DETERMINING IF THE UNITED STATES MILITARY IS READY TO ELIMINATE ITS PILOTS: USE OF COMBAT UNMANNED AERIAL VEHICLE

A thesis presented to the Faculty of the U.S. Army
Command and General Staff College in partial
fulfillment of the requirements for the
degree

MASTER OF MILITARY ART AND SCIENCE
General Studies

by

TOD R. FINGAL, MAJ, USAF
B.S., United States Air Force Academy, Colorado, 1986

Fort Leavenworth, Kansas
2001

MASTER OF MILITARY ART AND SCIENCE

THESIS APPROVAL PAGE

Name of Candidate: MAJ Tod R. Fingal

Thesis Title: Determining if the United States Military Is Ready to Eliminate Its Pilots: Use of Combat Unmanned Aerial Vehicle

Approved by:

____, Thesis Committee Chairman
Captain Graham H. Gordon, M.S., M.B.A.

____, Member
Colonel Raymond O. Knox, M.M.A.S., M.Ed.

____, Member
Rodler F. Morris, Ph.D.

Accepted this 1st day of June 2001 by:

____, Director, Graduate Degree Programs
Philip J. Brookes, Ph.D.

The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

DETERMINING IF THE UNITED STATES MILITARY IS READY TO ELIMINATE ITS PILOTS: USE OF COMBAT UAV by MAJ Tod R. Fingal, USAF, 93 pages.

This study investigates the viability of replacing manned aircraft with unmanned combat aerial vehicles in the armed reconnaissance mission. Increased costs associated with operating a viable Air Force combined with a growing aversion to human, combat losses have prompted military leaders to look for alternate means of conducting warfare. The unmanned combat aerial vehicle provides the future warfighter the capability to strike at the enemy without placing a pilot at risk, and the costs associated with operating the system are much lower than those of manned aircraft.

The study identifies the tasks required to conduct the armed reconnaissance mission and compares them to the tasks current unmanned systems can accomplish. Unmanned aerial vehicles currently perform many reconnaissance, surveillance and targeting missions, and unmanned combat aerial vehicles are in the military's concept development stage. They provide many of the capabilities needed to accomplish the armed reconnaissance mission.

To determine if the United States military should pursue the goal to replace manned aircraft with unmanned combat aerial vehicles, the study compares the strengths and weaknesses of both systems. The study concludes that the military should continue to develop unmanned systems capable of conducting the armed reconnaissance mission, but emphasis should not center on replacing manned aircraft. Rather, the unmanned combat aerial vehicle should be developed as a force multiplier and employed when the combat situation favors its use.

TABLE OF CONTENTS

LIST OF ACRONYMS

ACA	Airspace Control Authority
ACTD	Advanced Concept Technology Division
AI	Air Intercept
ARPA	Advanced Research Project Agency
ATO	Air Tasking Order
ATR	Automatic Target Recognition
AWACS	Airborne Warning and Control System
BDA	Battle Damage Assessment
CAS	Close Air Support
COBRA	Coastal Battlefield Reconnaissance and Analysis
DARO	Defense Airborne Research Office
DARPA	Defense Advanced Research Projects Agency
DEMPC	Data Exploitation Mission Planning Communication
ECM	Electronic Countermeasures
EO	Electro-optical
EW	Electronic Warfare
FY	Fiscal Year
GCS	Ground Control Station
GPS	Global Positioning System
HMLV	Highly-Maneuverable Lethal Vehicle
IADS	Integrated Air Defense System
INS	Internal Navigation System

IR	Infrared
IRSTS	Infrared Search and Tracking System
JFACC	Joint Forces Air Component Commander
JFC	Joint Forces Commander
JSTAR	Joint Surveillance Target Attack System
LOS	Line of Sight
NATO	North Atlantic Treaty Organization
RAPIN	Reliable Autonomous Precise Integrated Navigation
RSTA	Reconnaissance, Surveillance, and Targeting Acquisition
SAM	Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SEAD	Suppression of Enemy Air Defense
STARLOS	SAR Target Recognition and Location System
TCS	Tactical Control System
UAV	Unmanned Aerial Vehicle
UAVB	Unmanned Aerial Vehicle Battlelab
UCAV	Unmanned Combat Aerial Vehicle
UTA	Unmanned Tactical Aircraft
VTOL	Vertical Takeoff and Landing

