase"

B. SPECIFICATIONS.

1. Span: 49 ft. 8 in.
2. Length: 36 ft. 10 in.
3. Height: 14 ft. 4 in.
4. Weight: 6,100 lbs. maximum gross
5. Engine: Garrett TPE 331-1-101F turboprop of 650 hp.

C. CREW.**:** 3 - pilot, copilot, gunner. In transport configuration, the aircraft could carry 6 passengers or 5 troops with field gear or 1 litter patient, 3 ambulatory patients and 1 medical attendant.

D. ARMAMENT. One XM-197 20 mm side firing cannon plus up to 1925 lbs. of external stores on five pylons - two on each wing (1400 lbs. of stores max.) and a center fuselage pylon (525 lbs. of stores max.) - In combat evaluations, the maximum ordnance load was about 1300 lbs. The aircraft was also evaluated with side firing XM 93 7.62 mm minigun, XM 59 .50-cal. machine gun and XMU-470 20 mm fixed side firing gun pods. Ordnance tested included SUU-11 gun pods, 2.75" rocket pods, BDU 33 with 25 lb. bomblets, MK 81 250 lb. bombs, MK 82 500 lb. bombs, BLU-118 500 lb. napalm canister, CBU-55 500 lb. cluster bomb unit, MK-24 flares, ADU-272 canisters, smoke grenades and propaganda leaflet dispensers.

E. PERFORMANCE

1. Maximum speed: 148 knots at take-off power, 5,000 feet altitude, 6,000 lbs. gross weight
2. Cruising speed: 142 knots at maximum continuous power
3. Combat cruise speed: 129 knots
4. Range: 420 nautical miles
5. Endurance: 4.84 hours
6. Combat Radius: 162 to 201 nautical miles depending on mission

F. PICTURES.

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APPENDIX F. SEARCHER UAV

A. OVERVIEW OF ROYAL THAILANDS USE OF THE SEARCHER UAV PROGRAM AND PLATFORM INTRODUCTION

1. The Royal Thailand (Thai) Ministry of Defense and the Thailand Research Fund has embarked on a 3 year research program to develop and employ UAVs in support of critical homeland security and ancillary military operations. The aim of the project is to develop the UAV for Thailand to support the Intelligence, Surveillance, and Reconnaissance Mission (ISR). Researchers involved in this project include: The Royal Thai Air Force, The Royal Thai Army, and other affiliated University research organizations.

B. ROYAL THAI SEARCHER MK 1 UAV SPECIFICATIONS:

1. Manufacturer:
   - Israeli Aircraft Industries
2. Conceived Employment
   - Surveillance & Reconnaissance
     - Homeland Security and Military
   - Battlefield Observation and Target Acquisition
   - Real-time Imagery/Intelligence
   - Artillery Observation & Direction
3. Flight Profile(s):
   - Altitude Envelope
     - Maximum Altitude: 14,500 ft (4420.73 m)
     - Service Ceiling (Standard rate of Climb): 100 ft/min (30.48 m/min).
   - Maneuvering
     - Load Factor 2G
   - Air Speed Envelope
     - Maximum Airspeed: 120 kias
     - Minimum Airspeed:

- Autopilot engaged: 45 kias at leveled flight
- Flight servo loop 50 kias at 30° declination.
- Autopilot disengages: 45 kias at leveled flight.
  - Rate mode: 50 kias at 30° declination.
    - 85 kias at 60° declination.
- Stall airspeed: 42 kias at maximum weight.
- Circling airspeed: 55 kias.
- Decent for landing Airspeed: 65 kias.
- Landing Airspeed:
  - Headwind component <12 knots: 60 kias.
  - Headwind component > 12 knots: 60+5 (Crosswind – 12 kias).

4. Performance Characteristics:

- Input Power: Generator and GCU:
  - Power: 2000w.
  - Nominal Voltage: 28Vdc.
  - Minimum Voltage: 28Vdc.
  - Voltage quality: MIL-STD-704A.
  - Maximum Voltage: 32Vdc.
  - Ripple: Less than 4 VP-P.

C. (IMPROVED) SEARCHER MK II SPECIFICATIONS

1. Unmanned aerial vehicles and autonomous underwater vehicles are both areas of research that promise to extend the battlefield and increase the awareness of homeland security and military forces. The following specifications are provided as discussion points and all information was obtained on the unclassified network/internet. The primary source of this information was provided at the Israeli Aircraft Industries world wide web address as follows: http://www.iai.co.il/site/en/iai.asp?pi=18894. A promotion kit for the Searcher MK II may be obtained at the following wed address: http://www.iai.co.il/STORAGE/files/4/15744.pdf.

