NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

COVERING THE HOMELAND: NATIONAL GUARD UNMANNED AIRCRAFT SYSTEMS SUPPORT FOR WILDLAND FIREFIGHTING AND NATURAL DISASTER EVENTS

by

Robert G. Moose

December 2008

Thesis Advisor: James J. Wirtz
Second Reader: Timothy J. Doorey

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2008	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE: Covering the Homeland: National Guard Unmanned Aircraft Systems Support for Wildland Firefighting and Natural Disaster Events

5. FUNDING NUMBERS

6. AUTHOR(S) Robert G. Moose

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)

Over the past decade, the United States Government has had to cope with increasingly severe large-scale natural disasters. The 2004 hurricane season alone caused 167 deaths and an estimated $46 billion in damages. The following year, Hurricane Katrina took 1,330 lives and caused an estimated $96 billion in damages. The 2007 fire season saw over 85,000 wildland fires consume more than 9.3 million acres. In Southern California alone, wildfires forced over half a million people to evacuate their homes, destroyed over 3,079 structures, and caused over $1.8 billion in damages. This thesis examines the possible non-traditional and creative use of unmanned aircraft systems to mitigate the threat and effects of natural disasters, assist with search and rescue, and aid post-disaster recovery efforts. This work investigates the use of National Guard unmanned aircraft systems to provide lead agencies support prior to, during, and following major disaster incidents. The thesis also explores the benefits and challenges to setting up National Guard units operating unmanned aircraft systems within the United States equipped with specialized sensors in a similar fashion to the National Guard modular airborne firefighting system, and offers subjects for follow on research.

14. SUBJECT TERMS National Guard, Unmanned Aircraft System, Wildland Forest Fire, Natural Disaster, MQ-1 Predator, MQ-9 Reaper, Autonomous Modular Sensor, National Airspace System, Forest Service, National Interagency Fire Coordination Center, Department of Defense

15. NUMBER OF PAGES 125

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

THIS PAGE INTENTIONALLY LEFT BLANK

COVERING THE HOMELAND: NATIONAL GUARD UNMANNED AIRCRAFT SYSTEMS SUPPORT FOR WILDLAND FIREFIGHTING AND NATURAL DISASTER EVENTS

Robert G. Moose
Major, United States Air Force
M.S., University of North Dakota, 2007
B.S., Oregon State University, 1994

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF ARTS IN SECURITY STUDIES
(HOMELAND SECURITY AND DEFENSE)

from the

NAVAL POSTGRADUATE SCHOOL
December 2008

Author: Robert G. Moose

Approved by: James J. Wirtz
Thesis Advisor

Timothy J. Doorey
Second Reader

Harold A. Trinkunas
Chairman, Department of National Security Affairs

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Over the past decade, the United States Government has had to cope with increasingly severe large-scale natural disasters. The 2004 hurricane season alone caused 167 deaths and an estimated $46 billion in damages. The following year, Hurricane Katrina took 1,330 lives and caused an estimated $96 billion in damages. The 2007 fire season saw over 85,000 wildland fires consume more than 9.3 million acres. In Southern California alone, wildfires forced over half a million people to evacuate their homes, destroyed over 3,079 structures, and caused over $1.8 billion in damages. This thesis examines the possible non-traditional and creative use of unmanned aircraft systems to mitigate the threat and effects of natural disasters, assist with search and rescue, and aid post-disaster recovery efforts. This work investigates the use of National Guard unmanned aircraft systems to provide lead agencies support prior to, during, and following major disaster incidents. The thesis also explores the benefits and challenges to setting up National Guard units operating unmanned aircraft systems within the United States equipped with specialized sensors in a similar fashion to the National Guard modular airborne firefighting system, and offers subjects for follow on research.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

I would like to thank God for giving me the strength and courage to complete my studies. I would like to express my sincere appreciation to Professor James Wirtz, my thesis advisor, for his expert assistance and creative influence throughout this study. I would also like to specifically recognize CAPT Timothy Doorey, USN, for his expert opinion, guidance and patience during the research and completion of this thesis. My special thanks go out to Jeffrey Meyers at NASA's Ames Research Center, Commander Philip Hall at NASA's Dryden Flight Research Center, and Everett Hinkley at the United States Forest Service for their technical expertise and guidance during my research. Finally, I would like to extend my deepest gratitude to my lovely wife Angela and our wonderful children Alexis, Torin, and Kyra for their unconditional love and endless support.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. MAJOR RESEARCH QUESTION

The successful use of unmanned aircraft systems (UAS) to support combat operations has been proven in Operation ENDURING FREEDOM (OEF) and Operations IRAQI FREEDOM (OIF).[1] UASs continue to proliferate with the majority of the systems deployed to forward locations supporting on-going combat operations. In the near future, the Department of Defense (DoD) will possess a sufficient quantity of UASs that meet the combatant commander requirements and new UAS assets will remain state-side untasked.[2] The UASs remaining in the United States could provide a desperately needed capability to assist in natural disaster response assessment and recovery planning.[3]

Recent U.S. history reveals a compelling need for this capability in support of civil authorities in managing disaster response actions. Two compelling examples are the wildfire season of 2007 in Southern California and the combined effects generated by hurricanes Katrina and Rita in 2005.[4] This thesis will explore the capability and feasibility of using Department of Defense UAS assets to support civil authorities in response to natural disasters.

B. IMPORTANCE

Over the past decade, the United States Government has had to cope with increasingly severe large-scale natural disasters. Looking at the enormity of the problem begs the question, is there something more that could be done to

---

[1] *Government Accountability Office Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand Their Potential Uses within the National Airspace System*, (Washington, D.C. U.S. Government Accountability Office, May 15, 2008), Order No. GAO-08-511, 4.

[2] Office of the Secretary of Defense, *Unmanned Aircraft Systems Roadmap 2005-2030* (Washington, D.C., August 4, 2005), 67.

[3] Ibid., 3.

[4] Ibid., 11.

minimize the human suffering? A brief synopsis of select major natural disasters is telling. These disasters have significantly impacted the United States and stressed the United States Government during the resultant response efforts.

The United States has a long history of being affected by the Atlantic hurricane season. As the United States population has expanded over the last several decades, more people have moved closer to the coastline. The symbiotic interaction of an increasing population and global warming create a recipe for more severe disasters in the future, especially along the United State's coastline. The last five years provide anecdotal evidence to support this. The 2004 hurricane season caused 167 deaths and an estimated $46 billion in damages.[5] The following year, Hurricane Katrina became the most destructive natural disaster in United States history. The storm took 1,330 lives and caused an estimated $96 billion in damages.[6] One of the reasons for the incredible destruction was the amount of area the storm affected, over 93,000 square miles.[7] Being able to survey and cover this immense area to support recovery efforts is where unmanned aircraft systems have a niche.

In addition to the destruction caused by hurricanes, wildland forest fires have also become increasingly destructive. The United States Forest Service has spent over $1 billion a year on fire suppression in five of the last seven years.[8] This figure has tripled in the past 15 years as developments and population centers encroach on tracts of forest.[9] The statistical trends paint a bleak picture

---

[5] Frances Townsend, *The Federal Response to Hurricane Katrina: Lessons Learned* (Washington, D.C.: Office of the President of the United States, 2006), http://www.whitehouse.gov/reports/katrina-lessons-learned/chapter1.html (accessed December 4, 2008).

[6] Ibid.

[7] Ibid., 13.

[8] Arun Malik, "How Should We Tackle the Forest Fire Problem?" *Resources Magazine,* June 23, 2008, http://www.rff.org/Publications/WPC/Pages/08_06_23_Forest_Fires_Malik.aspx (accessed December 2, 2008).

[9] National Oceanic and Atmospheric Administration, "National Climate Data Center: Climate of 2007: Wildfire Season Summary," http://www.ncdc.noaa.gov/oa/climate/research/2007/fire07.html (accessed December 4, 2008).

for the future. In the past 25 years, the number of acres burned has nearly tripled. At the same time, the number of actual fires has been reduced by 50 percent, as depicted in Figure I and II.[10] In fact, six of the ten worst fire seasons have occurred since 2000. The 2007-fire season had the second most acres burned in United States history with over 85,000 wildland fires consuming more than 9.3 million acres.[11] This year was only surpassed by the acreage burned in 2006. In Southern California alone, wildfires forced over half a million people to evacuate their homes, destroyed over 3,079 structures, and caused over $1.8 billion in damages.[12]

---

[10] National Oceanic and Atmospheric Administration, "National Climate Data Center: Climate of 2007: Wildfire Season Summary," http://www.ncdc.noaa.gov/oa/climate/research/2007/fire07.html (accessed December 4, 2008).

[11] Ibid.

[12] California Department of Forestry and Fire Protection, *CAL FIRE 2007 Wildland Fire Summary* (Sacramento, CA: California Department of Forestry and Fire Protection, 2008), http://www.fire.ca.gov/communications/downloads/fact_sheets/2007Summary.pdf (accessed December 3, 2008), United States Bureau of Labor Statistics, *California Wildfires: An Employment and Wage Profile of the Affected Counties*, 2007, http://www.bls.gov/opub/ils/pdf/opbils63.pdf (accessed December 3, 2008), National Fire Protection Association, "Deadliest/large-Loss Fires," http://www.nfpa.org/itemDetail.asp?categoryID=954&itemID=23352&URL=Research&Reports/Fire statistics/Deadliest/large-loss fires&cookie_test=1 (accessed December 3, 2008).

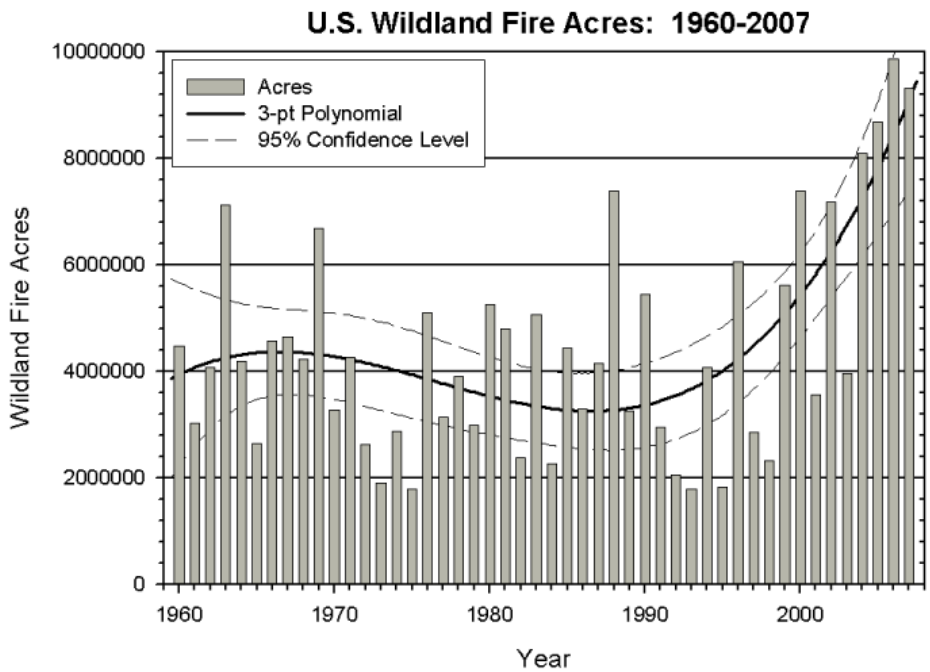

Figure 1. Increase in Acres Burned in United States[13]

[13] National Oceanic and Atmospheric Administration, "National Climate Data Center: Climate of 2007: Wildfire Season Summary."

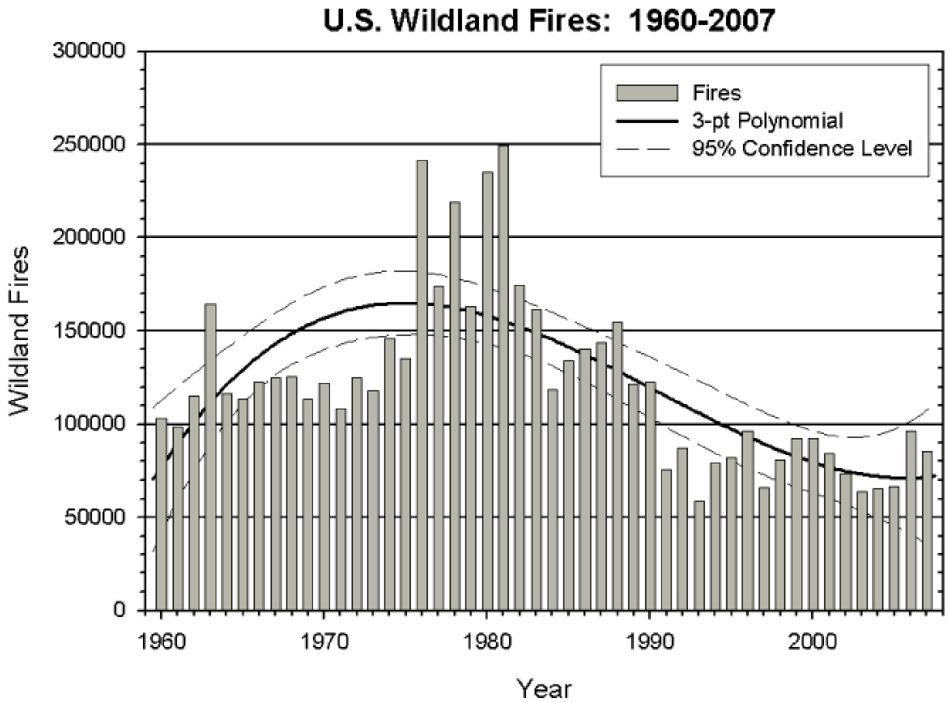

Figure 2. Decrease in Number of Fires[14]

The benefit UAS assets can provide to the civil authorities in assessing the damage caused by a natural disaster is unparalleled in the commercial sector.[15] There are also tangible benefits to using UAS assets to assist in fighting major wildfires. In the past, satellites have been used to assist firefighters battling large forest fires. The largest complaint from this usage was the revisit rate on data updates and classification issues.[16] UAS assets can provide continuous near real-time data on the fire. This type of data allows the lead agency (firefighters) to use available assets most efficiently. This data could be in the hands of the deployed firefighters near the fire lines, giving them a view of the fire

[14] National Oceanic and Atmospheric Administration, "National Climate Data Center: Climate of 2007: Wildfire Season Summary."

[15] *Government Accountability Office Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand Their Potential Uses within the National Airspace System,* 13.

[16] Jeffrey T. Richelson, *America's Silent Sentinels: DSP Satellites and National Security* (Lawrence, KS: University Press of Kansas, 1999), 235.

otherwise unavailable. This added capability makes it possible to fight the fire more efficiently and achieve containment sooner, reduce the severity of property damage, and reduce the risks to firefighters.

UAS assets can also provide considerable benefit in a post-disaster environment similar to hurricanes Katrina and Rita. Using the senor suites of the UAS, it is possible to gather comprehensive damage assessment data over broad areas.[17] This data makes it possible to determine the extent of the damage from flooding and wind damage. Based on this data, emergency planners can formulate a response and recovery plan, providing help to the most critical areas first. The UAS could also play a significant role in the search and rescue mission, helping locate survivors for rescue assets to recover.[18] In this role, UASs would be a force multiplier – saving time, money and lives.

The main area of friction in both of the two hypothetical scenarios listed above is the policy of using military assets to support civil government actions.[19] A traditional sticking point for using intelligence type assets in support of civil authorities is the legality of military assets collecting "intelligence data" over the United States. In either of the above roles, the legal challenges are minimized due to the nature of the data collected. This restriction and potential challenges originate from the use of Title 10 assets and also from Executive Order (EO) 12333.[20] An additional, but more minor legal issue is the end use of the data. Military collection of data used in support of law enforcement activities could

---

[17] John C. DeVane, *Applicability of Unmanned Aerial Systems to Homeland Defense Missions*, (Monterey, CA: Naval Postgraduate School, December 2006), 72.

[18] *Government Accountability Office Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand Their Potential Uses within the National Airspace System*, 11.

[19] Rusty L. Weiger, *Military Unmanned Aircraft Systems in Support of Homeland* Security (Carlisle Barracks, PA: U.S. Army War College, March 30, 2007), 5.

[20] Weiger, *Military Unmanned Aircraft Systems in Support of Homeland Security*, 6.

violate the Posse Comitatus Act (PCA).[21] Since there is no intention for the data to be used in any type of law enforcement role there should be not be any PCA challenges.

C. PROBLEMS AND HYPOTHESES

The main hypothesis of this thesis is to determine if UAS assets can and should be used to support civil authorities in response to wildfires or other major natural disasters. Of particular concern is where the assets are sourced as this has a significant impact on how they are employed. The research will show that National Guard UAS assets have fewer complications supporting civil authorities than do active duty assets.[22] National Guard assets are also geographically better situated to support requests from civil authorities in response to natural disasters.

This study also will show that using mission specific modular payloads for events such as wildfires provides significant benefit in support, while minimizing legal concerns. Crucial to the argument are the technical specifications of the baseline sensor suite integrated into the UAS. The limitations this sensor might produce for the firefighter will have to be mitigated. By looking at available commercial off the shelf (COTS) technology available, it is possible to integrate a sensor on the UAS to meet the firefighter's requirements.[23] It is envisioned that this data will allow firefighters to fight forest fires more efficiently, reducing costs, property damage, and personnel injury/death.

---

[21] Stephen R. Vina, *Border Security and Military Support: Legal Authorizations and Restrictions* (Washington, D.C.: Congressional Research Report for Congress, October 23, 2006), Library of Congress Congressional Research Service, Order Code RS22443, 2.

[22] Peter A. Topp, *What Should be the Relationship between the National Guard and United States Northern Command in Civil Support Operations Following Catastrophic Events* (Master's Thesis, Naval Postgraduate School, Monterey, CA), http://www.nps.edu (accessed July 24, 2008), 11.

[23] Michael Mecham, "Through the Smoke," *Aviation Week & Space Technology* 167, no. 11, September 17, 2007, 84, http://libproxy.nps.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=27129065&site=ehost-live&scope=site (accessed April 23, 2008).

A final issue is the legalities of using UAS assets domestically. Based on the current political and technological environment, some challenges might prove to be insurmountable. One of the largest problems with domestic UAS employment is the stigma attached to using military “intelligence” assets to collect data over the United States.[24] This concern is largely a moot point given the type of data collected. The data would not provide any semblance to an invasion of privacy. The data is application specific and is not of fine enough detail to single out individuals or provide attribution. The other major legal challenge to using UAS assets in support of civil authority requests is the ability to operate UAS assets in the National Airspace System (NAS). This is a significant challenge. There are possible measures and procedures that could be implemented to create a limited environment for safe UAS asset employment.

D. LITERATURE REVIEW

There is little research material or published works directly addressing UAS support to civil disaster responses involving forest fires or other major natural disasters. There are several common themes that persist throughout the body of current research. These themes are Homeland Defense roles for UAS assets; legal considerations and constraints; National Airspace System complications; and lack of discussion on applying UAS assets in civil support roles such as assisting in wildfire suppression and post disaster recovery efforts.

A significant amount of research has concentrated on the homeland defense role of the military in the post-9/11 environment.[25] There are several reports covering the use of UAS assets for Homeland Defense. Although these

[24] James Lillard Wilmeth IV, *United States Military Intelligence Support to Homeland Security* (Fort Leavenworth, KS: United States Command and General Staff College, May 26, 2004), 28.

[25] Elizabeth E. Dreiling, *The National Guard: A Future Homeland Security Paradigm?* (Fort Leavenworth, KS: U.S. Army Command and General Staff College, May 14, 2002); Jason T. Garkey, *In Support of the Common Domestic Defense: Unity of Command between Federal and State Controlled Military Forces* (Newport, RI: Naval War College, February 13, 2006); Kenneth A. Wheeler, *Evolving Military Strategy and Developing Homeland Security: An Opportunity to Share Resources* (Carlisle Barracks, PA: U.S. Army War College, May 3, 2004); U.S. Department of Defense, *Strategy for Homeland Defense and Civil Support* (Washington, D.C., June 2005).

works do not address the topic of this thesis, they do contribute some necessary portions of the argument. The relevant portion is the process for requesting Department of Defense support for domestic situations.[26]

Another related theme in the literature is the legality of using UAS intelligence sensors within the United States. The most often cited legal hurdles addressed are the Posse Comitatus Act and EO 12333.[27] For this thesis, focusing on National Guard employment of UAS assets will largely minimize these issues. Typically, PCA does not apply to National Guard forces in a state active duty role or under Title 32 status.[28] For the scenarios covered by this thesis, it is highly unlikely that National Guard forces employing UAS assets would be under Title 10 status, and thus, would not fall under the provisions of PCA.

There are two significant works that discuss UAS assets. The first source is the *Unmanned Aircraft Systems Roadmap 2005-2030.* This work covers all aspects of current UAS assets the Department of Defense employs, including a good overview of the airspace issue that must be overcome. The second work is a RAND report titled *Unmanned Aerial Vehicles: End-to-End Support Considerations*. This piece covers funding and fielding of UAS assets, a discussion not found in other works discovered to date.

An often-highlighted problem with UAS use is the ability of the assets to be used in domestic airspace.[29] This is a common theme in the literature and there are no concrete solutions offered. The best work covering this topic is the Government Accounting Office's report *Unmanned Aircraft Systems: Federal*

---

[26] *Government Accountability Office Technology Assessment: Protecting Structures and Improving Communications during Wildland Fires* (Washington, D.C.: U.S. Government Accountability Office, April 26, 2005), Order No. GAO-05-380. 62.

[27] DeVane, *Applicability of Unmanned Aerial Systems to Homeland Defense Missions*, 49.

[28] Alane Kochems, *Military Support to Civilian Authorities: An Assessment of the Response to Hurricane Katrina*, Backgrounder No. 1899 (Washington, D.C.: The Heritage Foundation, November 28, 2005), 3, http://www.heritage.org/research/homelanddefense/bg1899.cfm (accessed April 27, 2008).

[29] Office of the Secretary of Defense, *Unmanned Aircraft Systems Roadmap 2005-2030*, F-1.

Actions Needed to Ensure Safety and Expand Their Potential Uses within the National Airspace System. The National Airspace System issue will have to be addressed in the thesis, although it is unlikely that a workable comprehensive solution exists at this time. The solution rests on a technological break-through in sense-and-avoid technology.[30] The literature does indicate that there are efforts between the Federal Aviation Administration and Department of Defense to create procedural practices to allow limited UAS use of civil airspace.[31] A procedural based solution has potential on limited scales.