LIST OF ILLUSTRATIONS

Figure Page

LIST OF TABLES

Table Page

CHAPTER 1

INTRODUCTION

> By its conclusion, Allied Force employed a greater percentage of the U.S. Air Force than either Vietnam or Desert Storm--this considerable force provided tremendous capabilities for NATO. Ultimately, NATO achieved its objectives: Milosevic's forces left Kosovo and were replaced by an international peacekeeping force. In a testament to our readiness, we achieved our objectives without losing a single Airman in combat.[1]
>
> General John P. Jumper, Commander,

Background

During Operation ALLIED FORCE in Kosovo, the United States military flew combat missions with many restrictions placed upon them. One of the overarching purposes for these restrictions was to prevent aircrew casualties. "'The political support for this operation isn't so strong that it can tolerate high casualties,' insist[ed] retired Army General John Shalikashvili, who succeeded Powell as Chairman of the Joint Chiefs. 'You should avoid the casualties if you can, even if it takes a little longer.'"[2] General Shalikashvili's assessment is accurate with respect to the use of the United States military. National leaders use the military instrument of power more often today to support the National Security Strategy than they did prior to the Vietnam War, but today's political support is far less tolerant of the loss of American servicemen in the conduct of these operations. If future military operations must focus on preventing soldiers' casualties, does the United States military need to explore alternate means of conducting warfare to avoid the loss of human life? The use of unmanned aircraft offers one aerial-combat alternative for reducing human, combat losses.

The idea of using unmanned aircraft in combat roles was first introduced by the Germans in World War II. The German Army developed and employed the V-1 and proved that an unmanned vehicle could be used to achieve destructive effects on a target. The V-1s used by the Germans during the war were a "one-time use" weapon system that was destroyed as it hit the intended target.[3] During the same time frame, in an operation called Project Aphrodite, the United States employed B-17 and B-24 bombers filled with TNT or liquid petroleum and remotely flew them against enemy targets. The idea behind Project Aphrodite was to crash radio-controlled, worn-out aircraft into the target, a large city or industrial complex, and detonate the explosives. Project Aphrodite was largely unsuccessful because the aircraft were easily shot down, and the program was terminated due to a British fear that the Germans would retaliate in kind.[4] In the 1950s, the United States developed the Snark, an unmanned, intercontinental bomber designed for strategic attacks on the Soviet Union.[5] The Snark was also a one-time use weapon system. Although the V-1, Aphrodite and Snark more resemble today's cruise missiles, they set the stage for further unmanned aerial vehicle (UAV) research and development.

The Unites States military began experimenting with the use of unmanned reconnaissance aerial drones in the late 1950s, but the initial work proved unsuccessful and research and development stopped. Later, however, the cold war and the Vietnam War rekindled the desire to again begin research and development. During the Vietnam War, the United States military successfully employed UAVs in signals intelligence gathering and high-altitude and low-altitude image gathering missions. These UAVs, the Firefly, Frisbee and Lightning Bug, were sometimes difficult to maintain and operate, but they enabled the Air Force to collect imagery both day and night. The Frisbee, a target drone converted to a UAV by Teledyne Ryan Corporation, flew over 3,000 missions in Southwest Asia.[6] By the end of the Vietnam War, in an effort to reduce the number of combat casualties, the only aircraft permitted to fly reconnaissance missions over North Vietnam were the high-flying SR-71 Blackbird and the Lighting Bug UAV.[7] Following the Vietnam War, the United States military continued UAV research and development to use them as force multipliers.

During the post-Vietnam War time frame, the Israelis used their Mastiff and Scout UAVs as decoys to penetrate Syrian airspace in an effort to draw fire from the Syrian surface-to-air missile (SAM) sites. After the Syrian air defense forces expended all their missiles, the Israelis were able to use their manned fighters to locate and destroy the sites without the threat of being shot down.[8] Many programs were introduced over the years, but they often failed due to cost overruns and developmental problems. It was not until the Israeli Air Force effectively used UAVs to help defeat the Syrian air defenses in the Bekaa Valley in 1982 that the United States Navy and Air Force recognized the UAV's full potential.[9] This prompted the United States military to pursue the Pioneer and Predator UAVs' development.