1. Flight Profile(s)

- **Maximum Altitude: 16,000 – 20,000 ft
    - 4876 m – 6096 m
- **Maximum Range: 200km (Direct Line of Sight)
        - 250 w/ aid of airborne (UAV) platform
- **Maximum Endurance / Loiter: 12 – 15 hours

4. Datalinks and Payload information/configurations.
    - Standard MOSP (TV & IR Combi) or SAR EL/M 2055
    - IAI MOSP (Multi-Mission Optronic Stabilized Payload) combined TV/FLIR and/or air data relay are Standard
    - Direct line-of-sight datalink, UAV airborne data relay for beyond-line-of-sight datalink.
    - Dual real-time command uplink
    - Single real-time data and video downlink ability
        - Frequencies: Payload specific?
    - Autonomous return on datalink loss
    - * Maximum Payload Weight: 100kg (220lbs)

5. Operational Modes
    - Real-time payload and UAV control
    - GPS based interuptable airborne mission controller with real-time manual interrupt capability

6. Launch and Recovery
    - Automatic Take-off and Landing Capable
    - Take-off Weight 426 kg (940 lbs)

7. Airframe Dimensions and specifics
    - Wing Span: 8.55 m (28.10.ft)
    - Length 5.85m (19.2ft)
    - Powerplant: Rotary engine (73 hp)

8. Image of Searcher MK II

Image of The Searcher MK II UAV.

APPENDIX G. CYBER DEFENSE

NPS does not endorse or recommend any of these commercial products/services.

A. CYBER SCOUT SPECIFICATIONS.

1. Length 5 feet
2. wing span 5 ft
3. Weight ~ 10 Lb with 2 payload
4. 30 minutes to one hour flight time (hover dependant)
5. 60 mile range
6. Autopilot
7. Hand held viewer and joy-stick or flight system
8. Camera (one mile range)
9. 9 Volt battery for camera Electric power

B. PICTURES

C. CYBERBUG SPECIFICATIONS

1. Length 25-56 inches
2. wing span 30 inch to 60 inches
3. Weight ~ 2.6 Lb scalable to 6 pounds
4. 45 minutes to 3.5 hours flight time
5. 5-10 MPH
6. Autopilot / manual / GPS navigation
7. Hand held viewer and joy-stick
8. Camera (half mile effective range)
9. 9 Volt battery for camera
10. 11.1 Volt battery for BUG
11. Carrying case
12. Payload is scalable up to several pounds

D. PICTURE

CYBERDEFENSE
SYSTEMS™

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APPENDIX H. ROBO-HELI (UAV)

NPS does not endorse or recommend any of these commercial products/services. The information below was downloaded from the website www.intuitiveminds.net.

A. BACKGROUND. The applications for the Robo-Heli system are limited only by lack of imagination. We have selected local and state government protection, traffic monitoring, search and rescue, security surveillance, land surveying, building inspection, area monitoring, aerial mapping, and cinematography as our initial markets, and are currently seeking out new markets and customers for future development and growth.

The intelligence of any machine lies in its performance, adaptability and expandability. In order to fulfill these criteria, we chose a miniature helicopter as the foundation of our system. Then we equipped it with a collision avoidance system, wireless communication, GPS waypoint navigation, and the ability to be controlled and monitored from almost any computing platform, such as Windows, Macintosh, Linux, and several handheld computing environments. Developments for streaming video capture and a cellular phone platform are also on the horizon.

B. PICTURE.

APPENDIX I. BALLOON OPERATIONS

A. INTRODUCTION AND BACKGROUND

1. A less costly method of promoting and facilitating an airborne network and applicable components is with helium filled balloons that are capable of carrying networking components. NPS has experience with entering balloons as stationary nodes which extend the horizon of networks. The figure below displays one of NPS's family of experimental balloons.

B. NPS BALLOON ASSET SPECIFICATIONS

1. Operational requirements:
    - FAA or international equivalent (locale dependent)
    - Altitude considerations :
        - Field policy for NPS local experimentation area
            - Flown at 500 ft (152.4 m)
            - Requires banners or visible streamers every 50 ft (15.24 m)
                - 500 ft (152.4 m) may be FAA limit
2. Helium requirements:
    - Newer balloons: two to five (2-5) cans of helium
        - Lift capacity: up to 25 lift (11.34kg)
    - Older balloons: five (5) cans of helium
        - Lift capacity: up to 50 lbs (22.68kg)
    - Daily helium leaks (requires pre mission top–off)
        - Small percentage daily.
        - Temperature fluctuations affects leak rate.
3. Payload power:
    - Battery
        - Alternative line or wire power is rarely used.
    - Payloads draw about 20 watts with a bridge
        - 1 watt amp
            - GPS, freewave, video and video compression.
    - **Note**: winches and line to support tethered power are quite expensive.
        - As in any air operation, the lighter, the more optimal
4. Payload frequencies:
    - Standard NPS payloads:
        - 802.11b/g/i network which is 2.4Ghz
        - 900Mhz freewave radio to broadcast GPS data independently.

- Payload may be configured to broadcast any practical frequency desired.
- **Rf consideration**: generally only an omni antenna is useful based on altitude considerations.
  - Lower frequencies generally operate well with the omni antenna
  - Higher frequencies typically need more focused energy and antennas along with higher power requirements

5. Flight duration:
   - Theoretical: unlimited
     - NPS has flown balloons as high as 3000 ft (915m)
     - Weather, operations, and power dependent

C. WEATHER CONSIDERATIONS FOR OPTIMAL BALLOON OPERATIONS

1. Winds:
   - Maximum experimental use in winds **speeds < 20 kts**.
   - Must differentiate between launch conditions and winds at altitude
2. Rain:
   - Operation in rain is permittable
     - ** **caution**: mission payload must be watertight.
       - NPS payloads are not typically watertight.
3. Air pressure and temperature considerations:
   - ****caution**: changes in altitude and temperature affect the resultant pressure. E.g. high altitudes or large temperature changes
     - **Do not fill balloon full**
       - Balloon will **"pop a seam."**
       - **NPS** experience: not a catastrophic failure, but the balloon slowly looses lift over a few hours and you have to bring it in,
       - Likely the balloon would have to be sent to the manufacturer for repairs.