E. METHODS AND SOURCES

This thesis will utilize both process tracing and comparative analysis methodology. The process tracing will detail the requirements necessary to utilize an UAS asset in support of civil authorities. The comparative analysis will be based on currently fielded systems used to combat forest fires[32] and an experimental system employed by NASA during previous wildfire seasons.[33] Some lessons learned from previous tests can be applied to Department of Defense UAS asset employment. Both of these cases serve as the foundation for future UAS employment in a civil support role not related to law enforcement. The process of reconfiguring the assets and any employment considerations due to the changed configuration will be addressed.

This thesis will use primary sources through personal interviews with senior members of Cal Fire, the Federal Emergency Management Agency (FEMA), the Federal Aviation Administration (FAA), and the Department of Homeland Security (DHS). Additional resources may be utilized from academic reports and journals along with professional journals that cover topics related to

---

30 *Government Accountability Office Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand Their Potential Uses within the National Airspace System*, 3.

31 Ibid., 35.

32 *Government Accountability Office Technology Assessment: Protecting Structures and Improving Communications during Wildland Fires*, 66.

33 Mecham, "Through the Smoke," 84.

UAS employment. These sources will be available through database search engines such as EBSCO, LexisNexis, ProQuest, Project MUSE, Homeland Security Digital Library, and DTIC STINET.

F. THESIS OVERVIEW

The thesis will be organized into five chapters. The first chapter will serve as an introduction and provide the reader an overview of the current UASs fielded, which have the capability to provide the type of support described in this work. The second chapter will discuss the legal issues pertinent to employing UAS assets in a civil support role. The third chapter will discuss the sensor capabilities and limitations and available means to mitigate the shortfalls. The fourth chapter will cover the communications architecture required to provide the necessary support to emergency operations centers (EOCs) and front line firefighters. The final chapter is a conclusion compiling the data from Chapters II, III and IV to demonstrate how UAS assets will support civil authorities during both wildfire and natural disaster emergency responses.

THIS PAGE INTENTIONALLY LEFT BLANK

II. LEGAL AND SUITABILITY ISSUES

A. INTRODUCTION

There are two considerations that must be taken into account to use UASs in a Homeland Security role. First, the legality of using UAS assets to support domestic missions has to be assessed. Legal considerations include the role intelligence oversight plays, the Economy Act, and the Stafford Act. The second challenge is access to the National Airspace System (NAS). Both of these issues have to be addressed to permit routine use of UAS assets within the United States in support of Homeland Security missions. These issues will be addressed in this chapter.

Important to the discussion on intelligence oversight, the Economy Act, and the Stafford Act discussions is the status of forces operating the UAS assets. The underlying assumption for this thesis is that National Guard forces will be the primary units providing UAS support to domestic situation whether natural disasters or wildland forest fires. By focusing on National Guard forces, the legal issues are dealt with in the Title 32 arena, unless the President activated the forces under Title 10. For cases where National Guard units are federalized, standard active duty restraints stipulated for Title 10 forces will apply. In such situations, it is assessed that the overall impact is minimal given the nature of the missions and support envisioned in this thesis is not of a law enforcement nature, and thus, the Posse Comitatus Act will have negligible affect. In most cases, National Guard units will be working for the governor of their respective state and Posse Comitatus Act restrictions will not be a significant factor impacting mission accomplishment.

Just as important as having a solid legal foundation to gain approval for mission execution, it is critical to gain approval to operate the UAS assets in airspace other than the restricted airspace controlled by the military. It is hard to imagine all natural disasters and wildland forest fires being confined to land situated under restricted airspace. This, in fact, has not been the case over the past 10 years. To support these types of incidents, access to the National Airspace System is an overarching requirement. The specifics on why access has been limited to date, some successful integration cases, and possible procedural solutions for future operations will be investigated in this chapter.

B. INTELLIGENCE OVERSIGHT

The use of military forces to conduct missions on U.S. territory is constrained by both laws and historical public policy.[34] In recent history, tension has existed between the intelligence community and the American public. The findings of the Church Committee highlight this tension. The Church Report revealed that intelligence agencies had been collecting intelligence on U.S. citizens from 1936 to 1976 without any congressional oversight.[35] This activity, sanctioned by the Executive Branch, was determined to be an abuse of liberties and privacy rights.

Largely in response to the Church Committee findings, President Ronald Reagan enacted Executive Order 12333 in 1981. This order gave domestic intelligence collection responsibility to the Federal Bureau of Investigations (FBI). This dovetailed with the National Security Act of 1947, which focuses services' intelligence collection activities on foreign entities to support national security. In 1978, Congress enacted the Foreign Intelligence Surveillance Act (FISA) to limit electronic surveillance of U.S. citizens.[36]

---

34 Department of Defense, *Strategy for Homeland Defense and Civil Support* (Washington D.C., 2005), 26.

35 Frank Church and John G. Hightower, *Intelligence Activities and the Rights of Americans: Book II* (Washington, D.C., U.S. Government Printing Office, 1976), http://www.aarclibrary.org/publib/church/reports/book2/pdf/ChurchB2_2A_Summary.pdf (accessed 24 July 2008).

36 John C. DeVane, *Applicability of Unmanned Aerial Systems to Homeland Defense Missions* (Master's Thesis: Naval Postgraduate School, Monterey, CA), 49, http://www.nps.edu (accessed July 24, 2008).

In the post-9/11 environment, more people have become vocal about potential intelligence community infringement on their civil liberties and rights, which have occurred allegedly under the auspices of counter-terrorism. The use of UASs is one of the areas that concerns the population.[37] People fear that when UASs provide coverage for various events, there will be continuous surveillance of their activities. In most cases, this is fear is not a reality. UASs would be used under specific criteria and conditions where the needs of the many will outweigh the fears of a few.

What causes concern is the ability of UAS sensor capabilities, which allow individuals to be observed. It does not matter if the civilian is the target of the sensor or merely incidental target in the sensor's field of view.[38] What is often overlooked, however, is the precedents related to surveillance have already been set. The people who raise the objections do not make the same case for the removal of video cameras that record their movements in banks, department stores, or convenience stores. These individuals recognize that the cameras serve a purpose -- to deter criminal activity -- and if the activity is not deterred, to help catch and prosecute criminal acts.

1. Posse Comitatus Act

The U.S. Constitution provides for the use of military force to protect the nation. Despite the legal framework the founding fathers provided to guide and protect the nation, there have been cases where this was not followed.[39] These

---

37 United States Government Accountability Office, Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand their Potential Uses within the National Airspace System (Washington D.C.: U.S. Government Accountability Office, 2008). Since applications covered in this work do not cover electronic surveillance capabilities, FISA constrains will not be discussed.

38 DeVane, *Applicability of Unmanned Aerial Systems to Homeland Defense Missions*, 50.

39 John R. Brinkerhoff, "The Posse Comitatus Act and Homeland Security," *Journal of Homeland Security* (September 13, 2005), 3, http://www.homelandsecurity.org/journal/Articles/brinkerhoffpossecomitatus.htm (accessed July 24, 2008).

instances provided the situation for the creation of additional legal restrictions on the use of force. To ensure the military was not used domestically, a 19th century law was created called the Posse Comitatus Act (PCA). This law states:

> Whoever, except in cases and under circumstances expressly authorized by the Constitution or Act of Congress, willfully uses any part of the Army or the Air Force as a posse comitatus or otherwise to execute the laws shall be fined under this title or imprisoned not more than two years, or both.[40]

PCA typically prohibits the use of the federal military in activities such as arrest, seizure of evidence, search of persons, search of buildings, investigation of crime, interviewing witnesses, pursuit of an escaped prisoner or search of an area for a suspect.[41] This does not prevent federal military units from providing logistical support, technical advice, facilities, training, and other forms of assistance to civilian law enforcement agencies even through the assistance may aid those activities.[42] Most military support to civil agencies is characterized as passive support, and thus, does not violate the provisions of PCA.[43] The legality of military support to civil authorities was reinforced in the Homeland Security Act of 2002:

The Posse Comitatus Act has served the Nation well in limiting the use of the Armed Forces to enforce the law. Nevertheless, by its express terms, the Posse Comitatus Act is not a complete barrier to the use of the Armed Forces for a range of domestic purposes, including law enforcement functions, when the use of the Armed Forces is authorized by Act of Congress or the President

---

40 *U.S. Code: Title 18, Section 1385 use of Army and Air Force as Posse Comitatus,* (1878): 1385, http://uscode.law.cornell.edu/uscode/html/uscode18/usc_sec_18_00001385----000-.html (accessed July 24, 2008).

41 Jeffrey D. Brake, *Terrorism and the Military's Role in Domestic Crisis Management: Background and Issues for Congress* (Washington, D.C.: Library of Congress Congressional Research Service, 2001).

42 Ibid.

43 Ibid.

determines that the use of the Armed Forces is required to fulfill the President's obligations under the Constitution to respond promptly in time of war, insurrection, or other serious emergency.[44]

It is equally important to understand who is and is not subject to PCA restrictions.[45] As a general rule, federal forces, those serving in a Title 10 capacity, are subject to PCA restrictions. Those forces serving under Title 32, state militia forces serving under the control of the state governor, are not subject to PCA restrictions.[46]

2. Executive Order 12333

Executive Order 12333 is important for the use of UAS assets because these assets typically fulfill an intelligence type mission when employed in a combat environment. In the domestic environment, these assets may provide surveillance of the current situation to assist incident commanders on the scene of a disaster. Several Department of Defense (DoD) directives and instructions support the Executive Order by refining requirements and rules for the use of military intelligence assets in support of civil authorities. Department of Defense Instruction (DoDI) 5240.1-R, *Procedures Governing the Activities of DOD Intelligence Components that Affect United States Persons* outlines the rules for collecting information on U.S. persons.[47] Department of Defense Directive (DoDD) 5240.1, *DoD Intelligence Activities,* DoDD 5200.27, *Acquisition of Information Concerning Persons and Organizations not Affiliated with DoD,* DoDD 5525.5, *DoD Cooperation with Civilian Law Enforcement Officials,* and

[44] *Homeland Security Act of 2002,* Public Law H.R. 5005, (2002): 1, http://www.dhs.gov/xlibrary/assets/hr_5005_enr.pdf (accessed July 26, 2008).

[45] DeVane, *Applicability of Unmanned Aerial Systems to Homeland Defense Missions*, 55.

[46] Jason T. Garkey, "In Support of the Common Defense: Unity of Command between Federal and State Controlled Military Forces," *Naval War College*, 5, http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA463544&Location=U2&doc=GetTRDoc.pdf (accessed July 24, 2008).

[47] Under Secretary of Defense for Policy, *DoD Instruction 5240.1-R Procedures Governing the Activities of DOD Intelligence Components that Affect United States Persons* (Washington, D.C.: Department of Defense, 1982), 64, http://www.dtic.mil/whs/directives/corres/pdf/524001r.pdf (accessed August 8, 2008).

DIAI 5210.001, *Security Classification of Airborne Sensor Imagery* all provide additional guidance for the use of military assets in assisting civil authorities.[48] The type of request and the specific effects desired will determine whether the military asset can be used and what restrictions are placed on the collection and handling of information. Needless to say, there is an existing legal framework that permits the use of military assets in the domestic environment.

There are two types of sensors that will predominantly be used to support civil authorities. A thermal imager will be used to support forest fire fighting activities and synthetic aperture radar will be used to support major disaster recovery operations. Neither of these two sensors provides the fidelity of data necessary to increase the ire of those concerned with civil liberties and personal privacy. Each of the sensors is looking for data in the electromagnetic spectrum outside the visible realm where it could be attributable to an individual. This will impact the ability of the data to be shared with civil authorities. With no "U.S. persons" data captured, the restrictions on collecting and sharing the data will be greatly reduced.

An additional legal issue to consider when contemplating the employment of UAS assets in support of wild fires or major natural disasters is the Economy Act. This piece of legislation is the "primary law that allows federally controlled military assistance in wildland firefighting."[49] It allows federal agencies to purchase goods and services from other federal sources on a strictly reimbursable basis. The Economy Act is utilized when funds are available, it is decided that the request is in the best interests of the government, the services can be provided by the requested agency, and the requesting agency decides the resources cannot be provided by contract as conveniently or cheaply by commercial enterprises.[50] What is not required is for all commercial resources to

[48] DeVane, *Applicability of Unmanned Aerial Systems to Homeland Defense Missions*, 57.

[49] United States Government Accountability Office, *Technology Assessment: Protecting Structures and Improving Communications during Wildland Fires* (Washington, D.C.: U.S. Government Accountability Office, 2005).

[50] Ibid.

be exhausted prior to requesting assistance from a separate agency.[51] It is typically utilized prior to the President issuing a disaster declaration. Once the disaster declaration has been made, it activates an additional piece of legislation, the Stafford Act.

The Robert T. Stafford Disaster Relief and Emergency Assistance Act provides the legal foundation for the President to declare major disaster declarations. In doing this, the President also is authorized to direct federal agencies to provide assistance to states that are overwhelmed by the effects of the disaster, to include wildland fires. The Act also defines the type and scope of available assistance from the federal government. Additionally, the Act sets the specific conditions necessary for obtaining the assistance. This includes directing the Department of Defense to utilize resources in support of state civil authorities. Upon requests from state governors, the President can direct federal troops to deploy to states to provide defense support for the mission areas civil authorities have requested. One key requirement is for the Governor of the requesting state to certify that an effective response is beyond the capabilities of the state and local government. Once this has occurred, the President can "direct any federal agency to provide assistance to any state or local government for the mitigation, management, and control of any fire on public or private forest land or grasslands if it threatens to become a major disaster."[52]

In addition to these two pieces of federal legislation, there is a Department of Defense Directive that establishes the official Department of Defense policy on providing military assistance to civil authorities.[53] Department of Defense Directive 3025.15 assigns responsibilities and states the approval authorities

[51] United States Government Accountability Office, *Technology Assessment: Protecting Structures and Improving Communications during Wildland Fires.*

[52] Ibid.

[53] Ibid.

necessary for a request to be granted.[54] Each request is evaluated on the following criteria: legality, lethality, risk, cost, appropriateness, and readiness. Provided all these factors are favorable, a determination is made on whether the resources are available and the impact their use for firefighting has on military readiness. In the end, "the Secretary of Defense approves the order to deploy Department of Defense resources"[55] to support firefighting efforts.

Homeland Security Presidential Directive 5 gives the Secretary of Defense the responsibility to provide military support to civil authorities. This is done on the basis of three criteria: consistent with military readiness, legal, and appropriate. In a wildfire disaster declaration or other natural disaster emergency declaration, United States Northern Command (NORTHCOM) retains operational responsibility for executing the civil support mission once the Secretary of Defense approves. This type of Department of Defense support would take the form of "Military Support to Civil Authorities" (MSCA).[56]

For federal forces, the Federal Emergency Management Agency (FEMA) will reimburse the Department of Defense for incremental costs associated with civil support services provided. This means that FEMA will only cover the costs the federal government would not have otherwise incurred, like the troop's salary. This becomes a little more complicated when discussing National Guard forces in a Title 32 status, thus working for the state governor and not federalized. In this case, the state will have to cover a portion of the costs associated with employing Title 32 forces. The state can request federal assistance in funding the state

[54] John P. White, *DoD Directive 3025.15 Military Assistance to Civil Authorities* (Washington, D.C.: Department of Defense, 1997), 16, http://www.dtic.mil/whs/directives/corres/pdf/302515pdf (accessed August 8, 2008).

[55] United States Government Accountability Office, *Technology Assessment: Protecting Structures and Improving Communications during Wildland Fires*, 74.

[56] Alane Kochems, *Military Support to Civilian Authorities: An Assessment of the Response to Hurricane Katrina*, Backgrounder No. 1899 (Washington, D.C.: The Heritage Foundation, 2005), 2, http://www.heritage.org/research/homelanddefense/bg1899.cfm (accessed July 24, 2008).

active duty costs, but on a shared basis.[57] In states with National Guard units assigned UAS assets, the Governors still need express approval from the Secretary of Defense to use the Department of Defense UAS assets.[58]

C. NATIONAL AIRSPACE SYSTEM

Several legal hurdles must be crossed to utilize UAS assets in support of civil authorities requests. It is conceivable that the public can move past the use of traditional intelligence platforms being used to support natural disasters. In the end, many of the legal hurdles are manageable. The main stumbling point that will prevent UAS assets from supporting the next major natural disaster is access to the National Airspace System (NAS). This has been the largest and most contentious topic surrounding the use of UAS assets to support civil missions. It is of primary concern because if the UAS cannot get airborne, all the intelligence oversight and Stafford Act considerations are a moot point. The current rules enforced by the Federal Aviation Administration (FAA) require UAS assets to follow the same certification regulations as manned aircraft.[59] Until that happens, the FAA will not permit the UASs to fly except with a very specific exemption – a Certificate of Waiver or Authorization (COA).[60]

---

57 Peter A. Topp, *What Should be the Relationship between the National Guard and United States Northern Command in Civil Support Operations Following Catastrophic Events* (Master's Thesis, Naval Postgraduate School, Monterey, CA), http://www.nps.edu (accessed July 24, 2008), 20.

58 Rusty L. Weiger, *Military Unmanned Aircraft Systems in Support of Homeland Security* (Master of Strategic Studies, U.S. Army War College), 6, http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA469646&Location=U2&doc=GetTRDoc.pdf (accessed July 24, 2008).

59 United States Government Accountability Office, *Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand their Potential Uses within the National Airspace System*, 17.

60 *JO 7610.4M* (Washington D.C.: Federal Aviation Administration, 2007), 12-9-1, http://www.faa.gov/ (accessed July 24, 2008).

1. Current Restrictions

The current situation for UASs in the NAS is that they have to be confined to restricted or warning airspace.[61] Getting off the military reservation and into the general aviation airspace is where problems arise. The Federal Aviation Administration cites three main areas as requirements for routine access to the National Airspace System by UASs.

The first requirement is for the UAS to be able to operate in a fashion similar to a manned aircraft; that is, be able to observe the right of way rules and prevent mid-air collisions.[62] This requires the UAS to be able to sense-and-avoid other air traffic. Current efforts are under way to develop and field this type of technology so that UAS pilots will have the situational awareness and sufficient time to react to threatening air traffic to avoid collisions. The balance that has to be struck is between autonomous systems that will automatically maneuver the air vehicle to avoid a collision and systems that provide indicators to the pilot so avoidance maneuvers can be implemented manually.[63] Either means requires that the aircraft maintain the portion of airspace it is allocated. If the UAS is assigned a set altitude, the UAS will have to maneuver within that altitude, causing the pilot to have a single option of moving laterally.

Active systems and passive systems are under development.[64] For military UAS systems, a passive system would be desired in a combat environment because giving off emissions is not desired. Part of the mission set for the UAS is to be stealthy to avoid detection so the enemy does not know they are being watched. This has little bearing on civil support to natural disasters as those emergency responders and crews on the ground do not care if they are

---

[61] *JO 7610.4M*.

[62] Office of the Secretary of Defense, *Unmanned Systems Roadmap 2007-2032* (Washington, D.C.: Department of Defense, 2007), http://www.acq.osd.mil/usd/Unmanned%20Systems%20Roadma2007-2032.pdf (accessed July 24, 2008).

[63] Ibid.

[64] Ibid.

being watched or not; the incident command post just wants the data. For an active system that gives off emissions and uses the returns to build a picture for the pilot, this system would have the most appeal for a domestic use. Using an active system, it could be designed to sense the entire area around the UAS out to a specific distance, thus giving the pilot enough time to react and avoid potential collisions.

A passive detection system, while desired for combat theater employment on the grounds of survivability, would require the emissions of other aircraft. One model is to have a receiver that can receive the transponder signals of other civil aircraft.[65] This would require all aircraft flying in the National Airspace System to carry a transponder and to have it functioning properly prior to takeoff. Once the "what ifs" start, it is easy to see the complications with potential scenarios. If a plane is working fine on takeoff and the transponder breaks halfway through a two-hour flight, should the aircraft be forced to land to get the transponder fixed? How does the pilot of the aircraft know the transponder is no longer working properly? There are many complications that would have to be addressed, along with associated weight penalties impacting payload and range. The best solution is a combination of both active and passive detection systems to build the most complete situational awareness for the UAS pilots to avoid potential danger.

A second requirement the Federal Aviation Administration insists on is certification of the pilots and airframes. Under the current Federal Aviation Administration Regulations, the military is responsible for certifying both pilots and airframes operated by the services.[66] There is no Federal Aviation Administration certification for an F-16, nor are F-16 pilots officially certified under Federal Aviation Administration regulations or standards. The Department of Defense has agreed to establish its standards, to at a minimum, meet the Federal Aviation Administration standards and often the military requirements

[65] Office of the Secretary of Defense, *Unmanned Systems Roadmap 2007-2032.*

[66] Ibid.

exceed what the Federal Aviation Administration requires.[67] The certification for airworthiness of the airframe is a little different issue in the eyes of the Federal Aviation Administration. While the Federal Aviation Administration recognizes that military fighter aircraft have accidents, they accept that given the operating envelop, these losses are acceptable. The Federal Aviation Administration position on UAS, which hope to become certified for use in the National Airspace System, is for their reliability to approach that of the general aviation community.[68] To meet this goal, the UAS accident rate would have to get below a threshold of roughly one accident for every 100,000-flight hours.[69] Up until 2003, there were no UASs that had acquired that number of hours on the airframe. With all the activity in Iraq and Afghanistan, the MQ-1 Predator has surpassed that critical number, but the accident rate still remains around 32 accidents per 100,000 flight hours.[70] When a comparison is drawn between the different UAS systems, the MQ-1 is on par with or better than the F-16 for the respective place in the development and operational use of the aircraft.[71]

The main areas where reliability can be improved are in propulsion and takeoffs and landing. A large portion of UAS failures is the result of propulsion failures.[72] The second leading cause of accidents is pilot error, although the number of pilot errors in UASs is significantly less than in manned aircraft.[73] In addition to these two factors, the poor reliability numbers for UASs has been impacted by the means with which many of these systems were procured. There

[67] Office of the Secretary of Defense, *Airspace Integration Plan for Unmanned Aviation* (Washington, D.C.: Department of Defense, 2004), http://www.uavm.com/images/OSD_Airspace_Integration_Plan_112304_Airspace.pdf (accessed July 24, 2008).