The Pioneer UAV flew 330 missions during the Persian Gulf War and provided inexpensive, unmanned, over-the-horizon targeting, battle damage assessment, and reconnaissance. The six Pioneer UAVs operated by the Army, Navy, and Marines during Operation DESERT STORM prompted the Department of Defense to look at the use of

UAVs to fill some of the reconnaissance shortfalls the military was experiencing.[10] This led to the development of the Predator UAV. The Predator and the Pioneer were successfully employed during Operation JOINT ENDEAVOR in Bosnia. The Predator flew more than 350 sorties, totaling more than 2,800 hours, and provided military leaders with the needed ability to see enemy positions "over the horizon" prior to committing troops.[11] The successes UAVs achieved during operations in Iraq and Bosnia created a springboard for further UAV development.

Research Question

Over the past ten years, technological advances have rapidly accelerated UAV capabilities, and these developments have led some senior Air Force leaders to look into the feasibility of replacing combat aircraft over the battlefield with Unmanned Combat Aerial Vehicles (UCAVs). Due to the high costs associated with maintaining a robust air force, many other countries are looking at UCAVs as a cost effective way to provide national defense. The Department of Defense created the Defense Airborne Research Office (DARO) to consolidate the research and development of unmanned vehicles for all the services. Although DARO was disbanded in 1997, it established the framework to create unmanned combat vehicles to supplement and or replace manned, combat aircraft. This thesis will research the following question: Should the United States military pursue a goal to replace all manned, combat aircraft with UCAVs in order to reduce the risk of human, combat losses?

In order to answer the main thesis question thoroughly, secondary questions will also need to be researched and answered. This thesis will research what missions UCAVs must perform in order to accomplish today's manned, combat missions. Then it will research the capabilities UAVs currently enjoy and the capabilities presently under development. While researching UAV current capabilities, the thesis will also address today's system limitations and integration into the present combat force. Finally, this thesis will attempt to determine what capabilities the United States military would lose through the use of an all UCAV force and then compare that to the advantages it gains through their use.

Definitions

Throughout this study, the terms UAV and UCAV are used interchangeably, and this is done intentionally. Although the two terms are used interchangeably, they do not describe the same system. A UAV is a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semiballistic vehicles, cruise missiles, and artillery projectiles are not considered UAVs.[12] For the purpose of this thesis, the UCAV will have the same definition as the UAV with a few exceptions. The UCAV will always carry a lethal payload, and all UCAVs will be recoverable. Additionally, the term UCAV is used to describe the system this thesis is proposing as a replacement to manned, combat aircraft. UCAV describes the future systems currently being developed and conceptualized, and the term UAV is used to describe systems currently used by today's military.

Assumptions

During Operation PROVIDE COMFORT in northern Iraq, two United States Air Force F-15 pilots shot down two American Blackhawk helicopters killing all twenty-four people on board. The American public was outraged. "Restrictions must be placed on lethal UAVs because of the potential consequences of an accident or malfunction. Recent history has proven that the American public and the international community hold individuals and organizations accountable for decisions to use force.”[13] The first assumption upon which this thesis is based is that the American public’s reaction to lethal force “accidents” or “mistakes” will remain stringent. Because of this, the UCAV must employ a man-in-the-loop system to provide a safety outlet to minimize system malfunctions from causing catastrophic results. The man-in-the-loop system gives the UCAV controller the capability to interact with the vehicle. Interaction may involve remotely flying the UCAV, or it may simply involve giving the final weapons-release consent. This man-in-the-loop system is currently incorporated in today’s UAV systems, and UAVs are currently filling many requirements for today’s warfighters.