D. LOGISTICS AND SUPPORT DATA (TEAM REQUIREMENTS)

1. Launch and recovery

- 1-2 personnel (low or no wind conditions < 20 kts)
  - Experimental: two personnel in winds > 20 kts.
    - Note: optimal to have at least 2 - 3 people for the really large balloons and heavy payloads

2. Set up and recovery (inflation and deflation)
   - Larger balloons
     - Balloon inflation: approximately one (1) hour to fill.
     - Balloon deflation: approximately 30 minutes.
3. Support equipment
   - Helium
     - Regulator and hose to fill balloon
     - Tarp for shelter in the field.
4. Storage requirements
   - Dry condition
   - Balloon cannot be stored "wet" to include rain or dew.
     - Reason: wet balloon will rot.
     - **Recommend:** hanging balloon to dry prior to packing.
   - Collapsed balloon:
     - Approximately 10 lbs (4.55kg)
   - Inflated balloon (moderate wind)
     - Stow the balloon inflated with about 50' or so of line out.
     - ****caution**: never tie it off at the ground unattended, as wind will throw it into the ground and destroy the balloon.

E. BALLOON PLATFORM

1. Equipment

- 2' x 4' x 1/2'' plywood

  This serves as the center piece of the platform.
- (7) 2" x 4" x 4'

  \- These boards serve as the braces for the platform. Two boards will be the base for the platform. The remaining four will be spaced evenly between the ends of the base boards, leaving 2 feet in the center of the platform for the plywood center piece, as called for above. (1).

- (16-20) 2-1/2" Wood screws.
- (1) ¾" Pad Eye Screw

- The Pad Eye screw will be placed on the platform to create a space for the balloon to be stowed when preparing the balloon for operation.

2. Assembly.

- Make sure all 2x4's are approximately 48 inches long. Take three of these boards and lay them parallel to each other on a sturdy surface. Space them evenly over 48".

- Place the ½" plywood in the center of the three base boards. Ensure that that the plywood center piece is 24" wide and 48" long. Center the plywood on base boards so that approximately 24" (from the ends of center piece) of the base boards remain exposed. Fasten the center piece with wood screws (4 on each side and 2 on the sides of the center) to the base boards.

Obtain two of the remaining 2x4's. Place them in the same direction as the center board across the exposed portions of the base boards. Place them opposite of each other, perpendicular and aligned at the ends of the baseboards. Fasten these boards to the base boards with wood screws.

- Obtain the remaining two 2x4s. Place one of the remaining boards parallel to the center board and end board, ensure that the board is touching the center board. Attach with wood screws. Perform the same procedure with the remaining board on the other side of the center board. The space created with the 2x4s at the ends of base boards will provide an area to weigh down the platform to provide a stable platform for the balloon.

Figure 1 shows the completed product of the platform.

Figure 1 Completed balloon platform with helium bottles.

- The Pad-Eye screw should be placed on the outside of the platform on the center plywood and aligned to the winch assembly.

Figure 2 displays the Pad-Eye and its placement on the platform.

Figure 2 Pad-Eye screw

F. BALLOON WINCH

1. Winches and Recommendations.

- There are many winch assemblies on the market. They range in size and complexity. The winch used in this platform is a Scotty's Balloon Winch that has been modified to accommodate a 20-30 pound lift balloon. The center piece of the above platform is wide enough for most mid-size winches. The platform can be built with a number of dimensions to suit your winch. Remember to place the winch in the center of your platform.

- Determine the width of the base of the winch and measure an area in the center of the platform. An outline of the base on the plywood is helpful but not necessary. Once the appropriate width is determined, attach the winch base to the platform using wood screws. Ensure that the screws are extra strength to withstand the force of the operating balloon. For this assembly, the Scotty balloon winch comes with 4 (¼") Allen Wrench wood screws. These screws attach the base of the winch to the platform.

2. Winch Assembly

3.2.1 Equipment

- Scotty Marine Winch
  - The marine winch was modified to use as a "balloon winch". Most marine winches come with a steel cable commonly found in 150 foot lengths.
- 1000 ft of 300 pound fishing line or twine.
- 32 amp hour battery (small marine battery)
- Winch DC power adapter
  - The power adapter has been modified to control the winch motor to provide a mechanically controlled retrieving capability for the winch assembly.

3.2.2 Assembly

***3.2.2.1 Winch Modifications*.**

- The Scotty marine winch comes standard with 150 ft steel cable, a 2-3 foot arm extension for cable support and an "Auto-On-Off" switch. Figure 3 is a picture of the Scotty winch.

Figure 3 Scotty Marine Winch

- The winch has a 3 foot extension that attaches a pulley system to guide the towing line or cable. This particular winch has been modified to use with a 30 pound lift balloon.

  - The extension was tapered to approximately 18" in order to minimize the upward force on the winch when the balloon is tethered in the air.