[68] Office of the Secretary of Defense, *Unmanned Aerial Vehicle Reliability Study* (Washington, D.C.: Department of Defense, 2003), http://www.acq.osd.mil/uas/docs/reliabilitystudy.pdf (accessed July 24, 2008).

[69] Ibid.

[70] Ibid.

[71] Ibid.

[72] Ibid.

[73] Ibid.

is ample evidence supporting the lack of adequate testing being accomplished prior to the Department of Defense procuring the systems. This has resulted in frequent accidents and redesigning of the UASs to correct initial deficiencies.[74]

Under the current rules and regulations, UAS assets can gain access to the National Airspace System by receiving Federal Aviation Administration approval for a certification of authorization or waiver. The application for a certification of authorization or waiver has to be submitted “at least 60 days prior to the proposed commencement of UAS operations.”[75] There is a note in the publication that says, “in the event of real-time, short notice, contingency operations, this lead time may be reduced to the absolute minimum necessary to safely accomplish the mission.”[76] To complete the authorization or waiver request, the operator must provide nine pieces of information in the request:

1. Detailed description of flight operations including type of airspace
2. The physical characteristics of the UAS
3. UAS Flight performance characteristics
4. How the UAS will be piloted and how other aircraft will be avoided
5. Coordination procedures
6. Communications procedures
7. Routing and altitude procedures
8. Lost link or mission aborting procedures
9. Airworthy statement[77]

The fourth requirement is the source of the traditional sticking point involving routine access to the National Airspace System. The intent of the Federal Aviation Administration is to require the UAS operator to “provide the UAS with a method that provides an equivalent level of safety, comparable to

---

[74] United States General Accounting Office, *Force Structure: Improved Strategic Planning Can Enhance DOD's Unmanned Aerial Vehicles Efforts* (Washington, D.C. U.S. General Accounting Office, 2004)

[75] *JO 7610.4M*, 12-9-1.

[76] Ibid.

[77] Ibid.

see-and-avoid requirements for manned aircraft."[78] There are two different means to address this issue, through procedural fixes or through technological fixes. For the best solution, both of these would be combined to provide an added measure of comfort that potential collisions could be avoided.

There are a few additional requirements that Federal Aviation Administration mandates for UAS access to the National Airspace System utilizing a certification of authorization or waiver. The stipulation is the authorization or waiver is only good for a duration not to exceed one year.[79] This can play into the emergency management professional's favor by doing the legwork ahead of time to get the necessary requests in place in advance. While the use of UAS assets under an authorization or waiver would not be the same as "file and fly" procedures, which is where the UAS community would like to get to someday, it does greatly expedite the process and shorten the timeline for increased responsiveness. The Federal Aviation Administration also requires the UAS asset to have anti-collision lighting and a tunable transponder, which can be retuned in flight by the pilot.[80] Additionally, there is a requirement for instantaneous two-way communication between the pilot of the UAS and the Air Traffic Control facility responsible for the airspace the UAS is occupying. This is necessary for the pilot to respond to air traffic control clearances and advisories. The final requirement is for the UAS pilot to be responsible for collision avoidance with all non-participating aircraft and the safety of persons and property on the ground.[81]

One of the biggest hurdles to be overcome in gaining access to National Airspace System is the lack of policy documentation and established standards issued by the Federal Aviation Administration with which UAS manufacturers must comply. The first Federal Aviation Administration national policy document

---

[78] *JO 7610.4M*.

[79] Ibid.

[80] Ibid.

[81] Ibid.

to address UAS assets was issued on 27 March 2008. This is remarkable given the U.S. Air Force has been operating Predator UASs since 1994. On 17 April 2008, the Federal Aviation Administration authorized certification for the third General Atomics Predator B. The certification is an Experimental Certification, as the UAS will be used for continuation research and development and crew training.[82]

2. Operational Test Procedures Used to Date

There have been several test cases conducted to determine what benefit UAS assets can provide to emergency managers. The test cases all involved the National Aeronautics and Space Administration (NASA) Ikhana UAS, a modified Predator B. NASA submitted a certification of authorization or waiver for the operation of their UAS to survey wildfires in the Western United States during 2006, 2007 and again in 2008. In the NASA authorization, items such as detailed descriptions on the operations to be conducted, the ground system, and the communications and telemetry system were all covered. NASA also had to specify what would happen to the UAS should the command and control communications link drop out. To outline all these factors to the Federal Aviation Administration's satisfaction in 2006 took six months. The efforts to support the 2007 and 2008 fire seasons has led to a streamlined process for drafting and processing the authorization or waiver with the Federal Aviation Administration.[83]

The Federal Aviation Administration has also demonstrated the ability to grant certification of authorization or waivers on short notice. A case in point was a short notice tasking to NASA from the California governor for fire coverage in support of the Esperanza Fire Incident Command Center. In roughly 24 hours, an authorization was approved and the UAS was able to get airborne to provide the

---

[82] "UAS News January - June 2008," *Federal Aviation Administration,* http://www.faa.gov/about/office_org/headquarters_offices/avs/offices/air/hq/engineering/uavs (accessed August 6, 2008).

[83] Jay Levine, *The Ikhana: Uninhabited Aircraft System is Changing the Way Fires are Fought and Proving to be a Valuable Science Tool*, ed. Jay Levine (Edwards, CA: National Aeronautics and Space Administration, 2008), 4, http://www.nasa.gov (accessed July 24, 2008).

desired support. The result was 16 hours of coverage above the fire, which helped firefighters allocate resources to fight the fire.[84] Building on this success, NASA started drafting a certification of authorization or waiver for the 2007 fire season in late 2006. Part of the delay involved in getting the authorization signed off was the nature of the geographic boundaries NASA requested. Requesting permission to fly the UAS in airspace that ranges from the Mexican-U.S. border to Canada and from the Pacific Ocean to central Colorado generated pushback by the Federal Aviation Administration. As part of the certification of authorization or waiver, NASA identified over 280 potential landing sites should an emergency landing be required.[85]

NASA submitted the 2007 authorization request in February with the hope that it would be approved by July before the fire season really got started in August. When the request was finally approved, it was significantly scaled back geographically and included a stipulation that a flight plan had to be submitted three days prior to flight.[86] This reduced the types of fires Ikhana could support. It also complicated the utility of the flight plan because a fire can move significantly in three days. To their credit, Federal Aviation Administration air traffic controllers were responsive and accommodating in allowing the UAS to adjust the filed flight plan to adjust to the movement in the fire.[87]

On its first flight in 2007, Ikhana flew 1,200 miles during a ten-hour mission supporting the Zaca Fire in Santa Barbara County. This mission proved the utility of UAS assets to support wildfires. It was reported, "…because the smoke was so dense and they didn't know where the fire was, the incident commander was planning to send crews into an area where they would have been in harms way if it had not been for the imagery received from Ikhana."[88]

---

[84] Levine, *The Ikhana: Uninhabited Aircraft System is Changing the Way Fires are Fought and Proving to be a Valuable Science Tool*, 5.

[85] Ibid.

[86] Ibid.

[87] Ibid.

[88] Ibid., 3.

Additional missions supported fire fighters in Oregon, Washington, Idaho, Utah, Montana, and Wyoming. The longest mission during this support effort covered 3,200 miles over a 20-hour period. The final four missions for the 2007 fire season were flown over Southern California during 24-28 October, each lasting roughly nine hour each.[89]

A second case study of a Predator-class UAS is the Customs and Border Patrol's (CBP) UAS employment for border security. CBP operates Predator B UASs along the U.S. – Mexico border to spot and interdict illegal activity.[90] As a law enforcement agency, there are no issues with the Posse Comitatus Act or intelligence oversight. Most of the targets of the surveillance are believed to be non-U.S. persons, and thus, legitimate targets for surveillance collection. Although the agency is using its own resources to conduct a sanctioned mission, the UASs are still restricted with regard to operating in the National Airspace System.[91] The initial validation of concept orbits the CBP UASs operate in were within restricted airspace. CBP currently has a certification of authorization or waiver for 344 miles of the U.S. – Mexico border encompassing both Arizona and New Mexico airspace. There is also a certification of authorization or waiver in the approval process to access the airspace along 1,200 miles of the U.S. – Canada border.[92] The operations for this certification of authorization or waiver would be centered out of Grand Forks, North Dakota. For these orbits set up

---

[89] Levine, *The Ikhana: Uninhabited Aircraft System is Changing the Way Fires are Fought and Proving to be a Valuable Science Tool*, 5.

[90] United States Government Accountability Office, *Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand their Potential Uses within the National Airspace System*, 11.

[91] Ibid.

[92] Office of Customs and Border Protection Air and Marine, *Unmanned Aircraft Systems in Homeland Security* (Washington, D.C.: United States Customs and Border Protection, 2007), 15, http://www.cbgov/linkhandler/cgov/border_security/air_marine/uas_program/uas_dhs_kostelnik.ct t/uas_dhs_kostelnik.ppt (accessed August 18, 2008).

outside of restricted or warning airspace, CBP has to request and receive approval from the Federal Aviation Administration through the same certification process that the Department of Defense and NASA follow.[93]

One negative aspect of the CBP case is the safety record of CBP's UAS operations. CBP started operating Predator B UASs in 2005. In April 2006, CBP crashed one of them during a mission. It was determined that during a transition from one console to another, the pilot inadvertently shut off the fuel supply to the UAS, which caused it to crash.[94] It is incidents like these that cause the Federal Aviation Administration concern and raise their anxiety in granting routine access to the National Airspace System in addition to approving certification of authorization or waivers. Procedural fixes have been instituted by CBP to correct the human error, but the overall safety of UAS operations by CBP remains questionable in the Federal Aviation Administration's view.[95]

3. Procedural Fix Actions

Looking at Federal Aviation Administration documents, there are avenues that could be put in place for the use of UAS assets in support of civil authorities during crisis events. The use of certification of authorization or waivers is the best solution for an immediate way forward. Getting beyond the authorization process will involve employing the Altitude Reservation procedures outlined in JO 7610.4. It is Federal Aviation Administration policy to authorize airspace reservations under certain circumstances. Arguably, a major forest fire or nationally declared emergency would constitute such a circumstance and would meet the requirement of "airspace utilization under prescribed conditions."[96] The

---

[93] United States Government Accountability Office, *Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand their Potential Uses within the National Airspace System*, 9.

[94] Ibid.

[95] Del Quentin Wilber, "Drones Raise Safety Issues as Service Roles Multiply," *The Washington Post*, sec. A, July 20, 2007.

[96] *JO 7610.4M*, 3-1-1.

application of an altitude reservation is met given that the UAS assets would be required to “operate within prescribed altitudes, times, and/or areas.”[97] An UAS operating over a major forest fire could use this altitude reservation as an altitude block to keep other aircraft vertically and geographically deconflicted.

There are two types of altitude reservations classified by the Federal Aviation Administration. The first is a moving altitude reservation and the second is a stationary altitude reservation. The moving reservation is typically used for missions where the bubble around the aircraft moves with the aircraft. Instead of blocking all the airspace between point A and point B, a bubble is created around the aircraft, which moves with the aircraft as it transitions from point A to point B.[98] This moving reservation might be instituted to get the UAS to its on station orbit. Once there, the UAS would transition to a stationary altitude reservation.

A stationary altitude reservation is utilized to regulate all “activities within a fixed volume of airspace to be occupied for a specific time period.”[99] This reservation would reserve the airspace over the fire or natural disaster area so the UAS could operate feely with a lowered chance of mid-air collisions. A typical reservation would be for a set altitude block, typically 1,000 – 2,000 feet for vertical separation and the entire volume of airspace extending out beyond the existing boundaries of the fire lines. This, in effect, creates a horizontal volume of space to deconflict other aircraft from the UAS. In blocking only specific altitudes, it does not preclude other aircraft from transiting the geographic area. This is important because it is likely that aerial tankers will be flying in the area to drop water and slurry on the fire. These aircraft typically operate within 1,000 feet of altitude above the fire while in the immediate fire area. With a UAS operating at altitudes typically around 16,000 to 25,000 feet, there should be no issue with

[97] *JO 7610.4M*, 3-1-1.

[98] Ibid.

[99] Ibid.

plenty of airspace for other users to utilize. The reservation could also place a ceiling cap on the airspace so that commercial airliners can over fly the area and minimize impacts to normal routing and schedules.

As the application for an altitude reservation indicates, “consideration shall be given to total user requirements throughout the navigable airspace in accordance with the procedures prescribed herein.”[100] It also says, “Altitude reservations may encompass unmanned aircraft systems (UAS) activities and other special operations.”[101] There is one reason that the Federal Aviation Administration might not approve an altitude reservation, which is captured in the following verbiage, “Altitude reservations for single aircraft will not normally be approved unless the aircraft will join a tanker enroute and conduct air refueling.”[102]

In addition to what the Federal Aviation Administration has proposed or already has on the books, the DoD through the Air Force is looking for additional agreements to cover how military UAS assets are integrated into the National Airspace System. In an Air Force-Federal Aviation Administration agreement under consideration, UAS assets could conceivably be exempt from see-and-avoid requirements. The Air Force argument is based on the practices followed during natural disasters where the airspace above and around the affected area is closed to commercial traffic. The closure to commercial traffic significantly reduces the risk of mid-air collisions with civilian and commercial aircraft.[103] The ability to solve the impasse procedurally will hinge on how stubbornly the Federal Aviation Administration holds onto the requirement of see-and-avoid technology being incorporated into the UAS prior to access to the National Airspace System being granted.

---

[100] *JO 7610.4M*.

[101] Ibid.

[102] Ibid.

[103] Carlo Munoz, "Air Force UAVs Cleared for Domestic Duty," *InsideDefens.com*, http://www.military.com/features/0,15240,100537,00.html (accessed August 6, 2008).

4. Technological Solutions

For technological solutions to really improve the ability of UASs to fly in the National Airspace System, the civil aviation authorities have to establish a set of standards. Until that happens, the engineers that can design the necessary systems to the desired tolerances have nothing with which to work. With clearly defined criteria stipulated, avionics for see-and-avoid and collision avoidance could be created, certified, and fielded.[104]

One area where significant work has been done is in the use of redundant and robust flight control avionics. Athena Technologies has conducted tests with a subscale F/A-18 UAV where adaptive flight controls were able to recreate baseline aircraft performance after a simulation of the UAV receiving battle damage. The UAV was able to land autonomously. In the first experiment of the avionics capabilities, the test explored the ability of the UAV to recover from an in-flight ejection of an aileron.[105] This ability will increase the ability of UASs to operate reliably in all flight regimes.

In a follow-on test, nearly half of the UAV's right wing was ejected to simulate battle damage and in-flight failure. An additional test was conducted where 60 percent of the wing was ejected in flight to simulate the same conditions. In both cases, the UAV used on-board avionics to regain a baseline configuration to continue controlled flight until conducting an autonomously scheduled landing.[106] This technology could be critical to increasing the reliability concerns that have hampered the UAS community to date.

---

[104] David Hughes, "UAVs Face Hurdles in Gaining Access to Civil Airspace," *Aviation Week*, The McGraw Hill Companies, http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=awst&id=news/aw021207p1.xml (accessed August 20, 2008).

[105] Maureen Stevens, "Athena Successfully Controls and Autonomously Lands a Damaged UAV," *Athena Controls*, http://www.athenati.com/news_events/press_release/may_30_2007_-_athena_successfully_controls_and_autonomously_lands_a_damaged_uav.html (accessed August 6, 2008).

[106] Dave Gosch, "Rockwell Collins Successfully Controls and Lands Wing-Damaged UAV," Athena Controls, http://www.athenati.com/news_events/press_release/june_10_2008_-_rockwell_collins (accessed August 6, 2008).

D. CONCLUSION

Gaining approval for UAS support to natural disasters and wildland forest fires in not an easy task. There are legal and procedural hurdles preventing the easy and seamless integration of UAS assets into homeland security roles. This chapter briefly explored some of the legal challenges posed by intelligence oversight resulting from Executive Order 12333. The restraint on operations posed by the stipulations of the Posse Comitatus Act was also addressed. While the Posse Comitatus Act restraints are minimal for National Guard forces operating under state mandate, it is still important to keep the potential restrictions in mind, in case the National Guard units operating UASs become federalized.

In addition to the intelligence oversight issues, there are concerns over which agency would pay for the support provided by the National Guard units when called upon to support a disaster situation. Between the Economy Act and the Stafford Act, these issues are delineated and it is clear what the state must pay for and under what circumstances. It is also clear when the federal government can be expected to provide funding to reimburse the state for actions taken in response to disaster declarations.

Beyond the legal considerations highlighted so far, the greatest challenge to normalizing UAS operations to support disaster incidents is gaining routine access to the National Airspace System. NASA has invested considerable time and effort into improving the process with some small successes to date. National Guard units operating UASs will have to leverage these successes to establish similar relationships with the Federal Aviation Administration. As the reliability and positive control methods mature within the UAS community, the certification of waiver or authorization process should become streamlined. Requesting and receiving approval to fly in the National Airspace System in a matter of hours will often be responsive enough for UASs to support disaster events. The weeks and months the current process takes is unsatisfactory and precludes UAS support for events that are often over within the timeframe needed to gain permission to fly in support of them.

UAS assets have a wealth of potential to provide a needed and desired role supporting natural disasters and wildland forest fires. Gaining the approval to provide this support is possible both legally and procedurally. The next chapter will cover the hardware utilized to provide the data necessary for incident command center managers to make critical decisions during disaster events.

THIS PAGE INTENTIONALLY LEFT BLANK

III. PAYLOAD AND SENSOR CAPABILITIES

A. INTRODUCTION

This chapter will briefly look into the different types of sensors and payloads carried by UASs to support wildland firefighting missions and support for natural disasters. The use of the sensors described in this chapter highlight another way the Department of Defense and the National Guard can and should help the American public by supporting Homeland Security. These sensors and payloads can be broken up into two general categories. The first is the sensors indigenous to the platform. These systems are the electro optical sensors housed in the turret ball of the UAS. Also included in this category is the synthetic aperture radar and the infrared sensor also integrated into the UAS platform. The second category is comprised of those payloads added onto the platform to enhance mission capabilities. Some examples of these types of payloads covered are the Autonomous Modular Scanner and a communications relay payload. An important constraint on the selection of sensors and payloads is the UAS's rated payload capacity. The MQ-1 can carry 450 pounds of internal payload and an additional 300 pounds externally. The MQ-9 can carry 800 pounds internally and an additional 3,000 pounds externally.[107]

The electro optical and infrared sensors are proven sensors that have a strong track record supporting combat operations across the globe. These sensors have not been widely used to support domestic situations and natural disasters. The synthetic aperture radar system is also well suited for combat operations, but has not been widely used in natural disaster response efforts. Both of these areas will be assessed to determine potential impact and

---

[107] Kenneth Munson, ed., *Unmanned Aerial Vehicles and Targets*, no. 26 (United Kingdom: Jane's Information Group Limited, 2006), 194,197.

contribution during future domestic incidents. The Autonomous Modular Scanner will also be covered, identifying the key contributions the sensor has made to the wildland firefighting efforts in the Western United States.

The final payload covered in this section is the utility of a communications relay. The unique ability for long duration flight over remote areas where response personnel are deployed creates a need for additional communications throughput. These remote areas are often lacking in communications capacity between all the personnel responding to a disaster situation. In the case of a major natural disaster, often much of the communications infrastructure is destroyed or inoperative and the utility of a communications relay for handheld radios is needed. Likewise, major wildland forest fires cover vast geographic areas where terrain limits line of sight radios used by the command centers and front line firefighters. An airborne communications relay system would extend the range of the radios and enable dislocated personnel to maintain critical communications links. Without communications, it is impossible for an incident command center to execute a sound strategy to fight and contain wildland forest fires.

B. ELECTRO OPTICAL (EO) SENSORS

The MQ-1 Predator uses a Raytheon AN/AAS-52 Multispectral Targeting System A (MTS – A) sensor to provide an electro-optical picture to the sensor operator.[108] The sensor ball housing the MTS – A also includes the infrared sensor along with a laser-ranging system.[109] The MTS – A is comprised of two segments, weapons replaceable assembly one and weapons assembly two. Assembly one is the turret unit and houses the sensors along with an integrated

---

108 "Raytheon AN/AAS-52 Multispectral Targeting System A (MTS-A)," *Jane's Electro-Optic Systems*, http://www8.janes.com/Search/documentView.do?docId=/content1/janesdata/yb/jeos/jeos8417.htm@current&pageSelected=allJanes&keyword=MQ-1Payloads&backPath=http://search.janes.com/Search&Prod_Name=JEOS& (accessed August 28, 2008). The IR sensor will be covered in greater depth in the next section, while the laser-ranging system will not be discussed in this work.

109 Ibid.

inertial measurement unit. Assembly two is comprised of the electronics that run the sensors and produce the data. The electronics portion of the MTS – A utilizes Raytheon's local area processing, which is an automatic image optimization technique used to maximize displayed image information. This creates greater situational awareness for the sensor operator and enhances the long-range surveillance capability of the Predator.[110]

The MTS – A utilizes a charge-coupled device-television for gathering surveillance data. There is also a thermal infrared camera that can image in the infrared region of the electromagnetic spectrum. An important feature of the MTS – A is the capacity for the sensor to incorporate new technology. The current sensor has ample capacity to accept sensor improvements like multiple-wavelength sensors, TV cameras (both near-infrared and color), or additional avionics. The advances in electronic and optical design provide a clear growth path for image fusion and other performance enhancements through add-in circuitry.[111] A particular benefit to this potential growth in the sensor electronics is the multiple-wavelength sensors. A new sensor in the thermal infrared range with a high saturation temperature would be desirable for wildland firefighting support. With plug and play architecture, it would create minimal reconfiguration time, as an additional pod would not have to be uploaded onto a wing or the centerline hard-point. It also would minimally increase the weight of the sensor, and thus, not impact fuel load capacity.

The data from the electro-optical sensor is a video signal. Since it is not encrypted, it can be intercepted and watched by distant viewers.[112] Although this is not ideal for deployed military operations, it is less of a factor for domestic support missions. There are no concerns about sending non-encrypted data to

---

[110] "Raytheon AN/AAS-52 Multispectral Targeting System A (MTS-A)," *Jane's Electro-Optic Systems*.

[111] Ibid.

[112] John G. Drew and others, *Unmanned Aerial Vehicle End-to-End Support Considerations* (Santa Monica, CA: The RAND Corporation, 2005), 85, http://www.rand.org/ (accessed August 28, 2008).

the Forest Service and front line firefighters. The fact that there is no possibility of encryption key compromise increases the likelihood that the sensor data would be used directly by civil agencies.