UAVs currently fill intelligence, surveillance, and reconnaissance needs in the military, and expanded UAV roles continue to develop. As UAVs continue to accomplish more military roles, mission complexity increases. Dr. Leland M. Nicolai, a research analyst for Lockheed Martin Skunk Works’ UCAV programs, stated that missions for UCAVs in order of increasing complexity are as follows:

1. Intelligence, surveillance, and reconnaissance
2. Communications relay
3. Electronic warfare (EW) (jamming)
4. Air interdiction (fixed target strike)
5. Suppression of Enemy Air Defenses (SEAD)
6. Theater ballistic missile and cruise missile defense
7. Air defense

8. Battlefield interdiction (mobile target strike)

9. Close air support (CAS)

10. Air-to-Air combat[14]

This mission complexity hierarchy leads to a second assumption. The second assumption upon which this thesis is based is that if a UCAV can effectively accomplish one of the missions listed on Dr. Nicolai's list, then it can also accomplish the less complex missions listed before it. Historically UAVs have performed well in low threat scenarios. To effectively replace all manned, combat aircraft, this study's UCAV must posses the capability to penetrate an enemy's Integrated Air Defense System (IADS) and deal with an enemy's surface-to-air and air-to-air threats in order to put weapons on target. The IADS is a network of early-warning and target-tracking radars, communications equipment, command and control networks, and surface-to-air and air-to-air defense systems all orchestrated to accomplish the air defense mission. The UCAV must be able to survive in this heavily defended, combat arena. The UCAV must survive if it to successfully attack and destroy its given target.

The UCAV's target destruction capability leads to the last assumption. The final assumption upon which this thesis is based deals with munitions development. The Department of Defense is currently involved in programs to develop a smaller class of munitions to replace the military's current arsenal of 500, 1,000, and 2,000-pound munitions. This study assumes that these programs will continue to progress and that these small, smart munitions will be available for UCAV employment within the time frame of this study.

Limitations

The largest limitation of this thesis involves the rate at which technologies are progressing in developing the UCAV and its components. Many UCAV capabilities addressed in this study are currently in the developmental and testing stages, and obtaining the most current data is challenging. This obstacle was minimized through direct contact with the agencies conducting the research and development and through thorough and detailed information compilation in order to determine industry's trends. It is impossible to predict exactly where UCAV research and development will lead, but that is not important. This study focuses more on arriving at the point where a UCAV is capable of replacing manned aircraft, and not on the path taken to get there.

Another limitation in researching this thesis pertains to the information gathered from private industries. This thesis used data generated from private industries that are also trying to sell their technologies to the military for production. In some instances, the proposed design concepts may exceed actual capabilities. This thesis attempted to avoid slanted information through the comparison of multiple sources. Single-sourced documentation was omitted from this study. Additionally, competition among industries requires them to limit the information released pertaining to the progress they are making in UCAV development. This only affected this study in determining how quickly a UCAV will be produced, and setting a time frame for this study minimized its impact.

Finally, in order to keep the thesis as an unclassified document, there are some studies that were omitted to prevent the classification from changing. This obstacle was most prevalent when the thesis addressed the UCAV's future capabilities and electronic combat capabilities. Omitting the actual performance data of future systems and the specific electronic combat performance data, but still addressing the basic capabilities that the systems employ sidestepped this limitation.

Delimitations

This thesis involves a few delimitations in an effort to focus the topic's research and development. The first delimitation in this thesis is the role the UCAV will accomplish. Air interdiction is one of the United States Air Force's primary missions. "Air interdiction is employed to destroy, disrupt, divert, or delay the enemy's surface military potential before it can effectively engage friendly forces, or otherwise achieve its objectives."[15] Air interdiction missions are flown as preplanned missions against known enemy locations, or they are flown as flexible missions when the enemy's exact location is unknown. The armed reconnaissance mission is a type of flexible air interdiction that is planned against a particular area, rather than a particular target. The area may be defined by a box or grid, or may be defined as a stretch of a line-of-communication such as a railroad, highway, or river. When specific killboxes are used for this purpose, the mission is sometimes known as "killbox AI." Armed reconnaissance is normally flown into areas where lucrative targets are known or suspected to exist, or where mobile enemy surface units have moved to as a result of ground fighting.[16] For the sake of this study, the UCAV will perform the armed reconnaissance mission.