  - The 150 foot of cable has been replaced with 300 pound trawling line. The line is approximately 1000 feet in length and 1/8" thick. This modification renders the winch's attached counter useless.

  - The winch's power supply for retrieving the line was modified to allow for varying the speed of the winch motor. The "Auto-On-Off" switch must be in the "On" position to retrieve the line with DC power.

- The metal mounting was created to allow the winch to be placed in a vertical position and to allow for circular motion due to wind conditions when the balloon is in operation. This mounting is made from ¼" steel, cut into two sections.

  - The first section is manufactured to fit the dimensions of the winch body.

- The second section is the approximate dimensions of the winch's base.

- The dimensions of the mount are based on the size of the winch being used. The most important aspect of the mounting is to allow for movement of the winch during high wind conditions.

- The power adapter has been modified to add speed control to the winch. The power adapter is only used for retrieving the balloon.

3. Winch Operation

- The Scotty winch is very easy to use. This particular winch has a manual brake to control the deployment and retrieval of the balloon. The brake is also used to maintain the balloon at the desired height when deployed. The brake is located on top of the winch (Figure 3).

3.3.1 Deploying The Balloon

- To deploy the balloon, the manual brake must be released. To release the brake, the operator slowly pulls the brake handle in a downward motion (toward the operator). This will allow the brake pads to separate from the winch spool to deploy balloon line. The line is deployed by the lift of the balloon. The operator must pay attention to line tension during deployment for two reasons:

  - During initial operation the spool might bind and;
  - If the balloon is deployed too fast, the air speed around the balloon might create an extra lifting force. This force creates more tension on the line which could break the line if the force exceeds the line rating.

3.3.2 Retrieving the Balloon

- To retrieve the balloon, the power adapter must be connected to the winch. The following steps will guide you through connecting the adapter to the winch.

3.3.2.1 Connecting the Power Adapter

- The winch has an installed power cord for battery operation.
- Insert the power cord into the adapter. The connection for the cord can be found on the opposite side of the cable connections for the battery.
- Ensure that the adapter is in the "OFF" position. There are three positions for the adapter, "UP-OFF-DOWN". The adapter is also equipped with a

speed control rheostat. Ensure that this is turned fully counter clockwise in the "SLOW" position.

- Connect the adapter battery cables to the battery. Take note of the positive and negative terminals on the battery. Connect the appropriate cable to the marked terminal. For this adapter, the positive battery cable is "RED" and the negative cable is "BLACK".
- When the battery cables are connected, the winch is prepared for retrieving the balloon. Figure 4 shows the adapter and the winch power cord.

Figure 4 Winch Power Adapter, Battery Cables and Battery

3.3.2.2 Retrieving the Balloon

- Place or observe the winch "AUTO-ON-OFF" switch is in the "ON" position.
- Apply a tool to the inside of the winch pulley to guide towing line into the spool. For this assembly, a carabineer was used to perform this operation. Carabineers can be found at any sporting goods store.
- Turn the speed control rheostat slowly in the clockwise direction. The brake will automatically disengage and the winch will move in the retrieving direction. Control the speed to desired retrieval rate with the rheostat.
- Using the carabineer, guide the line onto the spool so it will wind evenly onto the spool.

- Once the balloon is retrieved, or at the desired height, turn the speed control rheostat counter clockwise to the "SLOW" position.
- Attach the balloon tether to the platform through the Pad-Eye screw. This can be done using the carabineer through a loop through the main tether of the balloon. Attaching your balloon to the platform allows the operator to attach the payload or to deflate the balloon for removal.

G. THE BALLOON

This balloon operation uses a 30 pound lift balloon. The particular balloon for this operation was bought from BlimpWorks. This balloon is made out of plastic and filled with helium. The diameter of the balloon is approximately 6 feet. The balloon is equipped with an inflation/deflation tube. The balloon has 12 attachment strings that are fastened to a center ring. The ring is connected to a nylon rope as a main tether to attach to the extra line from the winch. This balloon work is very sturdy and the leakage rate is minimal.

There are many balloons on the market. The important characteristics in searching for the best balloon for an operation are listed below:

- Lift (usually in pounds)
- Material (strong plastic is best)
- Wind sustainability
- Operation Time (inflate/deflate time)

1. Equipment

- (1) 30 lb lift outdoor balloon (BlimpWorks)
- (1) 12 ft rope
- (1) ¼" 10-15 ft Nylon rope
- (2) 250 cu ft bottles of helium
- (1) Air regulator with inlet/outlet pressure gauges
- 15 ft of Tygon tubing
- (1) Crescent wrench

2. Inflating the Balloon

- The balloon comes in cellophane wrap. Remove the balloon from the wrap.
- Layout the balloon and ensure that the 12 attachments (string) are free from binding.
- Attach the 12 ft rope to the top of the balloon. This will allow the operator a method to deflate the balloon when needed.
- Open the inflating tube.

- Attach the regulator to one of the helium bottles

    - The regulator will have two gauges. One gauge will monitor the pressure on the helium bottle and the other will monitor the pressure being applied to the balloon. Before installing the regulator to a bottle, ensure that the tygon tubing is attached to the outlet of the regulator.
    - Insert the regulator to the top of the bottle. The regulator will have female threads and must be twisted on the bottle. Use the crescent wrench to tighten the connection.