1. Uses in Civil Support Role

The use of the MTS – A in a civil support role is somewhat limited when law enforcement type activities are involved. The sensor can easily observe human activity but is limited in the use for fire observation due to infrared sensor thermal saturation in wildland firefighting situations. The TV camera system also is not ideal for firefighting applications because the TV cannot “look into” the smoke to “see” the leading edge of the fire. The camera would only be able to provide a view of the smoke column and not the flames and active areas of the fire. This is of limited utility to the firefighters.

One area where the TV sensor would provide support is in the post fire inventory of the burned area. When the Forest Service conducts surveys to develop rehabitualization plans, the TV images could be used to assess the situation. The infrared data collected during the fire also would be critical in developing plans based on observed fire intensity. Fire intensity data is important in determining the amount of damage sustained by the vegetation and soil.

An additional role the sensor suite could fulfill is in a post major natural disaster; the sensor could be used to survey vast expanses of the affected area to catalog damage. The TV camera would best conduct this type of area survey because there is likely to be limited utility in the infrared data. The survey would focus on critical infrastructure systems important to returning local areas to pre-event functionality.

2. Ranges and Specifications

Weights	
WRA – 1 Turret	130 lbs
WRA – 2 Electronics Unit	25 lbs
Electromagnetic Spectrum	
Spectral Bands	0.4 – 0.7 and 0.6 – 0.8 μm TV/NIR); 3-5 μm (MWIR)
Focal plane array	Cooled 640 x 480 InSb detector
Fields-of-View – Infrared	
Ultra-Narrow	0.6 x 0.8 ^{o}
Narrow	1.2 x 1.6 ^{o}
Medium	5.7 x 7.6 ^{o}
Medium-Wide	17 x 22 ^{o}
Wide	34 x 45 ^{o}
Fields-of View – TV	
Ultra-Narrow	0.21 x 0.27 ^{o}
Narrow	1.2 x 1.6 ^{o}
Medium	5.7 x 7.6 ^{o}
Medium-Wide	17 x 22 ^{o}
Wide	34 x 45 ^{o}
Electronic Zoom	
X2	0.11 x 0.14 ^{o} (TV) & 0.3 x 0.4 ^{o} (Infrared)
X4	0.06 x 0.07 ^{o} (TV) & 0.15 x 0.2 ^{o} (Infrared)
Gimbal data	
Azimuth coverage	360^{o} continuous
Elevation coverage	-120 to +60^{o}
Slew Rate	3 radians/second
Power Requirements	28v DC and/or 115v AC operation

Table 1. MTS – A Sensor Data[113]

[113] *Raytheon AN/AAS-52 Multispectral Targeting System A (MTS-A)*, 3.

Weights	
WRA – 1 Turret	230 lbs
WRA – 2 Electronics Unit	25 lbs
Fields-of-View – Infrared	
Ultra-Narrow	0.23 x 0.31 °
Narrow	2.8 x 3.7 °
Medium	5.7 x 7.6 °
Medium-Wide	17 x 22 °
Wide	34 x 45 °
Fields-of View – TV	
Ultra-Narrow	0.08 x 0.11 °
Narrow	0.47 x 0.63 °
Medium	5.7 x 7.6 °
Medium-Wide	17 x 22 °
Wide	34 x 45 °
Electronic Zoom	
Infrared	2:1 in smallest field of view
TV	4:1 in smallest field of view
Gimbal data	
Azimuth coverage	360° continuous
Elevation coverage	-135 to +40°
Slew Rate	2 radians/second
Power Requirements	28v DC

Table 2. MTS – B Sensor Data[114]

[114] "Raytheon AN/DAS-1 Multispectral Targeting System - B (MTS-B)," http://www8.janes.com/Search/documentView.do?docId=/content1/janesdata/yb/jeos/jeosa106.htm@current&pageSelected=allJanes&keyword=MTS-BSensor&backPath=http://search.janes.com/Search&Prod_Name=JEOS& (accessed August 28, 2008).

C. INFRARED SENSORS

To support wildland firefighting, the incident commander would like to have an understanding of what is happening with the fire. Information about the intensity of the fire, movement, rate of spread, fuel moisture and a measure of the air quality are important. This information would be critical to determining the need for evacuations and identifying potential evacuation routes that minimize the risk to the civil population.[115]

The ability to see through the smoke and haze to the ground level is highly desired. Standard electro-optical sensors do not have this ability; thermal imaging systems do. Two types of infrared sensors capable of providing this information are compatible with the UASs considered in this thesis. The first is standard UAS infrared sensor housed in the sensor turret ball. The second is an infrared sensor developed by NASA for experimental flights to assess environmental phenomena associated with wildland fires. The principles behind how both work are the same; the major differences are the spectrum of data being collected and the viewing geometry capabilities built into the two different sensors.

1. Standard IR Sensor

The standard infrared sensor in the MTS – A and MTS – B sensor suite are designed to look in the near infrared 0.6 – 0.8 μm and thermal infrared region 3-5 μm. The 0.6 – 0.8 μm range overlaps with the visible region, which transitions at 0.77 μm. The visible portion of the spectrum can still be processed through an infrared imager by looking at the associated reflected environmental radiation.[116] The thermal infrared region (3 – 5 μm) is associated with a window

[115] "Mission Profiles," http://innovationlabs.com/uav5/03_main.htm (accessed August 19, 2008).

[116] Pieter A. Jacobs, *Thermal Infrared Characterization of Ground Targets and Backgrounds*, Second Edition, TT70 (Bellingham, WA: Spie Press, 2006), 3.

region in the atmosphere where absorption is relatively unimportant.[117] This permits the sensor to detect emitted radiation from the target source.[118] One potential problem with this region and the 0.6 – 0.8 μm region is that a sensor would be unable to penetrate clouds and fog. At longer wavelengths, smoke and haze become more transparent, which would be critical to a fire fighting surveying mission.[119]

Within the MTS – A and MTS – B sensors, there are two types of different and distinct sensors. The first sensor is the charge-coupled device-television camera. This camera works both in daylight and in darkness by optimizing different portions of the electromagnetic spectrum. During daylight operations, the camera is primarily used in the visible light portion of the spectrum. At night, the same camera is utilized to look in the near infrared portion of the spectrum. This is accomplished through the use of image intensifiers, which amplify the ambient visible light and the light reflected off the target surface. This means that operations work better on clear, bright (high moon illumination) than on dark overcast nights where there is near total darkness. These types of nights are better suited for the use of the thermal imager, which senses self-emitted infrared radiation, proportional to temperature. The resulting image depicts brightness for the target proportional to the intensity of the energy being emitted.[120] For the sensor operator, there is a selection of either white being hot or black being hot. Depending on the target and the background, one setting might be better than the other.

---

[117] A. R. Jha, *Infrared Technology: Applications to Electrooptics, Photonic Devices, and Sensors* (New York: John Wiley & Sons, Inc., 2000), 66.

[118] Pieter A. Jacobs, *Thermal Infrared Characterization of Ground Targets and Backgrounds*, Second Edition ed., vol. TT70 (Bellingham, WA: Spie Press, 2006), 3.

[119] Jha, *Infrared Technology: Applications to Electrooptics, Photonic Devices, and Sensors*, 257.

[120] Herbert Kaplan, *Practical Applications of Infrared Thermal Sensing and Imaging Equipment*, Third Edition, TT75 (Bellingham, WA: Spie Press, 2007), 118.

For the sensors on the MQ-1 and MQ-9, both work well identifying personnel and vehicles based on infrared profiles. In some cases, the sensors also provide acceptable resolution for situations where objects are burning. For incidents where there are massive fires that are burning extremely hot, however, the sensors become saturated and are able to provide negligible utility. For this reason, an additional sensor is required to support forest firefighting efforts. This additional sensor also benefits from the added portion of the electromagnetic spectrum under observation to mitigate the effects of smoke and haze. The resultant product and data generated are useful to the firefighting agencies.

a. Uses in Civil Support Role

The infrared sensor would best be suited for use in post natural disaster type scenarios where there are large-scale search and rescue operations going on. For events such as wildfires, the infrared sensor data is of limited value due to thermal saturation. In a search and rescue type situation, both the near infrared sensor and the thermal camera could both be utilized to locate personnel in need of rescuing. The warm bodies of the survivors would stand out against the cool background of the local surface area, especially at night, when the background temperature of the Earth cools below human body temperatures. Using the platform in this capacity would allow vast areas to be covered relatively rapidly and expedite rescue forces to go directly to the survivors instead of spending time looking for someone to pick up. Additionally, the laser illuminator portion of the sensor turret could be utilized to highlight the exact location of the survivor for the rescue vehicle. This would greatly improve the efficiency of rescue assets, as they would not have to do as much searching; instead, focusing on the rescue portion of the mission. With most rescue helicopters having only three hours of fuel to conduct search missions, the long duration of a UAS would allow the limited fuel capacity of the helicopter to be maximized to its primary mission, rescuing survivors.

The UAS also could be utilized in an initial survey mode in a post natural disaster scenario. By flying a grid type pattern over the devastated area, the sensors could be used to look for major problems within the infrastructure. The infrared region would provide data on the location of fires, whether from gas line breaks or electrical system failures. Cataloging these types of problems along with visible failures in the road and bridge systems can be used to develop a strategy to dispatch first responders in a prioritized fashion. Utilizing the infrared point-outs, additional sensors on the UAS could be utilized to gather amplifying information on each specific "hot spot." The speed and range of the UASs would enable most disaster areas to be surveyed in the initial 24 hours following a major disaster over a wide geographic area. The data would have to be shared by multiple jurisdictions so the different incident command centers could take the appropriate actions.

b. Ranges

See Tables 1 and 2.

2. NASA Autonomous Modular Sensor

With known deficiencies in the ability to support large-scale fire situations among standard sensors carried by fielded UASs, an additional sensor is needed. To this end, researchers at NASA have worked on and developed a sensor specifically designed to look at different environmental factors. One of the applications for the developed sensor is to support wildland firefighters in characterizing the size and extent of the fire in order to fight it more effectively.

Researchers at NASA's Ames Research Center developed the Autonomous Modular Scanner (AMS). The sensor can detect temperature differences from less than one-half degree to approximately 1,000 degrees Fahrenheit. The sensor operates like a digital camera with specialized filters to detect light energy at visible, infrared and thermal wavelengths.[121] The pod housing the Autonomous Modular Sensor can be carried under the wing of a MQ-9 or under the centerline of an MQ-1. The pod can accommodate a payload up to 350 pounds.[122] The modular sensor can be uploaded onto the UAS in a matter of hours. Incorporating the modular sensor does not impact the use of the standard electro-optical and infrared sensors in the turret sensor ball.

An ideal sensor would consist of two channels looking in the infrared region at 2.0-2.8 μm and the second channel looking at 1.75 μm. An additional benefit is gained from two thermal channels looking in the thermal region at 2.75 μm and 10-11 μm. The 10 – 11 μm range coincides with a window in the atmosphere where there is little absorption.[123] This region also coincides with the background emittance of the earth's surface.[124] The 10 - 11 μm region also allows the sensor to see to the ground through the dense smoke generated by the fire.[125] Another key would be to give the sensor the ability to be pointed at specific target areas instead of always nadir looking. To assist with fire fighting efforts, the sensor suite should also be able to determine ground temperature and ground humidity levels. These factors would assist firefighters determine and predict fire movement.[126] This type of payload would weigh an estimated 200 pounds.

In an effort to support the U.S. Forest Service during wildland forest fires, NASA developed a capability to reconfiguration the sensor suite to fly on UASs.

[121] Beth Hagenauer, "NASA Responds to California Wildfire Emergency Imaging Request," *National Aeronautics and Space Administration*, http://www.nasa.gov/centers/dryden/news/NewsReleases/2008.08-30.html (accessed July 24, 2008).

[122] Frank Cutler, "Instrumentation Pods," *National Aeronautics and Space Administration*, http://www.nasa.gov/centers/dryden/research/ESCD/uavsar_pod.html (accessed July 24, 2008).

[123] Kaplan, *Practical Applications of Infrared Thermal Sensing and Imaging Equipment*, 118.

[124] Jacobs, *Thermal Infrared Characterization of Ground Targets and Backgrounds*, 12.

[125] Kaplan, *Practical Applications of Infrared Thermal Sensing and Imaging Equipment*, 119.

[126] "Bringing it all Together," http://innovationlabs.com/uav5/05_main.htm (accessed August 19, 2008).

The sensor features interchangeable scan heads that contain different spectrometers.[127] The spectrometers are configured based on the mission being supported. For supporting firefighting efforts, there is a UAS Wildfire spectrometer with fixed channels associated to spectral bands as depicted in Figure 3.[128] In addition to the scan head, there is a digitizer data system, an Applanix strap-down navigation system enclosure, Trimble Differential Global Positioning System – storage subsystem enclosure, power distributor, Global Positioning System antenna, and assorted cabling. The sensor has an internal capability to perform calibrations and geo-rectification of collected imagery.[129]

The actual Autonomous Modular Sensor is a multi-spectral imaging line scanner. The image is created by the sensor raster scanning across the UASs direction of travel and accumulating lines of pixels as the aircraft moves forward. The sensor has two settings used to configure the collected pixel size.[130] A change in the pixel size corresponds to the change in area imaged. The larger the pixel, the larger the area covered as the sensor scans. Important to determining the fidelity of the data collected is the scan rate. The Autonomous Modular Sensor payload features an infinitely adjustable scan rate ranging from roughly two scans every second to 33 scans every second.[131] To determine the impact on resolution, it is necessary to account for the UASs altitude and the pixel size setting as displayed in Figure 3.

Since the data is of a raster scan format, it has to be processed by a specific software package, which NASA created called the Collaborative Decision Environment.[132] The software allows the data to be put on the Internet and also

---

[127] E. Hildum, *Wildfire Scanner on Altair UAV: Western States Fire Mission* (Interface Configuration Document, Ames Research Center, 2006).

[128] Frank Cutler, "Instrumentation Pods," *National Aeronautics and Space Administration*, http://www.nasa.gov/centers/dryden/research/ESCD/uavsar_pod.html (accessed July 24, 2008).

[129] Ibid.

[130] Ibid., 4.

[131] Ibid.

[132] Jeffrey S. Myers, Ikhana AMS Sensor Information, September 23, 2008.

to be draped over additional data sets using Google Earth. The data is received at the ground station over the Ku-band satellite communications link. To support the U.S. Forest Service and other firefighting agencies, the sensor utilizes the 3.60 – 3.79 μm and the 10.26 – 11.26 μm spectral bands.[133] Both the long wave infrared and medium wave infrared bands feed into a fire detection algorithm to depict the hottest portions of the fire and the location of the leading edge of the fire.[134] Outside of these bands, the fire lines are not visible due to the obscura caused by the fire generated smoke. All the short wave infrared bands are utilized in the post-burn analysis and assessment.[135] This data helps the Forest Service determine strategies for rehabilitation of the affected areas and measures to implement to minimize erosion concerns.

This sensor, however, remains "one-of-a-kind." There are no commercially available surrogates on the market. NASA is working with the manufacturer of the sensor to develop a commercial design. The sensor is a derivative of the AADS-1268 scanner manufactured by Argon-ST.[136] The ability of this type of sensor to be more widely used by agencies other than NASA will depend on similar sensors becoming commercially available.

a. Uses in Civil Support Role

The autonomous modular scanner sensor was specifically designed to support research on wildfires. In the civil support role, it is suited to only look at a fire type incident given the thermal threshold of the data being collected. There might be some utility in flying the sensor in a post major natural disaster to pinpoint hotspots that are a result of the event. These "hotspots" might be the result of ruptured natural gas lines or other major fires that produce a thermal signature significant enough to be captured by the sensor. The data

[133] Jeffrey S. Myers, Ikhana AMS Sensor Information, September 23, 2008.

[134] Ibid.

[135] Ibid.

[136] Ibid.

would be useful to emergency responders, as the exact locations of fires would be known prior to dispatching. When the data is overlayed with other geographic information, it could be used to triage a number of fires in an area.

An additional application in a civil support role could possibly be to support chemical or radiological events. Since the sensor is an environmental research sensor, it is possible to reconfigure the twelve different channels to look at different spectral regions. By utilizing the different channels looking at unique spectral data, it is possible to detect specific signatures unique to different types of chemical or radiological events. In order for the sensor to be used to support these chemical or radiological circumstances, the sensor would first have to be configured and tested under controlled conditions. Once the proper settings were detailed and documented, the personnel operating the UASs could configure the sensor per the mission requirements prior to launching. This type of scenario is just theoretical at this point because no work has been conducted to prove the concept.

b. Ranges

Weights		
Sensor	250 lbs	
Pod	350 lbs	
Field-of-View		
1.25 mR pixel	43 ^{o}	
2.50 mR pixel	86 ^{o}	
Swath Width	716 pixels	
Scan Rate		
2 scans/sec		
33 scans/sec		
Spectral Band collected		
0.42 – 0.45 µm	0.76 – 0.90 µm	
0.45 – 0.52 µm	0.91 – 1.05 µm	
0.52 – 0.60 µm	1.55 – 1.75 µm	
0.60 – 0.62 µm	2.08 – 2.35 µm	
0.63 – 0.69 µm	3.60 – 3.79 µm	
0.69 – 0.75 µm	10.26 – 11.26 µm	
Resolution	1.25 mR	2.5 mR
15k mean sea level	6.0 meters	11.4 meters
25k mean sea level	10.1 meters	19.1 meters
35k mean sea level	14.1 meters	26.7 meters
Power Requirements	28v DC	

Table 3. Autonomous Modular Scanner Sensor Data[137][138]

[137] Hildum, *Wildfire Scanner on Altair UAV: Western States Fire Mission*, 4.

[138] Jeffrey S. Myers, AMS Sensor Range Resolution, September 24, 2008.

D. SYNTHETIC APERTURE RADAR

NASA has developed a sensor called the Uninhabited Air Vehicle Synthetic Aperture Radar system. This system can house up to 850 pounds of payload and interfaces with the UAS via the Military Armament Unit 12. This allows the payload to communicate with the aircraft and transmit the collected data over the communications paths the UAS is already utilizing. The electrical interface for the pod can handle 2.8 kilowatts at 28 volts, is configured for Ethernet, RS-422, analog signals, and coaxial cable connections. There is a fire detection system self-contained within the pod.[139]

The standard synthetic aperture radar sensor fits within the designed sensor compartment. Weighing in at 450 pounds, it is too heavy to be carried on the wing stations of the MQ-1.[140] Based on payload capacities, it could be placed in a pod and carried on a weapons station on the MQ-9. The sensor requires a 5 MHz Ku-band satellite communications channel to transmit data at a rate of 1.544 mega bits per second. These figures are for beyond line of sight operation. If the MQ-1 is operating within line of sight of the control station, the system will use a C-band communications link with 20 MHz of bandwidth transmitting at a rate of 20 MHz analog.[141] Based on likely scenarios, the MQ-1 or MQ-9 would not be employed in line of sight operations.

The MQ-9 has the AN/APY-8 Lynx I ground moving target indicator / synthetic aperture radar system already installed in the main payload bay and would not require a pod-based system.[142] Given the internal configuration, the

---

[139] Cutler, *Instrumentation Pods*, 1.

[140] Munson, *Unmanned Aerial Vehicles and Targets*, 194.

[141] Office of the Under Secretary of Defense (Acquisition & Technology OUSD (A&T)) Defense Airborne Reconnaissance Office (DARO), *UAV Annual Report FY 1996* (Washington, D.C.: Department of Defense, 1996), http://www.acq.osd.mil/daro/ (accessed August 20, 2008).

[142] "AN/APY-8 Lynx I/Lynx-ER Ground Moving Target Indicator (GMTI)/Synthetic Aperture Radar (SAR) Radars," http://www8.janes.com/Search/documentView.do?docId=/content1/janesdata/yb/jrew/jrew1806.htm@current&pageSelected=allJanes&keyword=MQ-1Payloads&backPath=http://search.janes.com/Search&Prod_Name=JREW& (accessed August 28, 2008).

synthetic aperture radar is already fully integrated into the data bus for transmitting data. Current procedures for the use of the synthetic aperture radar system involve taking several different radar scans over wide search areas, up to 100 square nautical miles.[143] With this data, it is possible to conduct automatic target recognition and change detection.

There are four basic modes for the radar: Geo-Referenced Stripmap (GRS), SAR Transit Stripmap (STS), SAR Spotlight (SSL), and Ground Moving Target Indicator.[144] The geo-referenced stripmap mode requires the system operator to specify a precise strip of the ground to be imaged. This allows the sensor to patch together a continuous and seamless strip of images on either side of the UAS to provide the desired coverage.[145] The UAS does not have to fly parallel to the area imaged. In the synthetic aperture radar transit stripmap mode, the system operator sets a specific range from the UAS where the sensor will image the ground. The seamless strip map produced will be parallel to the line of flight of the UAS. This mode is maintained until the system operator directs the radar to stop imaging or the UAS drifts from the originally desired line of flight.[146] If this happens, the radar will start a new strip map along the path parallel to the new line of flight. In the synthetic aperture radar spotlight mode, the system operator specifies a set of coordinates on which the radar will dwell. The radar will cease imaging the targeted area after commanded to stop when

---

[143] Caitlin Harrington, "MQ-9 Reaper Ground Controllers Look Forward to Improved Radar Processing Speed," *International Defence Review*, http://www8.janes.com/Search/documentView.do?docId=/content1/janesdata/mags/idr/history/idr2008/idr11586.htm@current&pageSelected=allJanes&keyword=MTS-BSensor&backPath=http://search.janes.com/Search&Prod_Name=IDR& (accessed August 28, 2008).

[144] "AN/APY-8 Lynx I/Lynx-ER Ground Moving Target Indicator (GMTI)/Synthetic Aperture Radar (SAR) Radars."

[145] Ibid.

[146] Ibid.

the UAS flies beyond the limits of the radar imaging capabilities.[147] The radar has the ability to produce spot images from either side of the UASs line of flight and resolution is increased by longer dwell times.[148]

1. Uses in Civil Support Role

The use of synthetic aperture radar in a civil support role is ideally suited to post major natural disaster damage assessments. The synthetic aperture radar imagery would be able to survey critical infrastructure and lines of communication to determine areas where disruption has occurred. Using the capabilities of the radar, detailed images can be forwarded to incident command centers where decision makers can use the information to develop a recovery strategy.