The definition of the armed reconnaissance mission uses the term mobile in describing the enemy's surface units. Do not confuse a mobile target with a moving target. A mobile target is defined as a target that is not fixed in space.[17] Realistically, any target can be moved within a given time frame. Therefore, for the purpose of this study, a mobile target is defined as a target that is moved within the time scale of the air tasking order's operation. A mobile target does not necessarily constitute a moving target, but rather a target moved within the time scale.

Simply limiting the UCAV's use to the armed reconnaissance mission does not provide the framework from which a careful system analysis can proceed. The United States military recognizes that it is required to operate in many different geographic locations and in multiple roles. From humanitarian assistance to full-scale war, the military must be prepared to operate at a moments notice. In evaluating the effectiveness of a particular military system, its impact will vary depending on the environment in which it is used. The scenario for this study is a major regional conflict in the Middle East. This study uses Operation DESERT STORM as the UCAV's test bed, and it is based upon a twenty-four-year time frame. This thesis' conclusions are based upon the UCAV's ability to perform the armed reconnaissance mission in the Middle Eastern environment by the year 2025.

The final delimitation for this thesis is that the study does not address any moral issue involved with using a UCAV to inflict damage on an enemy. Throughout history, societies have banned certain types of weapons they considered unethical to use. The United States' Project Aphrodite provides an example of a weapon system's use terminated due to social pressures. Shortly after the first remote-controlled B-17s and B-24s were used in combat, the British opposed further Aphrodite missions because they feared the Germans would retaliate due to the "terror" nature of the weapon. Although some studies do address the ethical issue involving the UCAV's use, this study will focus on the UCAV's technological aspects to determine if the capability exists to inflict damage on a target without exposing the operator to the threat. This thesis will address the human element in combat and the value the United States places on the American serviceman's life.

---

[1]John P. Jumper, "Statement of General John P. Jumper, Commander, United States Air Forces Europe, United States Air Force," 26 October 1999 [article on-line] available from http://www.house.gov/hasc/testimony/106thcongress/00-10-26jumper.htm; Internet; accessed 19 October 2000.

[2]Mark Thompson, "Grounded in Kosovo," *Time Magazine* 153, no. 21 (31 May 1999); [Article on-line] available from http://www.pathfinder.com/time/magazine/articles/0,3266,25695,00.html; Internet; accessed 20 October 2000.

[3]Michael H. Gorn, "Prophecy Fulfilled: Towards New Horizons and Its Legacy," *Air Force History and Museums Program* (1994), 28-35.

[4]Jack Olsen, *Aphrodite: Desperate Mission* (New York, New York: G.P. Putnam's Sons, 1970).

[5]Bruce W. Carmichael et al., *Strikestar 2025* (Maxwell Air Force Base, Alabama: Air University Press, 1996), 2-1.

[6]Steven M. Kosiak and Elizabeth E. Heeter, "Unmanned Aerial Vehicles – Current Plans and Prospects for the Future" 11 July 1997 [Database on-line]; available from http://www.csbaonline.org/4Publications/Archive/…/B.19970711.Unmanned_Aerial_Ve.htm; Internet; accessed 26 October 2000.

[7]Eric J. Labs and Evan W. Christman, "Options for Enhancing the Department of Defense's Unmanned Aerial Vehicle Programs," Report submitted to the Congressional Budget Office, September 1998 [Report on-line]; available from http://sun00781.dn.net/man/congress/1998/cbo-uav.htm; Internet; accessed 26 October 2000.

[8]Kosiak et al., 2.

[9]Labs and Christmas, 1.

[10]Carmichael et al., Chap. 2, p. 3.

[11]Pat McKenna, "Eyes of the Warrior," *Airman Magazine* 42, no. 7 (July 1998): 28.

[12]U.S. Department of Defense, Joint Publication 1-02, *DoD Dictionary of Military and Associated Terms* [CD-ROM] (Washington, DC: Government Printing Office, 12 January 1998): 473.

[13]Carmichael et al., Chap 4, p. 3.

[14]Leleand M. Nicolai, "Design Guidelines and Considerations for the UTA," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997, (Defense Technical Information Center, Record accession number ADA351279), 3.

[15]U.S. Department of the Air Force, Air Force Doctrine Document 2-1.3, *Counterland* [CD-ROM] (Washington, DC: Government Printing Office, 27 August 1999), 23 (hereafter cited as AFDD 2-1.3).