- Attach the balloon attachments to the 10-15 ft nylon rope with the attaching ring.

- Attach the nylon rope to the winch. This is performed by tying a knot to join the ends of the rope to the winch line or by using some attaching device. It is recommended to use a carabineer or another attaching ring similar to the one on the balloon. Attaching the balloon to the winch will prevent the balloon from being lost when inflating.

- Inflate the balloon

    - Open the valve at the top of the regulator. This will allow the helium in the bottle to pressurize the regulator up to the outlet. The operator should see a fluctuation of the first gauge indicating that the there is pressure in the bottle.

    - Insert the tygon tubing in the inflation tube of the balloon.

    - Open the outlet valve to the balloon. Monitor the pressure coming out of the second gauge. When air is applied to the balloon, the operator should monitor the placement of the tygon tubing in the balloon to prevent damaging the balloon. The high pressure of the helium has the potential to rip the plastic of the balloon.

    - The balloon has an inflation indication attached to the side of the balloon. It is a telltale indication similar to those found on the large ropes used on tugboats. When the line gets taught, the balloon is at max pressure. The balloon will take approximately 1-1/2" bottles to fill.

- Secure filling by shutting the outlet valve of the regulator then the inlet valve.

- Remove the tygon tubing from the balloon and shut the inflation tube.
- The balloon is ready for operation.

3. Deflating the Balloon

- Retrieve the balloon and secure it to the platform.
- Obtain the 12 ft rope attached to the top of the balloon.
- Remove the balloon from the winch.
- Open the inflating tube
- While holding onto the rope, allow the tube opening to rise. The helium will escape through this opening.
- As the balloon deflates, the operator will be able to apply pressure to the outside of the balloon to fully deflate the balloon.
- Stow the balloon.

Figure 5 shows the balloon assembly with attachments

Figure 5 Balloon in flight with “payload”

H. COMPUTER NETWORK/HOUSING AND ATTACHMENTS

I. ATTACHING THE PAYLOAD TO THE BALLOON

- The payload should be powered down prior to attaching to the balloon assembly. This ensures that the payload will be operational for up 5 hours when deployed with the balloon.

- The following steps will guide the operator to successfully deploy the payload and place the network in operation.

- On the bottom of the Pelco Hub, turn the "ON-OFF" switch to "ON". This can be monitored by noting the digital voltage display reads the rated voltage. (Approximately 16 volts when Hub is fully charged).

- Open the laptop and turn it on. Once logged in, start the GPS and Switch programs as described in Figures 6a through 6d.

- Close the laptop.

- The payload should be fully assembled with the laptop fastened to the Hub and V-straps rigged to the payload. Ensure that all antennas are attached (GPS and 8" omni antenna). Use the 4 Velcro straps to fasten the laptop to the Hub more securely. One strap is placed around the top of the laptop under the laptops external battery. The next strap will lay perpendicular to the strap mentioned above and through the wires attached to the Pelco Hub. This strap should be placed over the Hub's external battery to prevent the battery from sliding out when deploying the balloon.

- Create two secure loops in the 10-15 ft nylon rope attached to the balloon. These loops should be about 36"-48" apart. This will provide the attachments for the payload.

- Attach the payload to the balloon with the V-straps to the loops created above.

NOTE:

The operator must attach the payload with the GPS antenna on the uppermost loop. This is important to ensure that the GPS antenna can receive and transmit signals to the base station.

- Once the payload is attached, slowly deploy the balloon. (Section III. A.)

Figure 7 shows the balloon with the payload attached.

Figure 8 Balloon deployed with payload

J. ADDITIONAL EQUIPMENT WITH NOTES

This network used many over the shelf items. The few modifications were used in the Pelco Hub and Winch assembly. To make the network operational, the GPS transmitter and the 802.11 transmitter at the base station were modified to provide the necessary signal strength.

The GPS transmitter was amplified to approximately 1 Watt. 1 Watt is the United States FCC limit for transmission. The 802.11b signal was 200mW and was amplified using a directional antenna with a signal patch. These transmitters are shown in figures 8 and 9.

When placing the node in operation, the GPS transmitter must have line of sight acquisition to the balloon payload. The 802.11 transmitter needs to free from extremis background noise.

The characteristics of the GPS and 802.11 networks can be created to suit desired operations. This assembly and network is only an experiment and many parameters can be altered to fulfill operational goals.

APPENDIX J. SONY CAMERA

NPS does not endorse or recommend any of these commercial products/services. The information below was downloaded from company specification sheet.

A. SPECIFICATIONS. Sony camera: SNC-RZ30N Network PTZ Color Camera.

1. **General**
   - **Weight** 2 lb 10 oz (1.2 kg)
   - **Power requirements** DC 12 V via AC adaptor (100 to 240 V)
   - **Power consumption** 21.6 W (with ATA HDD card)
   - **Operating temperature** 32 °F to 104 °F (0 °C to + 40 °C)
   - **Storage temperature** -4 °F to 104 °F (-20 °C to + 60 °C)
   - **Operating humidity** 20% to 80% Non-condensing
   - **Storage humidity** 20% to 95% Non-condensing
   - **Dimensions (W x H x D)** 5 5/8 x 7 x 5 3/4 inches (140 x 175 x 144 mm)