Using the coherent change detection capability of the system, it is possible for the system to determine additional damage caused by aftershocks in an earthquake scenario. There is also some utility in using the radar and coherent change detection in search and rescue scenarios, depending on terrain. Since there could be a potential problem of radar shadow effects, the radar is more suited for open terrain. In cases of lost hikers or lost children, the radar has the ability to detect slight changes in the terrain, which might indicate human presence. For example, if a lost person walks across a clearing in the woods, the radar can detect slight changes in the surface of the field caused by the individual's footsteps.[149]

---

[147] "AN/APY-8 Lynx I/Lynx-ER Ground Moving Target Indicator (GMTI)/Synthetic Aperture Radar (SAR) Radars."

[148] Ibid.

[149] Ibid.

2. Ranges and Specifications

Frequency	16.7 GHz
Slant Range:	
Spotlight Synthetic Aperture Radar Mode	28 km (0.1 meter resolution)
	39 km (3.0 meter resolution)
	30:1 zoom factor
Stripmap Synthetic Aperture Radar Mode	54 km (0.3 meter resolution)
	87 km (3.0 meter resolution)
	935m wide swath
Squint Angle	
Spotlight Synthetic Aperture Radar Mode	45^{o} – 135^{o} or 50^{o} – 130^{o}
Stripmap Synthetic Aperture Radar Mode	45^{o} – 135^{o}
Ground Moving Target Indicator Mode	+/- 135^{o}
	3.2 – 11.25 km/hr vehicle detection
Power	1.2 kW (total)
Weight	115 lbs

Table 4. AN/APY-8 Lynx I Synthetic Aperture Radar Data[150]

E. COMMUNICATIONS

An additional payload UAS assets could be configured with is a communications pod. This pod would integrate into the UAS architecture to provide needed communications compatibility, added range, and throughput. For all practical purposes, the UAS would serve as a communications system over the disaster area while conducting the primary mission of collecting real-time data on the effects of the on-going disaster. The communications pod should have both cell and radio frequency voice capability.[151] The benefit of this type of communications pod would be in large fire situations where there are up to a thousand firefighters from all different agencies that might not have compatible communications equipment. The pod could provide that compatibility and allow

[150] "AN/APY-8 Lynx I/Lynx-ER Ground Moving Target Indicator (GMTI)/Synthetic Aperture Radar (SAR) Radars."

[151] *Bringing it all Together*.

the incident command center to keep in touch with all the fire teams and other emergency services personnel. An additional benefit of the voice cell capability is that it would not be altitude dependent.[152]

This pod would hold about 110 pounds of equipment. Depending on the communication systems the agencies are using, there might be a requirement for encryption capable equipment. Various agencies might also require programmable equipment to comply with their allocated frequency spectrum. A final consideration might be the necessity for data compression, all of which could be incorporated into a communications support pod.

As far back as 1996, the ability of UASs to serve as communications relay platforms has been demonstrated. A 1996 test using a Hunter UAS demonstrated the ability to relay very high frequency and ultra high frequency half-duplex voice and data transmissions to a range of 120 km. This test was conducted while the UAS was being operated in a beyond line of sight configuration.[153] Utilizing an MQ-1 or MQ-9, the ranges will be even greater given the increased altitude of UAS operations. For an MQ-1 operating at 15,000 feet, the footprint coverage is approximately 150 miles in diameter, terrain permitting.[154] As the altitude increases, so does the effective range. It would seem hard to imagine an incident commander refusing an asset that has the ability to extend his communications range from around five to seven nautical miles, to a range close to 50 times greater.[155] It is hard to conceive an incident command center being set up outside that range. Even with the large size of some fire complexes that have occurred in California, they have never exceeded 150 miles in length.

---

[152] *Bringing it all Together*.

[153] Office of the Under Secretary of Defense (Acquisition & Technology OUSD (A&T)) Defense Airborne Reconnaissance Office (DARO), *UAV Annual Report FY 1996*, 40.

[154] Edward B. Tomme, *The Paradigm Shift to Effects-Based Space: Near-Space as a Combat Space Effects Enabler* (Maxwell AFB, AL: Air University, 2005), 25.

[155] Anthony G. Knight and Aaron B. Luck, *Tactical Space - Beyond Line of Sight Alternatives for the Army and Marine Corps Ground Tactical Warfighter* (Master's Thesis, Naval Postgraduate School, Monterey, CA), 90.

One drawback to using the UAS as a communications relay is the time on station for the air vehicle. At some point, the UAS will have to leave the area and return to base for refueling and potential post-flight maintenance. If there is not another UAS arriving on station to relieve the departing asset, there will be a communications coverage gap. Depending on when this happens, this could have negative consequences for the firefighters on the ground. The departure of the asset can be planned and the incident commander made aware of the fact to make sure potential impacts are minimized.

The sensor payload configuration of the UAS will significantly impact the missions the UAS is able to conduct. For the MQ-1, there is only a 300 pound external store capability, so any additional payloads like the NASA Autonomous Modular Scanner sensor or a communications pod would have to be built small enough to meet this weight restriction.[156] The additional weight carried by the MQ-1 also means that the on-station mission time will be reduced. The addition of external stores requires the MQ-1 to off-load fuel due to the increased payload weight.[157] The vehicle is already at its design limits and it is a zero sum game; the addition of pods and sensors has an associated cost – fuel. For the MQ-9, the weight limit goes up to 3,000 pounds of external stores and makes most sensor or communications pods compatible without the sacrifice of fuel, and thus, duration.

Beyond just using the UAS as a communications relay during a wildland fire mission, the same payload could also support other major natural disasters. In post hurricane ravaged areas where much of the communications infrastructure is demolished, having a wide-ranging voice communications reach would benefit the different agencies working to assess and ensure personnel safety and security. Search and rescue personnel along with local and state law enforcement officials would all benefit from being able to communicate from within the devastated area to areas where traditional communications paths

---

156 Munson, *Unmanned Aerial Vehicles and Targets*, 194.

157 Drew and others, *Unmanned Aerial Vehicle End-to-End Support Considerations*, 76.

exist. A case in point is the area around Galveston and Houston, Texas in the wake of Hurricane Ike. Much of the immediate area where the storm made landfall was destroyed and communications were reduced to only hand-held radios. With their limited range, it is hard for the emergency responders to communicate over long distances, especially when much of the region is without power. Using an UAS to serve as a relay platform would alleviate some of the communications burden and enhance communication not only into the devastated area, but also to the surrounding areas less affected.

F. CONCLUSION

This chapter looked at several different payloads available on UASs to support wildland forest firefighting and natural disasters. The indigenous sensor suites provide good support for domestic natural disaster responses, but fall short supporting wildland forest fires. To cover this shortage, the Autonomous Modular Scanner has been developed and integrated into NASA's UAS operations. Based on the demonstrated utility of this sensor, additional Autonomous Modular Scanner sensors should be integrated into military UAS operations. Utilizing these sensors in conjunction with National Guard UASs would provide a needed capability in the Western United States and in other regions prone to natural wildland fires.

An additional payload capability briefly covered was the communications relay payload. Historical disaster response efforts demonstrate there is a need for this type of augmentation to current communications infrastructure. Disasters situations and wide ranging wildland forest fires only amplify the lack of useable communications throughput. To help fill this shortage of communications capacity, the use of a communications relay payload could effectively extend the range of handheld communications radios typically used by first responders during natural disasters. A communications relay payload on an UAS could effectively extend the range of these critical primary communications means deep into the affected areas. This would allow first responders to build the situational awareness of the incident command center leaders in conjunction with the other sensor data provided by the UAS.

UAS assets operated by National Guard units have the potential to provide more to the taxpayer than only supporting military operations in foreign theaters. There is utility to the assets that can be leveraged for domestic situations when needed most – in disaster response activities. By augmenting the existing air vehicles with additional payloads, significant benefits can be achieved in support of first responders and incident command center managers. The use of sensor payloads capable of collecting data in spectral bands not currently utilized would be one step in the right direction. This would allow wildland forest firefighters to better gauge the activity of the fire and develop better strategies for protecting citizens and property. The addition of a communications relay payload would benefit first responders in a post natural disaster situation by extending the range and interconnectivity of handheld radios. It would also benefit fire incident command centers by extending the effective reach of base station radios and allow for the decentralized execution from the central command center. Terrain and loss of commercial power would be minimized by communications relay capacity provided by UAS assets supporting the mission with traditional payloads.

The utility of both a communications relay payload and additional sensor coverage have been demonstrated by past disasters and incidents. The technical solutions have been drafted and implemented on a limited scale in research and development efforts. Additional effort is required to realize employable payloads that are smaller and lighter to minimize mission duration impacts. A standardized and procured payload for both of these areas has not been attempted. The UAS assets exist and could be made available to support the types of scenarios discussed in this work. The challenge is in putting the two together.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. COMMAND AND CONTROL LINKS

A. INTRODUCTION

This chapter explores UAS operations through the existing command and control architecture. Without communications paths, unmanned aircraft operations would not be possible. There have been improvements in autonomous unmanned aircraft systems, but it has not yet advanced to a point where a mission can be conducted without human interface. Even with an autonomous unmanned aircraft system, there still exists a requirement for a communications backbone to retrieve the data. Storing data collects until the unmanned aircraft returns from a mission achieves little as the value of the data is diminished due to the time lag in processing and exploitation. In a domestic natural disaster application, the human interface is required. Without the ability to reactively task the sensors and receive instant feedback on the situation being covered, the unmanned aircraft provides little benefit over manned aircraft.

To understand the architecture, it will be broken down into several distinct components. These four components are: line of sight, beyond line of sight, sensor data routing, and a direct downlink capability. The line of sight component of the architecture is limited by range, which provides limited utility in disaster response or wildland firefighting support missions. Since most disasters and wildland forest fires are not within close proximity to the unmanned aircraft home base, the beyond line of sight component must be utilized. Beyond line of sight operations are the primary method utilized during unmanned aircraft operations. Regardless of the length or duration of the mission being supported, unmanned aircraft systems require a component within the architecture to relay the data back to the command and control base for possible exploitation and further dissemination. In cases where the personnel on the ground in the disaster area need data immediately, there is a direct downlink capability. All of these components of the architecture will be further elaborated on throughout the rest of the chapter.

Not all unmanned aircraft systems operate in the same fashion. Army unmanned aircraft utilize different command and control links, typically a tactical common datalink. In contrast, the Air Force utilizes Ku-band satellites for command and control during most missions. Two reasons for this difference are the supported missions and the class of unmanned systems operated by the different services. The Army utilizes tactical unmanned aircraft systems that do not require long-range operations. The Air Force operates medium and long-endurance unmanned aircraft systems as part of the intelligence, surveillance, and reconnaissance constellation. Due to the ranges necessary to conduct typical surveillance or reconnaissance missions, beyond line of sight operations are required.

The unmanned aircraft covered by this work are both considered medium altitude systems. The respective command and control architectures are so similar; thus, both will be considered interchangeable. Both unmanned aircraft systems are operated by the active duty Air Force and the Air National Guard. While legal constraints affect active duty units differently than National Guard units operating the same system, the tactics, techniques, and procedures used to employ the unmanned aircraft are identical. A key benefit of utilizing unmanned aircraft assets, regardless of who owns and maintains the asset, is the speed at which the data is available to the end user. Prior to NASA employing the Ikhana aircraft, the process to collect wildfire related infrared data required an aircraft to fly a mission, land, and download the data for processing and then transfer the data to the incident command center. Using UASs, this lengthy process has been reduced from 4-8 hours to less than 15 minutes.[158] This is important when supporting natural disaster response efforts and wildland forest firefighting where time is critical.

B. LINE OF SIGHT COMMUNICATIONS PATHS

The primary command and control link used during all UAS operations is the line of sight link. This communications path is critical for takeoffs and landings.[159] It is also utilized for sensor checkout within proximity to the airfield to make sure the sensor suite is working prior to getting over the mission objective. If the mission is in the vicinity of the operating base, this link is the only command and control link utilized during the mission. This intra-theater communications capability permits operators to maintain control of the vehicle while allowing the UAS to transmit information obtained by onboard sensors to ground users.[160]

When operating in a line of sight configuration, the UAS is limited to approximately 70-120 nautical miles (~81-138 statute miles).[161],[162] In mountainous terrain, this range decreases as the elevated terrain would challenge the ability of the UAS to maintain line of sight with the ground station. The line of sight configuration utilizes a C-band communication path.[163] This path

[158] Vincent G. Ambrosia and others, *Collaborative Efforts in R&D and Applications of Imaging Wildfires* (Moffett Field CA: National Aeronautics and Space Administration Ames Research Center, 2004), 10, http://geo.arc.nasa.gov/sge/WRAP/projects/docs/RS2004_PAPER.PDF (accessed August 26, 2008).

[159] "Endurance UAV CONOPS (Concept of Operations) - Version 2," Air Combat Command, http://www.fas.org/irp/doddir/usaf/conops_uav/ (accessed October 21, 2008).

[160] United States Government Accountability Office, *Unmanned Aerial Vehicles: Improved Strategic and Acquisition Planning Can Help Address Emerging Challenges* (Washington, D.C.: U.S. Government Accountability Office, 2005).

[161] Philip Hall and others, *Operational Experience with Long Duration Wildfire Mapping UAS Missions over the Western United States* (Edwards, CA: National Aeronautics and Space Administration Dryden Flight Research Center, 2008), 4.

[162] *Endurance UAV CONOPS (Concept of Operations) - Version 2*, 2.4.7.

[163] Ibid.

is full duplex with data rates of approximately 4.5 megabits per second.[164] The high data rate allows the command and control and sensor data to be sent simultaneously.

The UAS also can employ a ground based line of sight extension. Utilizing a mobile ground control station, the UAS can extend line of sight operations an additional 100 nautical miles (~115 statute miles).[165] This is an important capability if satellite command and control channels are not available for use. Through the use of the mobile ground control station, the UAS can operate up to 220 nautical miles (~253 statute miles) from its fixed operating base. The lower line of sight range and the maximum line of sight range using a mobile ground control station are depicted in Figure 1.

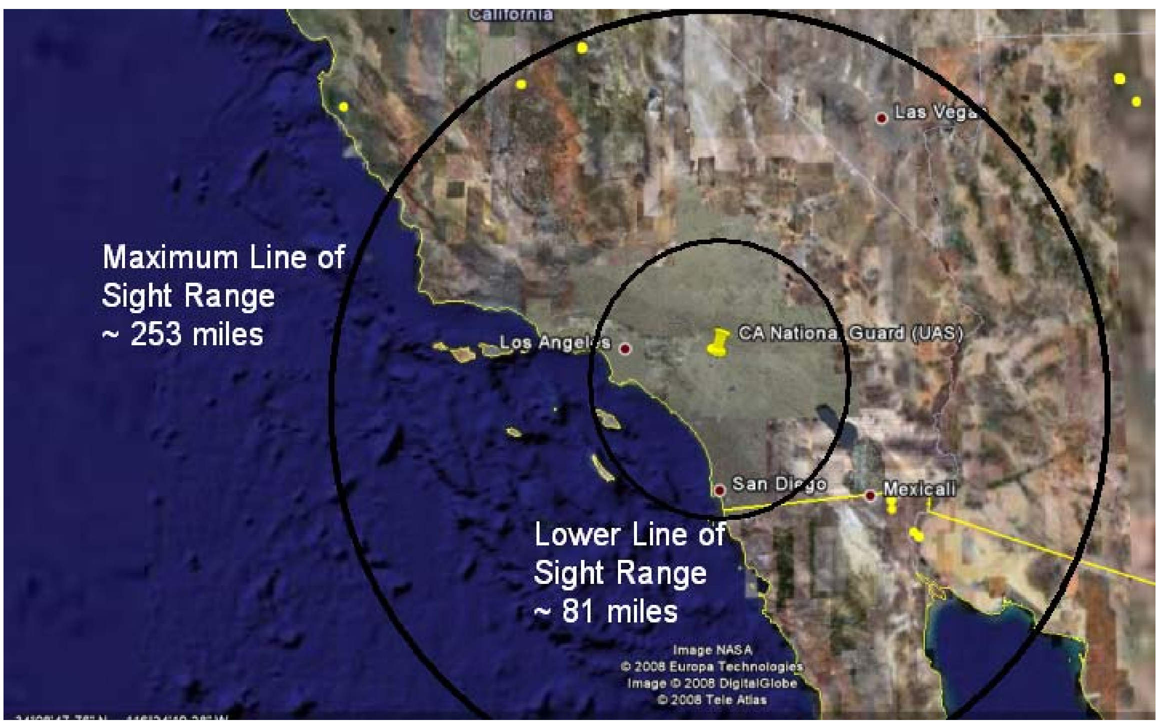

Figure 3. Line of Sight Range[166]

[164] *Endurance UAV CONOPS (Concept of Operations) - Version 2*, 2.4.7.

[165] Ibid.

[166] Image is from Google Earth, additional information created by the author.

In addition to these communication paths for commanding and controlling the unmanned aircraft, a communications path also must exist with the regional air traffic controller for airspace deconfliction issues.[167] As the UAS transitions in altitude or geographic space, the pilot will have to coordinate with the FAA air traffic controller in accordance with the approved certificate of waiver or authorization. To accomplish these critical communications, the aircraft operator utilizes an AN/ARC-210 very high frequency (VHF) and ultra high frequency (UHF) radio.[168] The UAS also operates an AN/APX-100 Interrogation – Friend or Foe transponder with modes I – IV. These modes can be interrogated from the air or ground and changed during flight by the operator.[169] This is necessary to ensure there are no airspace conflicts or potential collisions. This communications path is a voice only path and is available for both line of sight and beyond line of sight operations.

C. BEYOND LINE OF SIGHT COMMUNICATIONS PATHS

For missions that require the unmanned aircraft to travel beyond 120 nautical miles, the pilot must transition the command and control link over to a satellite based systems. This transition occurs while still within line of sight of the ground station but after aircraft and sensor systems have been verified. The transition allows the aircraft to be flown hundreds of miles from the operating airfield. Although fuel capacity is thus the main limitation on the range of the unmanned system, the satellite spot beam also creates some constraints.[170] Nevertheless, typical spot beams cover roughly 1,500 statute miles, which is sufficiently large enough to capture most unmanned aircraft missions.[171]

---

[167] Image is from Google Earth, additional information created by the author.

[168] Defense Airborne Reconnaissance Office, "Predator System Familiarization Guide," Defense Airborne Reconnaissance Office, http://www.fas.org/irp/agency/daro/predator/toc.html (accessed August 27, 2008).

[169] Ibid.

[170] *Endurance UAV CONOPS (Concept of Operations) - Version 2*, 6.2.2.3.

[171] Ibid.

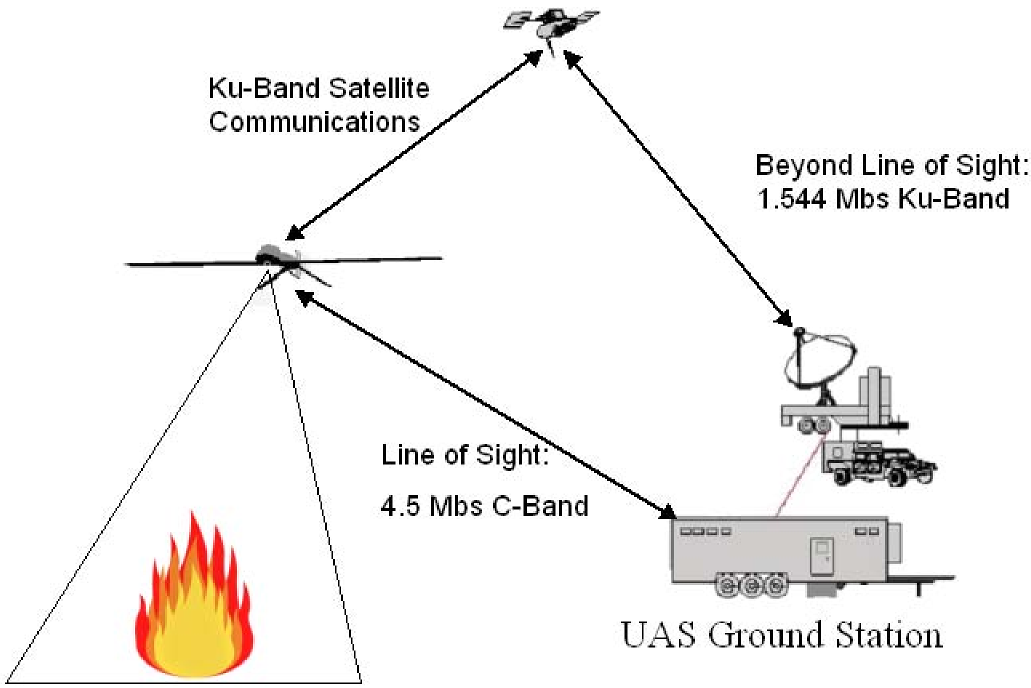

Figure 4. Command and Control Architectures[172]

The beyond line of sight communications architecture is dominated by the use of satellite communications links. The main limitation of the communications links is the availability of usable channels and bandwidth.[173] Currently, the military is heavily reliant on commercial satellite communications links to provide the necessary throughput to support unmanned aircraft flight operations. In fact, 80 percent of all intelligence and imagery is passed over commercial satellites.[174] The situation will only get worse as most commercial communications satellites have already reached or exceeded the designed mission life. Continued reliance

172 *Endurance UAV CONOPS (Concept of Operations) - Version 2*, 6.1.

173 Elizabeth Bone and Christopher Bolkcom, *Unmanned Aerial Vehicles: Background and Issues for Congress* (Washington, D.C.: Congressional Research Service, 2003).

174 Anthony G. Knight and Aaron B. Luck, *Tactical Space - Beyond Line of Sight Alternatives for the Army and Marine Corps Ground Tactical Warfighter* (Master's Thesis, Naval Postgraduate School, Monterey, CA), 47.

on commercial satellite communications bandwidth is complicated by future projections that only 44 percent of the necessary capacity for unmanned aircraft system operations will exist by 2010.[175] The low figure is based on the slow rate of replacement for the aging commercial satellite constellation and the increased rate of commercial communications satellite failures. The desired end state is to have this heavy reliance reduced to around 50 percent.[176] To achieve this, military and commercial communications satellite constellations have to expand to create the necessary capacity to support unmanned aircraft system requirements. One hundred percent should go across military satellites to remove the vulnerability of utilizing the commercial sector, but the reality is there is not a large enough budget or successful track record with past space systems to permit this. The military has had to accept the risk of a lack of protection and no assured access to the satellites, which is associated with using commercial satellites.[177] The expediency of being able to acquire and fund time in the commercial sector is the preferred choice.[178]

A major difference between operating over commercial satellites and military satellites is the issue of data encryption. With commercial satellites, the sensor data is not encrypted.[179] On military satellites, it is typically encrypted. The choice has historically been to utilize commercial satellites because military communication satellites support sensitive military communications. The reliance on commercial satellites could significantly impact mission accomplishment given that there might not be enough satellite resources to support all desired missions. Most of the beyond line of sight communications pathways are over commercial

---

[175] Office of the Secretary of Defense, *Unmanned Aircraft Systems Roadmap 2005-2030* (Washington, D.C.: Government Printing Office, 2005).