[16]AFDD 2-1.3, 27.

[17]B. D. Stewart, 1997, "The Operation Effectiveness of UCAVs in Mobile Target Attack," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997, (Defense Technical Information Center, Record accession number ADA351279), 2.

CHAPTER 2

LITERATURE REVIEW

The study of replacing manned aircraft with UCAVs is not a new concept to the United States military, and pertinent information exists in many literary works. Available information ranges from service doctrine to articles written about future developments in UAV technology. Since the available literature is quite extensive, this chapter will categorize the information into four areas. The first examines joint and service doctrine pertaining to the use of UAVs. The next examines literature involving the technologies UAVs currently enjoy. This chapter then focuses on literature involving research and development projects currently underway. The final part examines literature describing capabilities a UCAV must enjoy in order to effectively accomplish the armed reconnaissance mission. A thorough collection of information within the framework of these four categories will provide the basis for answering the primary thesis research question: Should the United States military pursue a goal to replace all manned, combat aircraft with UCAVs in order to reduce the risk of human, combat losses?

Joint and Service doctrine does not list tasks that a military service or unit must accomplish in order to accomplish a specific mission, but it does provide the framework from which military organizations can build. Joint Publication 1-02 defines doctrine as "fundamental principles by which the military forces or elements thereof guide their actions in support of national objectives. It is authoritative but requires judgment in application."[1] Understanding how doctrine is currently applied to the use of UAVs is critical to this thesis because it shows not only how the military views the use and potential uses of UAVs, but it also shows how the acceptance of UAV use in the military has evolved over time.

The use of UAVs is currently incorporated into Army, Navy, Air Force, and Joint doctrine. Perhaps the most significant trend, given the theme of this study, is what has not been written in the doctrine rather than what has. Current doctrine predominately pertains to UAV use in the reconnaissance role. Although there is some mention of the possible uses of UAVs beyond this conventional role, the preponderance of material restricts the UAV's use to nonlethal roles. Although it is not surprising that current doctrine does not openly discuss the use of UAVs or UCAVs in lethal roles, the references made towards the possibility of striking targets with UCAVs suggests the military is interested in the idea of limiting the American serviceman's exposure to dangerous, combat missions. Additionally, rising military costs make the UCAV an attractive alternative for conducting military operations at a substantially reduced cost.

An abundant amount of research material is available pertaining to the use of UAVs and the development of UCAVs. The United States Air Force, United States Navy, and United States Army have all conducted extensive studies concerning the use of UAVs, and they have developed departments dedicated to the integration of UAV technology into military operations. The Air Force has two operational UAV squadrons, and has programs for training Air Force personnel on operating UAV systems. Many articles have been written on the uses of UAVs, as well as articles concerning future UCAV development. In 1993 the Joint Staff established an office to control all the research and integration of UAVs. In 1995 the Air Force Chief of Staff also directed the Air University to conduct a study on uses of UAV technology in future operations. The

Advanced Research Projects Agency (ARPA) in Alexandria, Virginia, also has a high-altitude endurance UAV joint program office. The offices of the Pentagon Acquisitions Chief and the Assistant Secretary of Defense for C3I are developing a UAV master plan in cooperation with the Joint Staff, defense agencies, and Joint Forces Command. The master plan focuses on developing a strategy for future UAV and UCAV development.

The current trends in the material indicates that UAVs play a key role in reconnaissance missions in the military, and many sources address the concept of removing pilots from the combat arena. Air University's 1995 study, *Strikestar 2025*, looked into expanding the UAV's current reconnaissance role into a multimission strike role.[2] This study, along with other similar studies, suggests that the military needs to work toward the goal of removing pilots from the aerial battlefield. Recent military operations proved that the United States military has the capabilities to use unmanned aerial vehicles in a combat role. During Operation ALLIED FORCE, the Air Force tested the capability of equipping the Predator UAV with a laser designator to mark a target for a loitering fighter to strike. Although this capability was not utilized in actual combat, the laser-equipped Predator proved reliable during testing.