2. **Camera**
   - **Imager** 1/6 type Interline Transfer Super HAD CCD
   - **Pixels** 680,000 pixels (NTSC)
   - **Electronic shutter** 1/4 to 1/10,000 sec. (NTSC)
   - **Exposure** Auto [Full Auto (including backlight compensation), Shutter-priority, Iris-priority] and manual
   - **White balance** Auto, ATW, Indoor, Outdoor, One-push (trigger command), Manual
   - **EV Compensation** -1.75 to +1.75 (15 steps)
   - **Iris** Auto/Manual (F1.6 to close)
   - **Gain** Auto/Manual (-3 dB to 28 dB)
   - **Focus mode** Auto/Manual (Near, Far, One-push autofocus)

3. **Lens**
   - **Zoom Ratio** 25x optical zoom, 300x with digital zoom
   - **Horizontal viewing angle** 2.0 degrees to 45 degrees
   - **Focal length** f = 2.4 mm to 60 mm
   - **F-number** F1.6 (wide), F2.7 (tele)
   - **Minimum object distance** Tele: 800 mm Wide: 30 mm

4. **System/Network**
   - **CPU** 32-bit RISC processor
   - **RAM** 32 MB (includes 8 MB alarm buffer)
   - **Embedded flash memory** 8 MB
   - **Resolution** 736 x 480, 640 x 480, 320 x 240, 160 x 120 (NTSC)
   - **Compression** JPEG
   - **Compression ratio** 1/5 ~ 1/60 (10 steps)
   - **Frame rate** 30 fps max. (640 x 480) (NTSC)*
   - **Protocols** DHCP, TCP/IP, HTTP, ARP, FTP, SMTP, ICMP, and SNMP

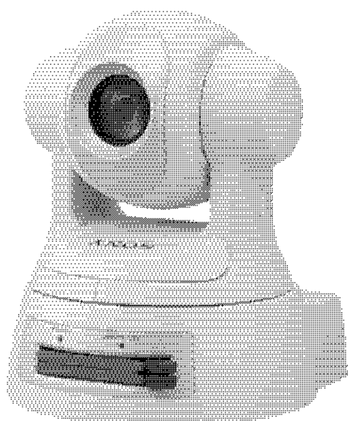
* Depending on network environment

5. **Interfaces**
   Ethernet 100Base-TX /10Base-T (RJ-45)
   PCMCIA Type II x 2
   Video Output Analog Composite (BNC x1)
   Sensor in 3
   Alarm out 2
   Serial IF RS-232C/485 (transparency only)

6. **Analog Video Output**
   Signal system SNC-RZ30N (NTSC)
   Sync system Internal
   Horizontal resolution 480 TV lines
   S/N ratio 48 dB
   Min. illumination 3 lx (color)

7. **Pan/Tilt**
   Pan angle -170 to +170 degrees
   Pan speed 2 sec./340 degrees
   Tilt angle -90 to +25 degrees
   Tilt speed 1.5 sec./115 degrees

B. PICTURE



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APPENDIX K. CROSSBOW SENSOR GRID

NPS does not endorse or recommend any of these commercial products/services. The information below was downloaded from the website www.xbow.com.

A. BACKGROUND. Crossbow Technology is the leading end-to-end solutions supplier in wireless sensor networks and the largest manufacturer of Smart Dust wireless sensors. Crossbow has deployed wireless sensors networks for large-scale commercial use, and Crossbow is currently supplying its Smart Dust products and services to several Fortune 100 companies. Crossbow's wireless sensor networking platform enables powerful, wireless, and automated data collection and monitoring systems.

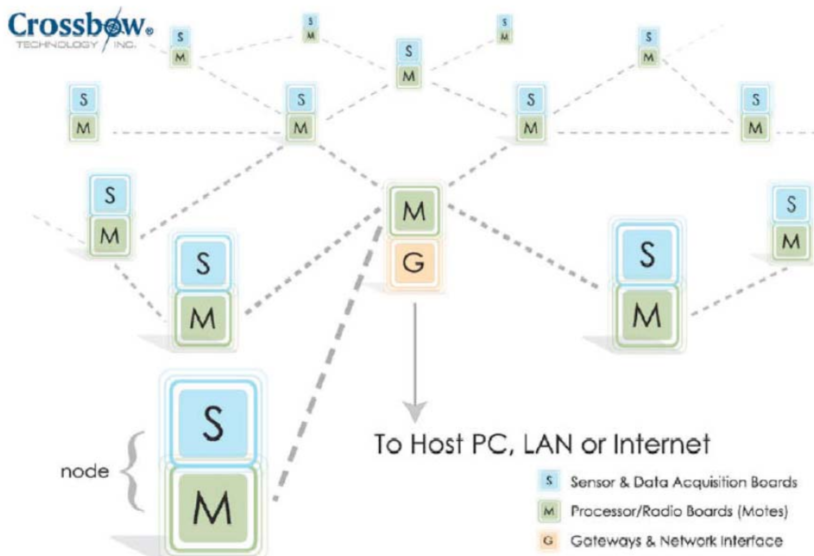
1. **MOTES / RADIOS**. The hardware platform consists of Processor/Radio boards (MPR) commonly referred to as Motes. These battery-powered devices run Crossbow's XMesh self-forming, micro-power, networking stack. In addition to running the XMesh networking stack, each Mote runs the open-source TinyOS operating system which provides low-level event and task management.