[176] Knight and Luck, *Tactical Space - Beyond Line of Sight Alternatives for the Army and Marine Corps Ground Tactical Warfighter*, 47.

[177] Ibid., 48.

[178] Marc Richard and others, "DOD Faces Tradeoffs in using Commercial Broadband SATCOM Systems," *The Edge,* Winter 2002, 1, http://www.mitre.org/news/the_edge/winter_02/richard.html (accessed August 27, 2008).

[179] *Endurance UAV CONOPS (Concept of Operations) - Version 2*, 1.6.4.

satellites leased by the Department of Defense. The availability of the required bandwidth will depend on the tempo of current missions utilizing the available leased bandwidth.[180]

One of the consistent challenges that all UASs will face for future employment is the availability of communications and bandwidth.[181] Much of the concern centers around the increasingly large amounts of communications bandwidth unmanned aircraft systems are consuming as the Department of Defense fields additional unmanned systems. The bandwidth is needed to support systems necessary to control flight, transmit collected payload data, and interface with air traffic control centers.[182] While the Predator and Reaper unmanned aircraft only require a single satellite communications channel, the Global Hawk unmanned aircraft system requires three satellite channels for a single mission.[183] Given the constraint on the amount of available commercial satellite communications transponders available to support unmanned aircraft missions, it is easy to understand that national security concerns requiring multiple simultaneous Global Hawk missions will quickly erode that amount of available government leased commercial bandwidth. It is not impossible to imagine a situation where there is no commercial communications satellite bandwidth available to support unmanned aircraft systems domestic disaster response operations in a beyond line of sight configuration.

The National Guard will have dedicated funding for the bandwidth necessary to train and maintain pilot currency. This resource should be leveraged to the maximum extent to support disaster relief efforts. This can be accomplished by using training and proficiency sorties to support homeland security taskings. The availability of bandwidth needed to support unmanned

---

[180] United States Government Accountability Office, *Unmanned Aerial Vehicles: Improved Strategic and Acquisition Planning Can Help Address Emerging Challenges*, i.

[181] Ibid.

[182] Ibid.

[183] Bone and Bolkcom, *Unmanned Aerial Vehicles: Background and Issues for Congress*, 17.

aircraft flight operations is currently constrained.[184] Costs would be greatly reduced if military satellite communications were utilized for these missions. Since the military does not charge the users of the satellites for the time or channels being used to support operations, there would be no associated cost. If military communications satellites were utilized, how would the government recover the associated or equivalent costs for this resource?

With the current constraint on military communications satellites, the possibility that National Guard unmanned aircraft missions supporting domestic events will be able to use military satellite communications channels is improbable. Commercial communications satellites will continue to support UAS missions on a cost competitive basis with the missions and units vying for the limited resources in an open and competitive market. This is an area where the Defense department could seek reimbursement since satellite transponder capacity has a known cost for a specific amount of satellite time used to support unmanned aircraft missions of a given duration.

D. DATA RETRIEVAL AND DISSEMINATION

Once the UAS has collected the desired data using the onboard sensors, the data is shipped back to the ground station for processing and dissemination. The communications path utilized for command and control also is utilized for the mission data.[185] Since there is very little processing accomplished by the sensor or the UAS, the data is downlinked to the ground station for processing.[186] Once

[184] United States Government Accountability Office, *Unmanned Aerial Vehicles: Improved Strategic and Acquisition Planning Can Help Address Emerging Challenges*, 2.

[185] *Endurance UAV CONOPS (Concept of Operations) - Version 2*, 2.4.7.

[186] Hall and others, *Operational Experience with Long Duration Wildfire Mapping UAS Missions Over the Western United States*, 6.

the data is processed, it is ready for wider dissemination to the end users. This process typically takes around ten minutes with expert personnel processing the data.[187]

For a wildland forest firefighting mission using the AMS sensor, the data is downloaded to NASA's Ames Research Center where several dedicated and experienced personnel process the data into a useable product format.[188] The processed data products are simultaneously forwarded to the National Interagency Fire Center in Boise ID and the incident command centers controlling the imaged fires.[189] From the time the data has been transmitted down from the UAS to the time it reaches the incident command center is typically around 10-15 minutes. While the data is not real-time data, it is close enough for the strategic picture the incident command center requires to develop strategies for fighting the fire. The data is moved from the NASA center to the other agencies over the Internet.[190]

Format increases the utility of the processed data made available to the incident command centers. The finished product is both geo- and terrain-rectified.[191] This helps the incident command centers in decision making because the images can be viewed on current mapping software like GoogleEarth.[192] This application allows additional layers of data to be added, helping managers visualize the extent of the fire and the terrain with which the front line firefighters are dealing. A more complete picture of the situation can be attained when the sensor data layer is combined with weather, terrain, population

---

187 Robert G. Moose, Ikhana Fire Mission, August 25, 2008.

188 Ibid.

189 "WRAP: Current Activities & Demonstrations: Future Missions: Altair Western States Fire Mission Concept Plan," http://geo.arc.nasa.gov/sge/WRAP/current/future_missions.html (accessed August 26, 2008).

190 Robert G. Moose, Ikhana AMS Sensor Specifications, September 23, 2008.

191 Ambrosia and others, *Collaborative Efforts in R&D and Applications of Imaging Wildfires*, 12.

192 Hall and others, *Operational Experience with Long Duration Wildfire Mapping UAS Missions over the Western United States*, 6.

area, and road data layers.[193] No longer will managers have to rely on estimates and guesses, an actual three-dimensional visualization product provides a ground truth upon which decisions are based.[194]

To utilize the same sensors in National Guard units, each UAS squadron or ground control station would have to add the capability to process the sensor data and provide an output that is usable to the firefighters. Utilizing the work already conducted by NASA, the processor could be co-located in the ground station and the processed product shipped out over the ground communications links already inherent in the system. This would also require the National Guard to adjust the training of the sensor operators to build the skill set to operate the AMS ground processing system software. It is assessed that it would be possible to teach personnel the right keystrokes for routine operations.[195] Contingency operations would require the specialized training that only the scientist and engineers currently operating the system possess.[196] While some of this expertise could be put into emergency checklists for the National Guard crews to run, it is not possible to cover all potential contingencies. In such cases, the National Guard unit would have to contact the NASA experts to resolve these rare issues.

An alternative solution to training the sensor operators to process the data would be to automate the process. Automation would enable the sensor operator to focus on the mission and directing the sensor to accomplish mission objectives without being distracted by processing activities. An automated processing capability also would be ideal for use in incident command centers where the finished products are used for decision-making. It is possible that with automated data processing, there would be fewer steps from raw data to finished product

---

[193] "WRAP: Current Activities & Demonstrations: Completed Missions," http://geo.arc.nasa.gov/sge/WRAP/current/com_missions.html (accessed August 26, 2008).

[194] Ambrosia and others, *Collaborative Efforts in R&D and Applications of Imaging Wildfires*, 10.

[195] Moose, *Ikhana Fire Mission*, 1-1.

[196] Ibid.

and less moving of the product over ad hoc communication paths. A downside to data processing automation would be the need to have a system able to receive the data and process it. This would require the incident command center to acquire new equipment and train personnel on system configuration to receive and export the useable product into the current system used to display situational information. When reacting to a disaster situation, this added infrastructure configuration activity might hamper the situation more than help it.

The current dissemination method works well; however, an additional option has merit. This unexplored method is the direct downlinking of the data to the firefighters and incident command center within the footprint of the UAS. This would speed up the dissemination timeline and provide the data directly to the front line users without having to transmit the data back to the ground station for further dissemination. It would also remove the Internet access requirement, although most Emergency Operation Centers and Incident Command Centers will have Internet access to support other applications necessary to execute the mission.

E. DIRECT DOWNLINK COMMUNICATION PATHS

There are two ways that a direct downlink from an UAS can be processed. One is to utilize the combat proven Remotely Operated Video Enhanced Receiver (ROVER) family of devices. The military currently has over 3,500 hand-held ROVERS deployed in theater supporting combat operations.[197] These devices allow the end user to view high-quality images from the UAS assets.[198] The second system is the VideoScout MC. Both of these systems can receive L

[197] Thom Shanker, "U.S. Pushes to Rely More on Remotely Piloted Craft - NYTimes.Com," *The New York Times Company*, http://www.nytimes.com/2008/06/05/washington/05military.html?_r=1&fta=y&oref=slogin (accessed October 20, 2008).

[198] Ibid.

and C band transmissions. Each of these systems have the potential to provide the front line firefighter with the same picture the incident command center has; thus, aiding in situational awareness.

The ROVER system is a portable receive only terminal. The terminal displays sensor data and can support real-time full motion video inputs. It has proven interoperability with Predator UAS operations.[199] The system is small, lightweight and rugged. The ruggedized laptop display weighs approximately 10.25 pounds with a battery installed. It has a 10-12 hour battery life, but can also be configured for AC or DC input power. This would eliminate the need for batteries and provide the fire crews the endurance needed to cover a long duration fire. The laptop can be immersed in up to three feet of water for up to 30 minutes. This is a good feature given the likelihood that the system would get wet during firefighting operations. It can take severe shocks, up to 9g and has an operating temperature range of –20^{o} Celsius to 70^{o} Celsius. The total weight of the complete system, laptop, receive antennas, power cords, batteries, carrying case is only 48 pounds.[200] This could easily be incorporated into wildland firefighting vehicles.

This laptop-based system provides ground users with the same view as the sensor operator. The Rover interface allows the incident commander to be able to see exactly what the sensor is seeing, and thus, more efficiently utilize the available resources to fight the fire.[201] It can also be used to develop a strategy to fight the fire and keep firefighters out of harm's way based on where and how fast the fire is moving in real-time. There is no delay associated with posting images to a website to be viewed in an application as a layer. For a firefighting situation, the ROVER device would require a software upgrade to process the raw data and convert it into a useable format for the user. The raw

---

[199] "L-3 Communications -> Products & Services -> ROVER 4 Receiver," http://www.l-3com.com/products-services/productservice.aspx?type=ps&id=820 (accessed August 25, 2008).

[200] Ibid.

[201] Ibid.

data being directly received from the UAS would have little meaning to the ROVER operator without the intermediary step of automated processing. In a natural disaster situation, the direct downlink of the sensor feed would have added utility to the ground user. The ground user would have the same view of the sensor footage as the sensor operator back at the operating base. In natural disaster situations, there would not be a need for software upgrades to manipulate the data into a useable format.

With the ROVER system at the command center, the vectoring of aerial tankers to drop on hot spots could also be more efficiently conducted. Having a birds-eye view of a large section of the fire at a time would enable the incident commander to direct the effort against the larger and more dangerous hotspots in a deliberate fashion. The methodical and deliberate use of air tankers to suppress hot spots within the fire line would allow ground based units to fight less intense portions of the fire with which they are more able to contend. This not only reduces the risk to the firefighters, but it also increases efficiency.

Another option similar to the ROVER receive equipment is the VideoScout®-MC. Like the ROVER, the system is waterproof and sturdy. This system is a mobile video exploitation and management system that has an integrated receiver to capture and display real-time metadata directly from UASs.[202] This system allows the user to view incoming video, archive, annotate, georeference, and disseminate the data to others in the area. The video and metadata is automatically indexed and stored for subsequent search and retrieval. These attributes allow the device to be used by field personnel as a remote video exploitation terminal.[203]

The software in the VideoScout® - MC allows for enhanced video by allowing the field personnel to normalize the light-dark content of the video. These features, along with the ability to edge sharpen and pixel enhancement,

---

[202] "VideoScout: Video Exploitation and Management," *L-3 Communications*, http://www.l-3com.com/apd/products/videoscout.htm (accessed September 17, 2008).

[203] Ibid.

will be important when dealing with infrared data that might be more difficult for the inexperienced person to understand. The system also has the ability to create snapshots and “frames of interest” for later use. These can be stored as either JPEG or NITF files. Using the snapshot function with the annotation functionality would be of great importance for the frontline firefighters. Using the annotation function, the operator can add symbology, free hand drawings, add colors, lines, and free hand notes to images prior to storing them as JPEG or NITF files. These files can also be transmitted to other users with the annotations embedded in the file. All the data received by the terminal can be stored on either CDs or DVDs for long-term storage and post event analysis.[204]

The VideoScout® - MC system seamlessly integrates with the Rover system. By tying into the ROVER system, the vehicle based receiver can collect the UAS data and then send it to the forward based VideoScout® - MC units. These units would be best suited for the dismounted firefighters working the fire lines in remote areas that still have line-of-sight to the mechanized ROVER assets. Such a system would allow vulnerable personnel to have good situational awareness of the approaching fire prior to becoming trapped in a dangerous situation. This could directly save firefighter lives.

F. CONCLUSION

Supporting an UAS mission is a complicated task that relies on a communications backbone. The line of sight portion of the communications architecture has the highest throughput potential for data, but will often not be utilized due to the geographically remote location of most disasters being supported. The beyond line of sight segment of the communications architecture allows for UAS support to disasters anywhere within the fuel range of the UAS. The limitation with beyond line of sight operations, however, is the reduced bandwidth for the sensor data. Despite this, a beyond line of sight configuration probably will be utilized when supporting wildland forest firefighting operations.

[204] "VideoScout: Video Exploitation and Management," *L-3 Communications*.

Just as important as getting the UAS over the disaster area or forest fire is the ability to collect and disseminate the sensor data. Collecting the data and translating it into a useable product is no small task. Current operations rely on a handful of expertly trained scientists and engineers. Normalizing the process so average citizens, who typify the UAS sensor operators, is a significant challenge. Provided the interpretation and exploitation of the sensor data can be automated, it could enable the direct downlinking of the sensor data to the incident command center and the firefighters on the fire lines. Utilizing proven commercial products like the ROVER family of products and VideoScout – MC has the potential to significantly increase the situational awareness of all personnel fighting a fire and reduce the danger to personnel and property. Having timely, accurate and actionable information is critical for incident managers making important decisions impacting how and where to attack the challenges posed by a raging forest fire or natural disaster.

V. CONCLUSION

A. INTRODUCTION

In this final chapter, a model is presented describing how National Guard units operating unmanned aircraft systems could be equipped to support the response to natural disasters and wildland forest fires. The model mirrors a program already in place for National Guard and Air Force Reserve units tasked with supporting forest firefighting efforts. There are no corollary programs to address disaster response efforts or synthetic aperture radar employment. The forest firefighting support program will be briefly covered to explain resource configuration and operations. The case will then be made for setting up a similar program for unmanned aircraft.

The chapter concludes by identifying a way ahead, including areas that need further study. Future research areas will be identified along with the importance to the overall concept put forth in this work.

B. MILITARY AVIATION SUPPORT TO FIREFIGHTING OPERATIONS

Throughout this thesis, various technical and legal issues have been addressed to demonstrate the ability of National Guard unmanned aircraft to assist in natural disaster and wildland firefighting efforts. During the past 34 years, the National Guard has utilized aircraft to assisted the Forest Service in forest firefighting efforts. Based on this track record of past National Guard support, the information assembled in this thesis can be applied to future wildland forest firefighting and natural disaster recovery support. Past National Guard aircraft support for forest fires has been conducted employing the Modular Airborne Fire-Fighting System (MAFFS).

1. Modular Airborne Fire-Fighting System

The modular airborne firefighting system is a joint program established by the Department of Defense and the U.S. Forest Service in 1974. The system is a self-contained, 3,000-gallon aerial fluid dispersal system, which can be fitted into the cargo area of C-130 aircraft. There are eight such systems, two in each of the following state: California, North Carolina, Wyoming, and Colorado. The National Guard operates all the systems, except for two operated by the Air Force Reserve in Colorado. The Forest Service owns the systems and requests the use of the fixed wing aircraft necessary for employment. When equipped with the modular airborne firefighting system, Air National Guard or Air Force Reserve personnel operate the C-130.[205]

The use of the modular firefighting system requires advanced planning to enable the rapid mobilization of the assets when conditions dictate. There are policies and procedures in place that qualify military units for a non-designated military mission. To accomplish this, extensive planning is required by both the military and the firefighting agencies. The modular airborne firefighting systems aircrews and aircraft must undergo a several step process prior to prepare for wildland firefighting missions. The pilots and aircrew have to undergo initial and refresher training. The crews are specifically qualified and identified by the unit and might have to be recalled to perform the mission. The aircraft also has to be prepared for the mission by removing external fuel tanks, loading the modular system into the cargo hold, and testing the system. Aircraft configuration actions combined with fueling the aircraft for the mission and preflight checks might mean the aircraft will not be able to support the front line fire agencies for 24 hours or more after the time of the request.[206]

---

[205] US Forest Service Aviation, "Modular Airborne FireFighting System (MAFFS)," http://www.fs.fed.us/fire/aviation/fixed_wing/maffs/system.html (accessed August 27, 2008).

[206] Ibid.

Modular airborne firefighting system assets are requested by the National Interagency Fire Center through military liaison officers working with the National Interagency Coordination Center. This is part of the interagency agreement reached between the Department of Defense, the Department of Agriculture, and the Department of the Interior in 1975. Through the agreement, the Defense department signed on "to provide firefighting support to wildland fire management agencies when needed."[207] These requests are typically only exercised when all civilian resources are committed and the need for additional resources exists. Since 1988, the military has provided modular firefighting system support during 13 fire seasons.[208]

2. Unmanned Aircraft Systems

Applying the modular airborne firefighting system model to unmanned aircraft systems reveals similar factors that impact the use of National Guard unmanned aircraft assets to support wildland firefighting missions. One of the first factors is the need to reconfigure the unmanned aircraft with the necessary sensor suite. If a communications relay capability were also required, that equipment would require additional time to be installed onto the unmanned aircraft. Finding and recalling the aircrew (pilot and sensor operator) qualified to fly the mission will take time. This would be in addition to the time required to make sure the proper certification of waiver or authorization to support the mission is in place and approved by the Federal Aviation Administration. In all, it might take upwards of 24 hours for the unmanned aircraft to arrive on-station and start providing support to the firefighters on the front line.

---

[207] National Interagency Fire Center, "Military Support in Wildland Fire Suppression," *National Interagency Fire Center*, http://www.nifc.gov/fire_info/military_support.htm (accessed August 27, 2008).

[208] Ibid. Years supported are 1988, 1989, 1990, 1994, 1996, 2000, 2001, 2002, 2003, 2004, 2006, 2007, and 2008.

Traditional military support to forest firefighting efforts require specialized training in what are determined to be "non-designated military missions."[209] In the case of unmanned aircraft operations, all missions conducted to support forest firefighting efforts would be consistent with traditional military missions. The *Military Use Handbook* specifically identifies a designated military mission as "reconnaissance/command and control activities."[210] Unmanned aircraft assets supporting forest firefighting efforts would be conducting a reconnaissance or surveillance role. As a designated mission, neither the Forest Service nor the National Interagency Fire Center would require specialized training. However, the National Guard units would require aircrews to be qualified on the configuration of the unmanned aircraft being utilized for the support mission. For all missions, the aircrews would need to be briefed on standard flight operations and communications procedures. As the National Interagency Fire Center *Military Use Handbook* directs, "Military aircraft assigned to an incident should be used to their fullest potential. Every effort should be made to take advantage of this military expertise."[211]

There are a few areas within the handbook that will be of particular interest for tasked unmanned aircraft units. The first is the restriction on night flying. The Forest Service has a policy that "aviation operations will be conducted during daylight hours under visual flight rule conditions."[212] For unmanned aircraft operations, this policy would not be conducive to providing the desired support. This is a great policy for manned aircraft that are operating at low altitudes in hazardous conditions. An unmanned aircraft asset will be operating at altitude in instrument flight rule conditions, regardless of day or night. One of the

[209] National Interagency Coordination Center, *National Interagency Fire Center: Military Use Handbook* (Boise, ID: National Interagency Coordination Center, 2006), 38, http://www.nifc.gov/nicc/predictive/intelligence/military/Military_Use_Handbook_2006_2.pdf (accessed August 27, 2008).

[210] National Interagency Coordination Center, *National Interagency Fire Center: Military use Handbook*, 38.

[211] Ibid., 39.

[212] Ibid., 41.

best times to collect infrared data on a fire is at night when the non-burning areas have cooled. The temperature difference between the two helps better define the actual fire line. In addition, without any visual observation during the overnight time period, the extent of the fire enlarging is not known. Permitting night operations for unmanned aircraft assets would provide the situational awareness to incident command center personnel so that when daylight flight operations resume, a sound strategy has been crafted to attack the fire in the most threatening areas. This is especially important early on in large fires where containment is low or nonexistent.

Another area where unmanned aircraft would have a difficult time complying with the stipulations of the *Military Use Handbook* is in the area of aircraft equipment requirements. The handbook requires under the heading of "designated military mission" the following requirements.[213]

- High visibility markings
- Complete set of current aeronautical charts covering the area of operations
- Equipped with one 760-channel VHF-AM aeronautical radio system operating in the 118 – 137 MHz bands with 25 kHz channel increments and minimum transmit power of five watts. The radio must also be furnished with a separate Guard receiver operating on 168.625 MHz.
- Global Positioning System used to locate the position of the aircraft at all times by referencing latitude and longitude coordinates

From the above list, the high visibility markings are easily created and could be complied with on short notice. The aeronautical charts would not be a problem; the ground control station would have access to all charts. Locational data of the unmanned aircraft would also not be a serious concern as the sensor operator and pilot have GPS derived coordinates of the aircraft at all times. The area where compliance is not likely is with the desired aeronautical radio. The unmanned aircraft has one radio used to communicate with air traffic controllers.

[213] National Interagency Coordination Center, *National Interagency Fire Center: Military Use Handbook*, 52.

The radio does not have the features which the *Military Use Handbook* requires. While this should not preclude the assistance of the unmanned aircraft from supporting operations, it might require a waiver to operate in the area of the fire.