This thesis will use reliability as one of the key criteria for determining if a UCAV can effectively accomplish the armed reconnaissance mission. The laser equipped Predator was not employed during Operation ALLIED FORCE due to controller-training limitations, and current materials reveal some critical limitations in the controller-vehicle interface. There are also reliability issues pertaining to early UAV operations, but trends indicate that UAV reliability is improving. This information is valuable to this study because it will help establish UAV reliability patterns.

The volume of material involving research and development projects currently underway is extensive. In 1997 a symposium was held in Athens, Greece, to discuss the status of unmanned tactical aerial vehicles that could deliver weapons.[3] This multinational symposium produced a large number of research studies on applications, operational concepts, and UCAV techniques and technologies. The studies provided a very good summary of the status of UCAVs from operational, systems, and technological points of view. Information gathered from this symposium, as well as information gathered from agencies within the Department of Defense provided the basis for determining UCAV capabilities that are within a few years of development. This area is important because it helps establish emerging capabilities UCAVs can expect to enjoy within this study's timeframe. Because advancements in UAV technology are progressing at a rapid pace, literature pertaining to developmental issues will shed light on where military planners can--may need to--focus in order to enjoy the maximum effectiveness of UAV technology.

In determining if a UCAV can effectively accomplish the armed reconnaissance mission, this thesis defines the tasks necessary to accomplish the mission. There are quite a few studies on requirements needed for a UCAV to accomplish a combat mission. Individual studies as well as studies sponsored by the Department of Defense have produced a list of realistic requirements for the UCAV. The literature is consistent in areas, such as reliability, survivability, and flexibility, and these areas will be used to establish criteria for UCAV effectiveness. These criteria are essential in determining if the United States military should pursue a goal to replace manned aircraft with UCAVs

4

[1]U.S. Department of Defense, Joint Publication 1-02, *DoD Dictionary of Military and Associated Terms* [CD-ROM] (Washington, DC: Government Printing Office, 12 January 1998).

[2]Bruce W. Carmichael et al., *Strikestar 2025* (Maxwell Air Force Base, Alabama: Air University Press, 1996), 3.

[3]Thomas D. Taylor, "Technical Evaluation Report," (Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997) (Defense Technical Information Center, Record accession number ADA351279).
[4]

CHAPTER 3

RESEARCH METHODOLOGY

The research methodology of this thesis follows a four-step process to determine if the United States military should pursue a goal to replace all manned, combat aircraft with UCAVs in order to reduce the risk of human, combat losses. The research begins by identifying what capabilities UCAVs must enjoy in order to accomplish an armed reconnaissance mission. Next, the research focuses on how UAVs are currently employed in today's military and the UAV and UCAV programs that are currently under development. Through comparing the requirements against the UCAV's current and near-future capabilities, the thesis will then determine the shortfalls, if any, in using UCAVs in a combat role. Finally, in order to effectively determine the feasibility of replacing manned aircraft with UCAVs, this thesis will compare the strengths and weaknesses in both manned and unmanned flight with the overall goal of accomplishing the mission.

The first research step involves identifying the capabilities a UCAV must employ in order to accomplish the armed reconnaissance mission. "Armed reconnaissance is normally flown into areas where lucrative targets are known or suspected to exist, or where mobile enemy surface units have moved to as a result of ground fighting."[1] In cases where suspected enemy target areas cannot be predetermined, armed reconnaissance missions can be launched in an on-call or airborne alert status until a target area is identified. Command and control assets can pass target area location information to the orbiting UCAV, and the UCAV can then depart its orbit to strike the identified target. Therefore, in order to accomplish this mission, the UCAV must posses the following capabilities:

1. Survivability. The capability of the UCAV to withstand external threats to accomplishing the mission. This includes maneuverability and self-protection capability. Vulnerability is also included and it involves the UCAV's ability to operate after sustaining partial damage.[2]

2. Reliability. The UCAV design must minimize failures due to internal and external threats. Internal threats involve hardware malfunctions while external threats involve design shortfalls and handling errors.[3] Reliability problems also affect the UCAV's operational safety.