2. **SENSORS.** Sensor and data acquisition cards (MTS and MDA) mate directly to the Mote Processor Radio boards. The industry's widest range of sensor support includes both direct sensing as well as interfaces for external sensors.

3. **GATEWAYS.** The Stargate 'Gateway' and the Mote Interface Boards (MIB), allow developers to interface Motes to PCs, PDAs, the WWW, and existing wired/wireless networks and protocols.

4. **CUSTOMIZATION**. The TinyOS operating system is open-source, extendable, and scalable. Code modules are wired together allowing fluent-C programmers to rapidly customize existing applications written and distributed by Crossbow Technology

B. PICTURE.


Crossbow
TECHNOLOGY INC.
S
M
G
node
To Host PC, LAN or Internet
Sensor & Data Acquisition Boards
Processor/Radio Boards (Motes)
Gateways & Network Interface


S
MICAX SERIES
MICAXDOT SERIES
DATA ACQUISITION BOARD
SENSOR BOARDS
DATA ACQUISITION BOARD
SENSOR BOARDS
MDA300
MTS101
MTS300
MTS400
MTS310
MTS420
MDA500CA
MTS510CA
M
MICAz SERIES
MICA2DOT SERIES
MICA2 SERIES
MPR400
MPR500
MPR2400

K-2

APPENDIX L. INTER-4 TACTICOMP PDA

NPS does not endorse or recommend any of these commercial products/services. The information below was downloaded from the website www.xbow.com.

A. BACKGROUND. The Tacticomp handheld computer, with its internal networking capability that could provide the functionality of several pieces of gear, such as the Soldier radio, Global Positioning System receiver and laser rangefinder in one package.

B. PICTURE.

APPENDIX M. COASTS FUNCTIONAL AREAS

Functional Area	Personnel	Description
Project Oversight	Mr. Ehlert / Mr. Steckler Wg. Cdr Thanan (RTAF)	Guidance and management of overall project goals and operations.
Balloon / UAV Operations	LT Lee Capt. Valentine ENS Crouch	Build and establish an operating GPS/802.11 network node as payload on a balloon or UAV.
PDAs	Capt. Caceres LT Hochstedler	Provide connectivity for wearable computing via a personal data assistant.
802.11 Mesh	Capt Cooper Capt Thomason	Provide 802.11 connectivity for sensors with breadcrumbs.
OFDM	Capt. Caceres LT Hochstedler	Broaden the connectivity between a common base station and two or more remote locations within a wireless network.
Modeling & Simulation	Capt. Lancaster	Provide network models and simulations that match real world networking criteria.
Sensor Grid	LT Cone	Establish network monitored sensors comprised of GPS, video, audio, and other sensors.
Video	LT Cone LT Lee	Provide video connectivity to through the network to the NOC and TOC.
Network Topology	Mr. Clement Mr. Hale CPT Pailom (RTA)	Define the layer 1 (physical layer) requirements and components for the overall network operations.
Situational Awareness	Mr. Hale Mr. Clement	Interface with COTS providers to establish a situational awareness solution for the COASTS program.
Vuln. Assessment	Maj Oros Capt Goodwin Capt Kessel	Define, establish, and provide solutions for the critical network vulnerabilities.

APPENDIX N. NPS THESIS RESEARCH IN SUPPORT OF COASTS

Capt. Caceras	wearable computing devices ISO tactical USMC operations
LT Cone	integrating sensor technology to wireless networks
ENS Crouch	UAV swarming & human factors
LT Hochstetler	wireless network technologies ISO small boat/riverine operations
Capt. Lancaster	OPNET modeling and simulation
LT Lee	wireless network technologies ISO tactical jungle deployments
Capt Thomason	high-bandwidth end user tactical wireless networking / 802.11n
Capt. Valentine	COTS technologies ISO southern Thailand issues

APPENDIX O. MEASURES OF PERFORMANCE

Event	Team
Effectively assemble the balloon platform with winch.	Balloon
Effectively attach payload to balloon assembly.	Balloon
Launch and Recover balloon (altitude 3000 feet).	Balloon
Measure and evaluate the power requirements in order to create realistic estimates for the May demonstration.	Balloon
Effectively transmit video data through 802.11 b network to command post.	Balloon
Monitor throughput time for data transfer to command post.	Balloon
Monitor connectivity between UAVs and balloon payload.	Balloon
Monitor for GPS connectivity with balloon and command post. (Can we see the balloon with GPS software?)	Balloon
Effectively install and stabilize the camera, housing and blower.	Balloon
Effectively power the camera and blower using organic power supply	Balloon
Measure and evaluate the power requirements in order to create realistic estimates for the May demonstration.	Balloon
Effectively transmit video data through 802.11 b network to command post.	Balloon
Effectively view the transmitted data with a high degree of resolution and reliability.	Balloon
Effectively control the camera to conduct focus, pan, tilt, zoom functions.	Balloon
Effectively setup computer to digitize data from CyberDefense UAV RF link.	CyberDefense UAV
Transmit digitized video feed onto network through 802.11 breadcrumb network.	CyberDefense UAV
Effectively view the transmitted data with a high degree of resolution and reliability at the MCP.	CyberDefense UAV
Effectively provide GPS coordinates of the UAV and UAV control station to the MCC.	CyberDefense UAV
Effectively set-up and launch the Cyber Bug UAV (3 lb payload).	CyberDefense UAV
Test and maintain connectivity to the Cyber Bug UAV.	CyberDefense UAV
Effectively switch payloads between visible and IR cameras (3 lb payload).	CyberDefense UAV
Measure and evaluate power requirements for the May demo.	CyberDefense UAV
Explore and capture techniques, tactics and procedures which can be leveraged in further testing.	CyberDefense UAV
Effectively set-up and launch the Cyber Bug UAV (12.5 lb payload).	CyberDefense