In a separate document also used by the National Interagency Fire Center as a guide for wildland forest fire support, the section on aviation contains valuable information on employing unmanned aircraft assets in a support role. The *Wildland Fire and Aviation Program Management and Operations Guide 2008*, addresses airspace coordination and transponder usage by all firefighting aircraft. The guide requires all aircraft supporting firefighting operations to have an operable transponder "set to 1255 when engaged in, or traveling to, firefighting operations, unless given a discrete code by Air Traffic Control."[214] Temporary Flight Restrictions in the vicinity of the fire are also covered. There are several Internet links provided to access the flight restriction information, which is updated every 30 minutes during normal duty hours, every day of the week.[215] An Internet link also contained within the guide provides access to tactical charts with specific flight restriction information, including the incident name, frequencies, and affected altitudes.[216] The information is important when requesting modifications to pre-approved certifications of waiver or authorizations from the Federal Aviation Administration. The unmanned aircraft flight profile and orbit could also be populated into the accessible charts for other aviation assets' awareness and reference.

3. Mirror Imaging

Existing military assets in the form of the modular airborne firefighting system equipment is employed in fighting wildland forest fires. This system is a resource of last resort when all other civilian resources have been committed or

---

214 Department of the Interior and Bureau of Indian Affairs, "Wildland Fire and Aviation Program Management and Operations Guide 2008," National Interagency Fire Center, http://www.nifc.gov/policies/blue_book.htm (accessed October 24, 2008).

215 Ibid.

216 Ibid.

otherwise exhausted.[217] The employment of unmanned aircraft should follow this same model. When wildland forest fires erupt that are beyond the capacity of the National Interagency Fire Center to resource, National Guard unmanned aircraft assets should be called upon to support the agency leading the firefighting effort. The situational awareness and persistence offered by the unmanned aircraft asset is key to developing a comprehensive strategy to achieve containment in the shortest possible timeframe. Without the unmanned aircraft, determining the extent and scope of the fire is much more difficult. During the overnight hours, the fire can grow significantly as the incident command center does not have the resources necessary to monitor the entire fire perimeter. In the absence of this knowledge, the developed strategy might overlook important factors and end up endangering both personnel and private property.

An alternative employment methodology is to utilize UAS assets prior to major fires exceeding the capabilities of the state's resources. Using California as an example, the Governor could direct the National Guard to launch an UAS aircraft during forecasted periods of strong Santa Ana winds. The UAS could look for small fires or ignition sources in the infrared spectrum to vector in firefighters prior to a fire getting out of control. The ability of weather forecasters to predict Santa Ana winds provides sufficient time for the certification of authorization or waiver to be approved and implemented.

A sound method to employ unmanned aircraft assets would be to equip the National Guard units operating unmanned aircraft systems with the sensor packages necessary to support firefighting operations. In addition to the infrared sensor augmentation, supplying communications relay pods would greatly benefit not just firefighting missions, but also support first responders during natural disasters. Using the Forest Service's history of equipping the National Guard and

[217] Department of the Interior and Bureau of Indian Affairs, "Wildland Fire and Aviation Program Management and Operations Guide 2008."

Air Force Reserve with modular airborne firefighting system equipment, doing the same with the unmanned aircraft assets would be a significant improvement over current capabilities.

Another critical step in developing the support relationship is for the governors of the states operating unmanned aircraft assets to require certifications of waiver or authorizations to be created, enabling the unmanned aircraft assets to gain access to the National Airspace System. Having these authorizations "on the shelf" to implement on a moment's notice speeds the response time for the assets. Instead of waiting months to get the waiver or authorization approved, by which time the fire is contained or extinguished, the unmanned aircraft could be in the air within a day supporting the incident command center and the front line firefighters.

Based on the known geography and health of the state's forests, it is reasonable to expect the forest service to provide assistance in determining areas most prone to future fires. This data would serve as the starting point for developing the certifications of waiver or authorizations. If a major fire event occurs that is outside of the approved authorizations, the authorization closest to meeting the requirements can be amended with the Federal Aviation Administration, enabling the unmanned aircraft to provide the necessary support. This amendment process could be accomplished in conjunction with the establishment of temporary flight restrictions.

With the long duration nature of unmanned aircraft operations, a couple of training sorties could provide the necessary training for the flight crews on the operation and employment of the payloads utilized during the support missions. As Lieutenant General Steven Blum, the chief of the National Guard Bureau stated in August 2006, "We can take some of the training we're doing and make it have some operational good here at home."[218] The overall impact on the unit would be minimal as the current syllabus training sorties could be utilized. Each pilot and sensor operator certified on the unmanned aircraft configuration and payloads could be tracked for short notice tasking.

C. OUTSTANDING ISSUES REQUIRING RESOLUTION

The first and largest issue requiring further study is the integration of unmanned aircraft systems into the national airspace system. The Federal Aviation Administration has serious concerns about the ability of unmanned aircraft to "see and avoid" other air traffic. Until this concern and unmanned aircraft reliability issues are cleared up, routine access to the national airspace will not be a reality. In the meantime, unmanned aircraft operators will be able to fly limited missions in the national airspace utilizing the certification of waiver or authorization.

National Guard unmanned aircraft can follow a model developed by NASA to gain access to the national airspace system.[219] Using designated restricted airspace, the National Guard unmanned aircraft can ascend into Class A airspace and then exit the restricted airspace into the national airspace system under air traffic controller positive control. Once under the air traffic controller's guidance, the mission can proceed according to the certification of waiver or authorization.

A second potential hurdle to implementing what has been called for in this thesis is the acquisition of infrared sensors to outfit the National Guard unmanned aircraft systems. The current spectral coverage provided by the Multi-

[218] Caitlin Harrington, "National Guard Predators are Ready for Action," http://www8.janes.com/Search/documentView.do?docId=/content1/janesdata/mags/jdw/history/jdw2006/jdw30092.htm@current&pageSelected=allJanes&keyword=MQ-1Payloads&backPath=http://search.janes.com/Search&Prod_Name=JDW& (accessed August 28, 2008).

[219] Philip Hall and others, *Operational Experience with Long Duration Wildfire Mapping UAS Missions over the Western United States* (Edwards, CA: National Aeronautics and Space Administration Dryden Flight Research Center, 2008), 15.

Spectral Targeting System A is not sufficient to provide the fidelity of data needed by the incident command center managers. It is unknown what the spectral coverage is for the Multi-Spectral Targeting System B. The company that markets both systems does not provide the data or any information on the ability for either sensor to be modified to include the necessary spectral bands.[220]

The need to add a pod-based sensor also creates problems. The sensor currently used for forest firefighting mission support is a one of a kind system.[221] Since there are no commercially produced sensors like it, it would be difficult to outfit the National Guard units with the necessary equipment. Should a company agree to produce the sensor for limited procurement, it is not known how long production would take. It is also not known how much this type of sensor would cost. All of these questions would need to be answered before National Guard units could outfit unmanned aircraft with the necessary equipment.

There are two possible funding mechanisms should either sensor acquisition path come to fruition. One path is to use the Department of Homeland Security. The Homeland Security department has a grant process where funds are made available to assist in acquiring needed equipment or facilities to assist in homeland security missions.[222] Many of the grants go to support first responders. Using this process, it is possible to secure funding for both the sensors and the communications relay payloads.

The second funding mechanism is to utilize the Assistance to Firefighters Grant Program. This grant program is administered by the Federal Emergency Management Agency within the Department of Homeland Security. The grant process is designed to "maintain an all-hazards focus and not limit the list of

---

[220] Per the Raytheon website (http://www.raytheon.com/contact/) "We do not entertain requests for academic research assistance, (accessed August 27, 2008).

[221] Jeffrey S. Myers, Ikhana AMS Sensor Information, September 23, 2008.

[222] Department of Homeland Security, "DHS Announces Release of Application Guidance for Over $3 Billion in Grant Programs," Department of Homeland Security, http://www.dhs.gov/xnews/releases/pr_1201882070387.shtm (accessed November 4, 2008).

eligible activities."[223] There are 14 different purposes the grant can be used for including, acquiring firefighting vehicles and acquiring firefighting equipment. Of note, "Department of Homeland Security has the discretion to decide which of those purposes will be funded for a given grant year."[224] Based on this information, it would be possible for the National Guard units to be equipped with firefighting equipment (sensor or communications payload) through this grant process. Regardless of which grant process is used, it would be the Forest Service submitting the request, not the National Guard. The Forest Service would own the equipment, and use the unmanned aircraft assets identically to how the modular airborne firefighting system is utilized.

The final issue requiring resolution so unmanned aircraft systems can mimic the modular airborne firefighting system is the creation of a memorandum of understanding or agreement. As with the modular airborne firefighting system, the aircraft are owned and tasked by the Department of Defense. The National Guard provides the personnel and facilities to operate and maintain the assets, but the Defense department still "owns" the physical assets and has to be consulted prior to the unmanned aircraft supporting civil missions. While it is not envisioned that the Defense department would block the use of assets to support wildland forest firefighting missions or natural disaster response activities, the mechanisms for facilitating such civil support missions are still required.

There are currently two agreements, which govern the use of military assets to assist in wildland firefighting. The first agreement is between the Department of Defense, the Department of Agriculture, and the Department of the Interior providing guidelines, responsibilities, and reimbursement factors to be used during wildland firefighting. With this agreement, the Department of Defense provides assistance in two situations:

[223] Lennard G. Kruger, *Assistance to Firefighters Program: Distribution of Fire Grant Funding* (Washington, D.C.: Congressional Research Service, 2008).

[224] Ibid.

> Department of Defense can provide assistance when National Interagency Fire Center has requested it and Department of Defense has determined that military assistance is required and justified to suppress a wildland fire. Assistance can be requested for fires on federal, state, or private property. Requests should state that all available or suitable civilian resources have been committed and that requested support does not compete with private enterprise.[225]

> Department of Defense can provide assistance when a forest or grassland fire on state or private property is declared a major disaster, or a determination for emergency assistance is made by the President, and the required military support is requested by the Federal Emergency Management Agency Regional Director, under the Disaster Relief Act of 1974.[226]

The second agreement is between the Department of Defense and the National Interagency Fire Center governing the use of military helicopters in wildland firefighting operations. This agreement might serve as a template for a needed unmanned aircraft system agreement as it emphasizes flight safety standards and the desire for safety to not be compromised in the name of fighting a fire. Since access to the National Airspace System is predicated on safety and reliability, it is important for the Department of Defense to come to a similar agreement with the agencies supported to ensure an understanding that aircraft safety is not negotiable.

The need for agreements is based on the customary noninvolvement of federal military forces in domestic events. It is recognized that there are situations where the Defense department will be called upon to support domestic agencies with military capabilities. Defense support of civil authorities, referred to as civil support, is Defense department support, including federal military forces, the Department's career civilian and contractor personnel, and Department of Defense agency and component assets, for domestic emergencies and for

[225] United States Government Accountability Office, *Technology Assessment: Protecting Structures and Improving Communications during Wildland Fires* (Washington, D.C.: U.S. Government Accountability Office, 2005).

[226] Ibid.

designated law enforcement and other activities.[227] The Defense department provides defense support to civil authorities when directed to do so by the President or Secretary of Defense. Within the Department of Defense, U.S. Northern Command (NORTHCOM) is responsible for planning, organizing, and executing homeland defense and civil support missions within the continental U.S., Alaska, and territorial waters.[228] In the event of major catastrophes, the President will direct Defense department to provide substantial support to civil authorities. The Department of Defense's response will be planned, practiced, and carefully integrated into the national response.[229]

Civil authorities are most likely to request Defense department support when unique capabilities are needed or when civilian responders are overwhelmed. The Department of Defense's contributions to the comprehensive national response effort can be critical, particularly in the near-term, as the Department of Homeland Security and other agencies strengthen their preparedness and response capabilities.[230] The Defense department must unify its efforts to promote the integration and sharing of applicable Department of Defense capabilities, equipment, and technologies with federal, state, local, and tribal authorities. Sharing relevant technology, capabilities, and expertise strengthens the nation's ability to respond to domestic emergencies.[231] Utilizing National Guard unmanned aircraft is just one small component of this sharing.

Although the Defense department is directed to support other agencies, the command and control mechanisms are retained by the military. Even in national emergencies, the Defense department retains control over assigned assets. At no time does the Department of Homeland Security exercise

---

[227] Department of Defense, *Strategy for Homeland Defense and Civil Support* (Washington, D.C., 2005), 5.

[228] Ibid., 8.

[229] Ibid., 9.

[230] Ibid, 14.

[231] Ibid., 19.

command and control authority over Reserve or National Guard forces.[232] National Guard forces are managed by the state governors, unless federalized by the President. Despite the states controlling the National Guard units on a daily basis, the majority of the financial resources and equipment are from federal funding. There exists the potential for seams to develop between the state and federal level when resources are requested in some major natural disaster scenarios. This seam can widen if Department of Homeland Security planners do not understand that National Guard units have limited assets. Conducting well thought out command post and field-training exercises can reduce these seams. Such exercises not only educate the different organizations on capabilities and limitations of unmanned systems, but also highlight areas where additional attention is needed to streamline support.

State resources do not have reserves that can be called up and activated if situations worsen. Domestic events are viewed as local events until escalating beyond the response capability of the local and state government.[233] For most natural disasters, military assistance is supporting other agencies responding to a disaster. The Department of Defense tries to be reactive and flexible in responding to assistance requests for domestic disasters.[234] To mitigate some of these seams, the National Guard is primarily the provider for domestic emergencies. This is due to the ease with which governors can task state units to perform military operations within the state boundaries.[235]

---

[232] Kenneth A. Wheeler, *Evolving Military Strategy and Developing Homeland Security: An Opportunity to Share Resources* (Master of Strategic Studies, U.S. Army War College), 10, http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA424016&Location=U2&doc=GetTRDoc.pdf (accessed July 24, 2008).

[233] Ibid., 9.

[234] Ibid., 10.

[235] Ibid.

D. ACTIVE DUTY UAS ASSET USE IN CIVIL SUPPORT ROLE

The U.S. Air Force's 2008-2013 budget forecast seeks $13 billion to purchase 241 additional unmanned aircraft systems. These unmanned aircraft would create 12 new MQ-9 Reaper squadrons.[236] This is part of the USAF plan to expand the MQ-1 Predator and MQ-9 Reaper unmanned aircraft systems inventory to 15 squadrons.[237]

A logical conclusion is to use this large resource for domestic crisis support. Unfortunately, intelligence oversight concerns prevent these numerous unmanned aircraft from supporting domestic natural disaster or wildland forest fire events. National Guard assets are attractive, as they are not legally bound by the tight legal restrictions that hamper active duty asset support. The more permissive legal environment for National Guard unmanned assets makes the assets the logical choice to provide the desired support. While still bound by legal requirements, state controlled unmanned assets have significantly more latitude in the operations environment than do active duty unmanned assets. A favorable legal environment, along with close physical proximity to the disaster area, is two strong points for supporting the use of National Guard unmanned aircraft.

It would appear that with available unmanned assets, there would be plenty of resources to go around to support the response to natural disasters and wildland forest firefighting type missions. The sticking point with active duty unmanned assets is the primary mission of globally supporting combatant commanders. The second problem is the locations of the squadrons operating the assets. The majority of the squadrons are in states not prone to wildland forest fires, though homeland security support to major disaster events like flooding or post hurricane relief can be supported. As federal assets, the

[236] Robert S. Dudney, "A Better UAV Flight Plan," *Air Force Magazine,* April 2007, p 2 http://www.airforce-magazine.com/MagazineArchive/Pages/2007/April%202007/0407edit.aspx (accessed July 24, 2008).

[237] Robert S. Dudney, "Where do UAVs Go from Here?" *Air Force Magazine,* July 2005, 2 http://www.airforce-magazine.com/MagazineArchive/Pages/2005/July%202005/0705edit.aspx (accessed July 24, 2008).

intelligence oversight issues loom large along with command and control issues. The governor of the state does not control the federal assets. Even with National Guard operated unmanned aircraft, it is one problem set to support disasters within the state boundaries of the unit's home state; it becomes increasingly complicated when neighboring states and beyond are brought into the equation.

E. CHALLENGES

Realizing unmanned aircraft support to domestic disaster situations requires addressing several critical areas. At the heart of the desired end state is the ability of the unmanned aircraft to collect the necessary data to support response operations. The airframe and communication links are proven and acquired resources, although there are associated challenges. What is missing when it comes to making this vision a reality are legal permissions, the proper sensor, and the necessary bandwidth for command and control. Of the three, the sensor is the easiest to solve as it involves hardware with known specifications that engineers can design too. Command and control bandwidth will continue to challenge the UAS community, though if the crisis or disaster is severe enough, the funding will be made available to "free up" the necessary communication paths for support activities. The legal access issue is more complicated and a solution will take considerable effort by Congress and the Obama administration.

1. Communications Paths

An area for additional research and detailed study is the availability of frequency spectrum for the operation of military unmanned aircraft assets within the United States. In addition to the frequency spectrum availability and system frequency deconfliction issues is the need for increased satellite communications bandwidth to pass command and control and payload data through the system. Communication overload already is a critical issue, even with the nominal number of unmanned aircraft currently fielded.

Surveying the lifespan of the satellites providing the bandwidth also is important. There are many satellites currently in orbit providing the Ku-band coverage necessary for domestic support. What is not clearly portrayed is the future shortage of Ku-band coverage. The shortage will result from existing satellites failing without subsequent replacement satellites being launched. Estimating when this situation will unfold and the cost/effort to maintain or expand Ku-band coverage requires additional research.

2. Sensor

The sensor portion of the model has two possible solutions. The first is to add the necessary spectral coverage to the current sensor suite indigenous to the unmanned aircraft. The second solution is to purchase an Autonomous Modular Sensor type sensor. The Autonomous Modular Sensor is a one of a kind sensor so there are not additional sensors to be purchased and integrated into the unmanned aircraft squadrons. Either option will require a contract to be let for additional sensors or components to be built. Once the sensors are built for and purchased by the Forest Service, the National Guard personnel will have to train with either the sensor as an additional payload or integrated into the airframe. The personnel will also have to train on the ground processing hardware and software necessary to convert the data from the sensor into a usable output for incident managers to utilize. If the sensor is an additional payload on the unmanned aircraft, the unit will have to establish an annual training plan to keep a suitable number of crews proficient with sensor operations and processing.

One option for an executable model is to use the current sensor suite with minor modifications. Raytheon advertises the sensor suites on both the MQ-1 and MQ-9 as being “plug and play” expandable. Using this capability, it might prove more suitable to expand the spectrum the sensor covers to match that of the Autonomous Modular Sensor. Increased spectral band coverage has several benefits. The first is the additional weight resulting from the change would be minimal. This would not impact the range or flight characteristics of the unmanned aircraft. Due to the weight savings, the unmanned aircraft would also be able to carry the communications relay payload. This would enable the unmanned aircraft to satisfy multiple missions simultaneously. A final benefit would be the minimal maintenance and time needed to reconfigure the aircraft pre- and post-mission. Not having to upload and download a pod on the wing station would save considerable time and effort. It also would save the unmanned aircraft from the wear and tear resulting from the stresses the sensor pod places on the airframe. Having the sensor suite provide the necessary spectral coverage would be ideal, as it would not significantly alter the flight characteristics of the unmanned aircraft, removing the requirement to have specifically trained crews.

The second option for an executable model is to operationalize a pod configured sensor based on NASA’s Autonomous Modular Sensor design. There are several problems with doing this. The first challenge is the cost associated with developing and purchasing a sensor that is not commercially available. Once the sensor is developed, there is the issue of certification that would be required for the sensor to become part of the weapons system. The time required to test and certify the sensor would create a significant lag in actually fielding the sensor.

Regardless of which option is picked, there is an additional concern regarding the end processor for the sensor data. The current ground control station does not have the necessary software to process the data sent back from the senor. In order to make the data actionable, a computer system has to be integrated into the overall system. Such integration efforts would also require testing and certification to ensure the additions to the system are compatible and do not cause interference issues. To accelerate the process of fielding the ground processing hardware and software, the National Guard units could start by verifying the compatibility of NASA’s Collaborative Decision Environment software.[238] A portion of the verification would ensure the software is compatible with the ground station, while additional verification is necessary for the returning aircraft sensor data. This is especially important if a plug in change to the standard sensor ball is the course chosen. A commercial Autonomous Modular Sensor equivalent should have few compatibility issues. Central to displaying the data will be the ability of the software suite to georectify the data and produce a useable output. With an Autonomous Modular Sensor based sensor configuration, this should not be a problem as the position of the sensor scans is embedded in the returned sensor data. For a plug-in change to the standard unmanned aircraft sensor suite, this could be a larger issue. It is unknown if the sensor positional data is included in the standard sensor data downlink. This information is critical to conducting georectification of the data. Without the data being georectified, it will not be able to be displayed in software applications like Google Earth where other useable data layers can be added to create better situational awareness to incident commanders.

F. CONCLUSION

Additional resources are needed to support first responders during natural disaster recovery operations and when fighting wildland forest fires. Although there is no guarantee that the current trend in increasingly sever natural disasters will continue, indications are more devastating situations can be expected. The current methodology of spending billions of dollars on suppression activities will be significantly aided by the use of unmanned aircraft systems. Key to reducing the amount of necessary funding is taking a proactive mindset, rather than continuing in a reactive mode. As the population continues to increase and expand the forest-urban interface, the damage figures for future fires will increase. The fact that out of the ten most costly wildland fires in United States

[238] Vincent G. Ambrosia and others, *Instructions for Installing and Using the Collaborative Decision Environment (CDE) Data Visualization Tools*, 6th ed. (Edwards, CA: National Aeronautics and Space Administration, 2007), 8.

history, three of the top four have occurred in the past five years.[239] All three of these fires have occurred in California and have resulted in over $1 billion in damages.[240]

Fires will not be the only disasters that can benefit from the creative use of unmanned aircraft systems. Major flooding incidents like those that plagued the upper Midwest during 1993 and 2008 can also utilize the support provided by unmanned aircraft.[241] The ability to provide assistance in the damage assessment and recovery phase has not yet been realized. Similarly, the capability that unmanned aircraft could provide in a post hurricane landfall scenario has not been fully appreciated. Utilizing unmanned aircraft systems in non-traditional roles can reduce the human suffering by locating survivors sooner and providing critical situational information to the incident command centers so sound strategies can be formulated to provide relief efforts. The loss of property may not be preventable, but the severe loss of life experienced during Hurricane Katrina is.

Unmanned aircraft systems have the capacity to provide this much needed support in a cost-effective and less dangerous manner. Utilizing National Guard units operating these assets is the best solution to the problem set. America's citizen soldiers are willing and capable of supporting disaster and emergency response operations within their states when equipped, trained, and empowered to do so. Most important in working towards making this a reality is equipping the unmanned aircraft with the necessary payloads and sensors. Increasing the spectral coverage of the infrared sensor is critical to supporting forest firefighting operations. Whether the increased coverage comes from a pod mounted commercial sensor based on NASA's design or an added plug-in

---

[239] Insurance Information Institute, "Wildland Fires," http://www.iii.org/media/facts/statsbyissue/wildfires/ (accessed December 3, 2008).

[240] Ibid.

[241] Rick Mattoon, "Midwest Economy: Assessing the Midwest Floods of 2008 (and 1993)," *Federal Reserve Bank of Chicago*, http://midwest.chicagofedblogs.org/archives/2008/07/mattoon_flood_b.html (accessed December 3, 2008).

component for the current sensor suite, there is a need to augment the current capabilities of the unmanned aircraft sensors to detect different portions of forest fires for incident command center managers. Armed with this additional information, managers will be better able to allocate resources and personnel to execute a sound strategy containing wildland forest fires in the quickest amount of time. This will reduce the risk to personal property and lives.

Unmanned aircraft systems require access to the National Airspace System to support domestic disaster events. While it is not likely that such access will become a routine practice in the foreseeable future, it is important to develop procedures and relationships between agencies to smooth the access approval process. Putting procedures in place that enable the Federal Aviation Administration to grant permission for flight operation on the scale of hours and not days or months would be the goal. NASA has demonstrated that this is possible. Utilizing pre-planned certification of waiver or authorizations to cover likely scenarios is the best course of action. Crafting these requests well in advance and getting approval so the certifications are sitting on the shelf to be executed when the need arises is the best practice given the current state of unmanned aircraft operations. As reliability increases and better sense and avoid technology is proven and certified, progress will move towards unmanned aircraft units being able to file and fly missions. Until this occurs, using pre-approved certification of waiver or authorizations, which can be modified and re-approved, will offer the best chance of supporting short notice tasking.

Other areas that also need to be addressed to ensure unmanned aircraft assets can support domestic disaster situations. The first issue is the availability of bandwidth. Looking at current Ku-band satellite transponder availability is a lengthy process. There are numerous commercial communications satellite providers that have to be surveyed to determine the availability to support a disaster contingency. An additional consideration not covered in this work was the cost and funding lines necessary to equip units to accomplish the identified mission if so tasked. Some of the funding mechanisms were highlighted, but detailed figures and timelines will require further study.

Unmanned aircraft systems are valuable assets under the control of state governors, which are currently being underutilized to support state and local response to natural disasters. By adding meaningful capability to these assets, significant benefit would be gained by the incident command center managers responsible to state and federal authorities for the response efforts. While challenges remain, these hurdles are temporary and can be overcome with effort and focus. Where there is a will, success is sure to follow and the result will be quickly realized during the next natural disaster or wildland forest fire season.

LIST OF REFERENCES

Ambrosia, Vincent G., James A. Brass, Paul Greenfield, and Steve Wegener. *Collaborative Efforts in R&D and Applications of Imaging Wildfires*. Moffett Field CA: National Aeronautics and Space Administration Ames Research Center, 2004.

Ambrosia, Vincent G., Steve Dunagan, Don Sullivan, and Francis Enomoto. *Instructions for Installing and Using the Collaborative Decision Environment (CDE) Data Visualization Tools*. Wildfire Research and Applications Partnership: Western States Fire Mission 2007. 6th ed. Edwards, CA: National Aeronautics and Space Administration, 2007.

"AN/APY-8 Lynx I/Lynx-ER Ground Moving Target Indicator (GMTI)/Synthetic Aperture Radar (SAR) Radars." http://www8.janes.com/Search/documentView.do?docId=/content1/janesdata/yb/jrew/jrew1806.htm@current&pageSelected=allJanes&keyword=MQ-1Payloads&backPath=http://search.janes.com/Search&Prod_Name=JREW& (accessed August 28, 2008).

Bone, Elizabeth and Christopher Bolkcom. *Unmanned Aerial Vehicles: Background and Issues for Congress*. Washington, D.C.: Congressional Research Service, 2003.

Brake, Jeffrey D. *Terrorism and the Military's Role in Domestic Crisis Management: Background and Issues for Congress*. Washington, D.C.: Library of Congress Congressional Research Service, 2001.

"Bringing it all Together." http://innovationlabs.com/uav5/05_main.htm (accessed August 19, 2008).

Brinkerhoff, John R. "The Posse Comitatus Act and Homeland Security." *Journal of Homeland Security*, September 13, 2005.

California Department of Forestry and Fire Protection. *CAL FIRE 2007 Wildland Fire Summary*. Sacramento, CA: California Department of Forestry and Fire Protection, 2008.

Church, Frank and John G. Hightower. *Intelligence Activities and the Rights of Americans: Book II*. Washington, D.C.: U.S. Government Printing Office, 1976.

Cutler, Frank. "Instrumentation Pods." *National Aeronautics and Space Administration*. http://www.nasa.gov/centers/dryden/research/ESCD/uavsar_pod.html (accessed July 24, 2008).

Defense Airborne Reconnaissance Office. "Predator System Familiarization Guide." *Defense Airborne Reconnaissance Office*. http://www.fas.org/irp/agency/daro/predator/toc.html (accessed August 27, 2008).

DeGarmo, Mathew T. *Issues Concerning Integration of Unmanned Aerial Vehicles in Civil Airspace.* The Mitre Corporation. (November 2004) http://www.mitre.org/work/tech_papers/tech_papers_04/04_1232/04_1232.pdf. (accessed July 24, 2008).

Department of Defense. *Strategy for Homeland Defense and Civil Support*. Washington, D.C., 2005.

Department of Homeland Security. "DHS Announces Release of Application Guidance for Over $3 Billion in Grant Programs." *Department of Homeland Security.* http://www.dhs.gov/xnews/releases/pr_1201882070387.shtm (accessed November 4, 2008).

Department of the Interior and Bureau of Indian Affairs. "Wildland Fire and Aviation Program Management and Operations Guide 2008." *National Interagency Fire Center*. http://www.nifc.gov/policies/blue_book.htm (accessed October 24, 2008).

DeVane, John C. *Applicability of Unmanned Aerial Systems to Homeland Defense Missions*. Master's Thesis, Naval Postgraduate School, Monterey, CA, 2006.

Dreiling, Elizabeth E. *The National Guard: A Future Homeland Security Paradigm?* U.S. Army Command and General Staff College, Fort Leavenworth, KS, May 14, 2002.

Drew, John G., Russell Shaver, Kristin F. Lynch, Mahyar A. Amouzegar, and Don Snyder. *Unmanned Aerial Vehicle End-to-End Support Considerations*. Santa Monica, CA: The RAND Corporation, 2005.

Dudney, Robert S. A Better UAV Flight Plan. *Air Force Magazine,* April 2007, 2, http://www.airforce-magazine.com/MagazineArchive/Pages/2007/April%202007/0407edit.aspx (accessed July 24, 2008).

———. Where Do UAVs Go from Here? *Air Force Magazine,* July 2005, 2, http://www.airforce-magazine.com/MagazineArchive/Pages/2005/July%202005/0705edit.aspx . (accessed July 24, 2008).

"Endurance UAV CONOPS (Concept of Operations) - Version 2." *Air Combat Command*. http://www.fas.org/irp/doddir/usaf/conops_uav/ (accessed October 21, 2008).

Garkey, Jason T. "In Support of the Common Defense: Unity of Command between Federal and State Controlled Military Forces." *Naval War College*, 2006, http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA463544&Location=U2&doc=GetTRDoc.pdf (accessed July 24, 2008).

Gosch, Dave. "Rockwell Collins Successfully Controls and Lands Wing-Damaged UAV." *Athena Controls*. http://www.athenati.com/news_events/press_release/june_10_2008_-_rockwell_collins (accessed August 6, 2008).

Hagenauer, Beth. "NASA Responds to California Wildfire Emergency Imaging Request." *National Aeronautics and Space Administration*. http://www.nasa.gov/centers/dryden/news/NewsReleases/2008.08-30.html (accessed July 24, 2008).

Hall, Philip, Brent Cobleigh, Greg Buoni, and Kathleen Howell. *Operational Experience with Long Duration Wildfire Mapping UAS Missions Over the Western United States*. Edwards, CA: National Aeronautics and Space Administration Dryden Flight Research Center, 2008.

Harrington, Caitlin. "MQ-9 Reaper Ground Controllers Look Forward to Improved Radar Processing Speed." *International Defence Review*. http://www8.janes.com/Search/documentView.do?docId=/content1/janesdata/mags/idr/history/idr2008/idr11586.htm@current&pageSelected=allJanes&keyword=MTS-BSensor&backPath=http://search.janes.com/Search&Prod_Name=IDR& (accessed August 28, 2008).

———. "National Guard Predators are Ready for Action." http://www8.janes.com/Search/documentView.do?docId=/content1/janesdata/mags/jdw/history/jdw2006/jdw30092.htm@current&pageSelected=allJanes&keyword=MQ-1Payloads&backPath=http://search.janes.com/Search&Prod_Name=JDW& (accessed August 28, 2008).

Hildum, E. "Wildfire Scanner on Altair UAV: Western States Fire Mission." Interface Configuration Document, *Ames Research Center*.

Homeland Security Act of 2002. Translated by 107th Congress. Public Law 107-296 ed. vol. H.R. 5005. Washington, D.C.: 2002.

Hughes, David. "UAVs Face Hurdles in Gaining Access to Civil Airspace." *Aviation Week.* The McGraw Hill Companies. http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=awst&id=news/aw021207p1.xml (accessed August 20, 2008).

Insurance Information Institute. "Wildland Fires." http://www.iii.org/media/facts/statsbyissue/wildfires/ (accessed December 3, 2008).

Jacobs, Pieter A. *Thermal Infrared Characterization of Ground Targets and Backgrounds*. Tutorial Texts in Optical Engineering. Second Edition, TT70. Bellingham, WA: Spie Press, 2006.

Jha, A. R. *Infrared Technology: Applications to Electrooptics, Photonic Devices, and Sensors*. Wiley Series in Microwave and Optical Engineering. Edited by Kai Chang. New York: John Wiley & Sons, Inc., 2000.

JO 7610.4M. Washington, D.C.: Federal Aviation Administration, 2007.

Johnson, Jada E. *Mission Tasking of Unmanned Vehicles*. Naval Postgraduate School: Monterey, CA, June 2004.

Jumper, John. *The U.S. Air Force and Homeland Civil Support (White Paper).* Air Force Doctrine Center: Maxwell, AL, 2002.

Kaplan, Herbert. *Practical Applications of Infrared Thermal Sensing and Imaging Equipment*. Tutorial Texts in Optical Engineering. Third Edition, TT75. Bellingham, WA: Spie Press, 2007.

Knight, Anthony G. and Aaron B. Luck. *Tactical Space - Beyond Line of Sight Alternatives for the Army and Marine Corps Ground Tactical Warfighter*. Master's Thesis, Naval Postgraduate School, Monterey, CA, 2007.

Kochems, Alane. *Military Support to Civilian Authorities: An Assessment of the Response to Hurricane Katrina*. Backgrounder No. 1899. Washington, D.C.: The Heritage Foundation, 2005.

Kruger, Lennard G. *Assistance to Firefighters Program: Distribution of Fire Grant Funding*. Washington, D.C.: Congressional Research Service, 2008.

"L-3 Communications -> Products & Services -> ROVER 4 Receiver." http://www.l-3com.com/products-services/productservice.aspx?type=ps&id=820 (accessed August 25, 2008).

Levine, Jay. *The Ikhana: Uninhabited Aircraft System is Changing the Way Fires are Fought and Proving to be a Valuable Science Tool*. Edited by Jay Levine. Edwards, CA: National Aeronautics and Space Administration, 2008.

Malik, Arun. How Should We Tackle the Forest Fire Problem? *Resources Magazine*. June 23, 2008, http://www.rff.org/Publications/WPC/Pages/08_06_23_Forest_Fires_Malik.aspx (accessed December 3, 2008).

Mattoon, Rick. "Midwest Economy: Assessing the Midwest Floods of 2008 (and 1993)." *Federal Reserve Bank of Chicago*. http://midwest.chicagofedblogs.org/archives/2008/07/mattoon_flood_b.html (accessed December 3, 2008).

Mecham, Michael. “Through the Smoke.” *Aviation Week & Space Technology* 167, no. 11, September 17, 2007.

Moose, Robert G. *Ikhana AMS Sensor Specifications*. Edited by Jeffrey S. Myers. Personal E-Mail, 2008.

———. *Ikhana Fire Mission*, Edited by Philip Hall. Personal E-Mail, 2008.

"Mission Profiles." http://innovationlabs.com/uav5/03_main.htm (accessed August 19, 2008).

Munoz, Carlo. "Air Force UAVs Cleared for Domestic Duty." *InsideDefens.com*. http://www.military.com/features/0,15240,100537,00.html (accessed August 6, 2008).

Munson, Kenneth, ed. *Unmanned Aerial Vehicles and Targets*. Jane's. no. 26. United Kingdom: Jane's Information Group Limited, 2006.

Myers, Jeffrey S. *Ikhana AMS Sensor Information*. Edited by Robert G. Moose. E-mail discussion, 2008.

———. *AMS Sensor Range Resolution*, Edited by Robert G. Moose, 2008.

National Fire Protection Association. "Deadliest/large-Loss Fires." http://www.nfpa.org/itemDetail.asp?categoryID=954&itemID=23352&URL=Research&Reports/Fire statistics/Deadliest/large-loss fires&cookie_test=1 (accessed December 3, 2008).

National Interagency Coordination Center. *National Interagency Fire Center: Military use Handbook*. Boise, ID: National Interagency Coordination Center, 2006.

National Interagency Fire Center. "Military Support in Wildland Fire Suppression." *National Interagency Fire Center*. http://www.nifc.gov/fire_info/military_support.htm (accessed August 27, 2008).

National Oceanic and Atmospheric Administration. "National Climate Data Center: Climate of 2007: Wildfire Season Summary." http://www.ncdc.noaa.gov/oa/climate/research/2007/fire07.html (accessed December 3, 2008).

Office of Customs and Border Protection Air and Marine. *Unmanned Aircraft Systems in Homeland Security*. Washington, D.C.: United States Customs and Border Protection, 2007.

Office of Management and Budget. *A Review of Existing Authorities and Procedures for Using Military Assets in Fighting Wildfires*, May 17, 2004.

Office of the Secretary of Defense. *Unmanned Aircraft Systems Roadmap 2005-2030.* Washington, D.C.: August 4, 2005.

_____. *Unmanned Aircraft Systems Roadmap 2005-2030*. Washington, D.C.: Government Printing Office, 2005, http://www.acq.osd.mil/uas/docs/reliabilitystudy.pdf (accessed July 24, 2008).

_____. *Unmanned Systems Roadmap 2007-2032*. Washington, D.C.: Department of Defense, 2007, http://www.acq.osd.mil/usd/Unmanned%20Systems%20Roadmap.2007-2032.pdf (accessed July 24, 2008).

———. *Airspace Integration Plan for Unmanned Aviation*. Washington, D.C.: Department of Defense, 2004, http://www.uavm.com/images/OSD_Airspace_Integration_Plan_112304_Airspace.pdf. (accessed July 24, 2008).

———. *Unmanned Aerial Vehicle Reliability Study*. Washington D.C.: Department of Defense, 2003.

Office of the Under Secretary of Defense (Acquisition & Technology OUSD (A&T)) Defense Airborne Reconnaissance Office (DARO). *UAV Annual Report FY 1996*. Washington, D.C.: Department of Defense, 1996.

"Raytheon AN/AAS-52 Multispectral Targeting System A (MTS-A)." *Jane's Electro-Optic Systems*. http://www8.janes.com/Search/documentView.do?docId=/content1/janesdata/yb/jeos/jeos8417.htm@current&pageSelected=allJanes&keyword=MQ-1Payloads&backPath=http://search.janes.com/Search&Prod_Name=JEOS& (accessed August 28, 2008).

"Raytheon AN/DAS-1 Multispectral Targeting System - B (MTS-B)." http://www8.janes.com/Search/documentView.do?docId=/content1/janesdata/yb/jeos/jeosa106.htm@current&pageSelected=allJanes&keyword=MTS-BSensor&backPath=http://search.janes.com/Search&Prod_Name=JEOS& (accessed August 28, 2008).

Richard, Marc, John Atwood, David Crawford, and Diane Shaffer. "DOD Faces Tradeoffs in Using Commercial Broadband SATCOM Systems." *The Edge,* Winter 2002.

Shanker, Thom. "U.S. Pushes to Rely More on Remotely Piloted Craft - NYTimes.Com." *The New York Times Company*. http://www.nytimes.com/2008/06/05/washington/05military.html?_r=1&fta=y&oref=slogin (accessed October 20, 2008).

Schultz, David V. *A Department of Homeland Security Reserves (DHS-R): Simultaneously Protecting the Homeland While Alleviating the Increased DoD Role in Homeland Defense and Security*. Naval Postgraduate School: Monterey, CA, December 2007.

Stevens, Maureen. "Athena Successfully Controls and Autonomously Lands a Damaged UAV." *Athena Controls*. http://www.athenati.com/news_events/press_release/may_30_2007_-_athena_successfully_controls_and_autonomously_lands_a_damaged_uav.html (accessed August 6, 2008).

Tomme, Edward B. *The Paradigm Shift to Effects-Based Space: Near-Space as a Combat Space Effects Enabler*. Maxwell AFB, AL: Air University, 2005.

Topp, Peter A. *What Should be the Relationship between the National Guard and United States Northern Command in Civil Support Operations Following Catastrophic Events*. Master's Thesis, Naval Postgraduate School, Monterey, CA. http://www.nps.edu (accessed July 24, 2008).

Townsend, Frances. *The Federal Response to Hurricane Katrina: Lessons Learned*. Washington, D.C.: Office of the President of the United States, 2006.

"UAS News January - June 2008*." Federal Aviation Administration*. http://www.faa.gov/about/office_org/headquarters_offices/avs/offices/air/hq/engineering/uavs (accessed August 6, 2008).

Under Secretary of Defense for Policy. *DoD Instruction 5240.1-R Procedures Governing the Activities of DoD Intelligence Components that Affect United States Persons*. Washington, D.C.: Department of Defense, 1982.

United States Bureau of Labor Statistics. *California Wildfires: An Employment and Wage Profile of the Affected Counties*, 2007.

United States Congress. *Hearing before the Committee on Energy and Natural Resources: Preparedness for the 2007 Wildfire Season*. Washington, D.C.: U.S. Government Printing Office, June 26, 2007.

United States Congress. *Hearing before the Subcommittee on Energy and Natural Resources: Firefighting Aircraft*. Washington, D.C.: U.S. Government Printing Office, February 15, 2006.

United States Department of Defense. DoD Directive 3025.15. *Military Assistance to Civil Authorities*. Washington, D.C.: Government Printing Office, February 1997.

United States General Accounting Office. *Force Structure: Improved Strategic Planning Can Enhance DoD's Unmanned Aerial Vehicles Efforts*. Washington, D.C.: U.S. General Accounting Office, 2004.

United States Government Accountability Office. *Enhanced National Guard Readiness for Civil Support Missions May Depend on DoD's Implementation of the 2008 National Defense Authorization Act*. Washington, D.C.: U.S. Government Accountability Office, 2008.

United States Government Accountability Office. *Technology Assessment: Protecting Structures and Improving Communications during Wildland Fires*. Washington, D.C.: U.S. Government Accountability Office, 2005.

United States Government Accountability Office. *Unmanned Aerial Vehicles: Improved Strategic and Acquisition Planning Can Help Address Emerging Challenges*. Washington, D.C.: U.S. Government Accountability Office, 2005.

United States Government Accountability Office. *Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand their Potential Uses within the National Airspace System*. Washington, D.C.: U.S. Government Accountability Office, 2008.

United States Forest Service Aviation. "Modular Airborne FireFighting System (MAFFS)." http://www.fs.fed.us/fire/aviation/fixed_wing/maffs/system.html (accessed August 27, 2008).

United States President. *Executive Order.* "United States Intelligence Activities, Executive Order 12333." Federal Register 46, No. 59941, December 4, 1981.

U.S. Code: Title 18, Section 1385 Use of Army and Air Force as Posse Comitatus. Public Law, ed., Washington, D.C.: 1878.

Verga, Peter. Statement Presented Before the 110th Congress Committee on Homeland Security and Governmental Affairs, July 19, 2007.

"VideoScout: Video Exploitation and Management." *L-3 Communications*. http://www.l-3com.com/apd/products/videoscout.htm (accessed September 17, 2008).

Vina, Stephen R. *Border Security and Military Support: Legal Authorizations and Restrictions*. Washington, D.C.: Congressional Research Service Report for Congress. Library of Congress Congressional Research Service, Order Code RS22443, October 23, 2006.

Weiger, Rusty L. *Military Unmanned Aircraft Systems in Support of Homeland Security*. Master of Strategic Studies. U.S. Army War College, 2007, http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA469646&Location=U2&doc=GetTRDoc.pdf (accessed July 24, 2008).

Wheeler, Kenneth A. *Evolving Military Strategy and Developing Homeland Security: An Opportunity to Share Resources*. Master of Strategic Studies. U.S. Army War College, 2004, http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA424016&Location=U2&doc=GetTRDoc.pdf (accessed July 24, 2008).

White, John P. *DoD Directive 3025.15 Military Assistance to Civil Authorities*. Washington, D.C.: Department of Defense, 1997.

Wilber, Del Quentin. "Drones Raise Safety Issues as Service Roles Multiply." *The Washington Post,* sec. A., July 20, 2007.

Wilmeth IV, James Lillard. *United States Military Intelligence Support to Homeland Security*. United States Command and General Staff College. Fort Leavenworth, KS, May 26, 2004.

"WRAP: Current Activities & Demonstrations: Completed Missions." http://geo.arc.nasa.gov/sge/WRAP/current/com_missions.html (accessed August 26, 2008).

"WRAP: Current Activities & Demonstrations: Future Missions: Altair Western States Fire Mission Concept Plan." http://geo.arc.nasa.gov/sge/WRAP/current/future_missions.html (accessed August 26, 2008).

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California