	UAV
Effectively switch payloads between visible and IR cameras (12.5 lb payload).	CyberDefense UAV
Explore range limitations of RF link.	CyberDefense UAV
Effectively install and stabilize the 802.11 equipment.	RTAF AU-23
Effectively power the 802.11 equipment using organic power supply	RTAF AU-23
Measure and evaluate the power requirements in order to create realistic estimates for the May demonstration.	RTAF AU-23
Effectively transmit data through 802.11 network to command post in a mobile situation.	RTAF AU-23
Effectively control the camera to conduct focus, pan, tilt, zoom functions.	RTAF AU-23
Effectively run GPChat on Tacticomps and Laptops	MCP
Effectively display network status	MCP
Effectively display sensor data from each sensor node	MCP
Effectively communicate with each non-sensor node	MCP
Effectively access remote services across SATCOM	MCP
Effectively stream data across SATCOM	MCP
Effectively receive and respond to requests for data from MCP	RTSC
Effectively receive and display streaming data from MCP	RTSC
Effectively receive and respond to requests for data from MCP	RTAF HQ
Effectively receive and display streaming data from MCP	RTAF HQ
Associate Tacticomp to Mountain SSID in order to establish separate 802.11b WLAN at the Mountain Communications Facility.	Handheld
Associate Tacticomp to LopBuri SSID in order to establish separate 802.11b WLAN at downtown communication facility.	Handheld
Perform ping or like procedure to test connectivity across the wireless link.	Handheld
Access Internet, file server, or computer at MCP from a Tacticomp at both the Mountain Communications facility and Royal Thai Supreme Command at Lop Buri across the wireless 802.16 network.	Handheld
Transmit streaming video across the network.	Handheld
Test Voice Over IP functionality with headset on Tacticomp.	Handheld
Control Sony camera across the network.	Handheld
Activate GPS.	Handheld
Activate Situational Awareness software.	Handheld
Conduct network operations.	Handheld
Measure and evaluate whether the R-PDA successfully receives all situational awareness traffic and maintains a shared common operational picture.	Handheld
Measure and evaluate the ease of use, completeness and accuracy of shared common operational picture, and resolution provided to the tactical user.	Handheld

Measure and evaluate power requirements in order to create realistic estimates for the March Field Experiment.	Handheld
Explore and capture techniques, tactics and procedures which can be leveraged in further testing.	Handheld
Successfully align one foot flat panel antennas in order to establish a six mile point-to-point link between Mountain Communications Facility and MCP.	802.16
Successfully align two foot flat panel antennas in order to establish a ten mile point-to-point link between LopBuri and MCP.	802.16
Successfully connect host computer or switch on distant ends of the wireless link and ping across the network.	802.16
Access Internet, file server, or computer at MCP from a host at both the Mountain Communications facility and downtown communication facility at Lop Buri across the wireless 802.16 network.	802.16
Establish an 802.11 WLAN using WE Breadcrumb (SSID Mountain) off of the 802.16 link	802.16
Establish an 802.11 WLAN using WE Breadcrumb (SSID LopBuri) off of the 802.16 link	802.16
Utilize 802.16 link to transmit streaming video across the network using laptop (i.e. Panasonic CF-48) and Tacticomp.	802.16
Utilize 802.16 link to test Voice Over IP functionality with headset on Tacticomp.	802.16
Utilize 802.16 link to control Sony camera across the network using laptop (i.e. Panasonic CF-48) and Tacticomp.	802.16
Utilize 802.16 link to operate Situational Awareness software.	802.16
Conduct network operations	802.16
Measure and evaluate whether all host terminals successfully receive all situational awareness traffic and maintain a shared common operational picture.	802.16
Measure and evaluate the ease of installing, operating and maintaining an 802.16 wireless network, and completeness and accuracy of the shared common operational picture provided to the tactical user.	802.16
Explore and capture techniques, tactics and procedures which can be leveraged in further testing.	802.16
Effectively install and stabilize the 802.11 camera, housing and blower.	RTAF UAV
Effectively power the camera and blower using organic power supply	RTAF UAV
Measure and evaluate the power requirements in order to create realistic estimates for the May demonstration.	RTAF UAV
Effectively transmit video data through 802.11 network to command post in a stationary situation.	RTAF UAV
Effectively transmit video data through 802.11 network to command post in a mobile situation.	RTAF UAV
Effectively view the transmitted data with a high degree of resolution and reliability.	RTAF UAV

Effectively control the camera to conduct focus, pan, tilt, zoom functions.	RTAF UAV
Helicopter UAV TBD	
Handheld Linguistic Translator TBD	

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