3. Controllability. This is inherent in the armed reconnaissance mission due to the flexibility the mission requires. A man-in-the-loop feature permits the operator to make a rational, judgmental and moral assessment of the situation before employing weapons.[4] Controllability is essential to accomplish the armed reconnaissance mission.

4. Flexibility. Includes altitude, weather, day and night operation, and speed (time to target).

5. Lethality. Includes capability to deliver munitions that have different target area effects based upon target type.

6. Range and Endurance. Involves ability to fly to the target area, loiter if necessary, and then recover to the base of departure.

These required UCAV capabilities are compatible with capabilities required of today's manned, fighter aircraft. Although specifics within each category may change over time, the basic concepts within the framework of these criteria will remain constant.

The next step in researching this thesis focuses on how UAVs are currently employed in today's military. Many of the UCAV's required capabilities are already enjoyed in the military's UAV program, and programs currently in the developmental stage are improving upon these capabilities. Although UAV use has mainly been restricted to traditional reconnaissance missions, the United States military has used UAVs in limited combat roles since the Vietnam War. Recent force structure downsizing combined with increased weapon system costs motivated the Department of Defense to increase UAV research and development projects in an effort to develop more effective war-fighting methods. Because of this, current UAV programs under development are addressing the criteria listed above. This study will describe where the current and developmental capabilities already meet the required capabilities and how minor variations to the current capabilities can be modified to meet capabilities not currently enjoyed. Additionally, research will include analysis on how well UAVs integrate with today's strike packages.

Once the information on current and developmental capabilities is presented, the thesis will then begin the comparative process. UCAV shortfalls can easily be established by comparing the required capabilities to the current and near future capabilities. The shortfalls will be addressed, and research will focus on the feasibility in eliminating the shortfalls. Again, this thesis established a time frame of 2025, so the feasibility will reference this timeline.

In an effort to answer the primary question of determining if UCAVs should replace all manned aircraft, this thesis will also compare manned aircraft missions to UCAV use. The criteria used will involve the UCAV requirements previously mentioned as well as a cost analysis and human factor limitations. This thesis will analyze the strengths and weaknesses of both manned and unmanned aircraft use to help determine if it is logical to conduct the armed reconnaissance mission with UCAVs. During cost analysis, research and development costs, as well as system operating and training costs will be studied. Although difficult to quantify the value of the American serviceman, this thesis will also address the value of limiting the serviceman's exposure to danger.

Human factor limitations will be incorporated into the study for both manned and unmanned aircraft. Human factor areas involve physiological and psychological limitations to accomplishing the mission. In manned aircraft missions, the pilot is affected physically by the G-forces encountered during maneuvering flight and psychologically by the stresses associated with combat. The UCAV operator is not exposed to the physical stresses involved with flying the UCAV, but he is physically affected in what he can sense in the battle area. The operator is also psychologically affected due to the nature of delivering weapons on a target without being threatened himself. This thesis will study these issues and incorporate the results into the study's strengths and weaknesses matrix.

The four-step research methodology process used in this thesis provides a sequential, yet interdependent process of answering the primary question. Each step relates to and builds upon the previous step, and this systematic approach provides the opportunity to easily incorporate information from multiple sources to help develop a cohesive study. In addition, this methodology provides an easy opportunity to focus research on the different process steps to validate the results.

The strength of the research methodology may also be one of its weaknesses. Although the study is well focused, a danger exists in overlooking information pertinent to UCAV use due to limiting information to the aforementioned steps. Continuously focusing on the primary question throughout the information research and analysis was accomplished in an effort to minimize this weakness.

---

[1]U.S. Department of the Air Force, Air Force Doctrine Document 2-1.3, *Counterland* [CD-ROM] (Washington, DC: Government Printing Office, 27 August 1999), 27.

[2]D. Scheithauser and G. Wunderlich, "System Integrity Considerations for Unmanned Tactical Aircraft," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997, (Defense Technical Information Center, Record accession number ADA351279), 6.

[3]Ibid.

[4]Leleand M. Nicolai, "Design Guidelines and Considerations for the UTA," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997, (Defense Technical Information Center, Record accession number ADA351279), 1.

CHAPTER 4

ANALYSIS

> From time to time a new invention astonishes the world, and is hailed by the prophets as the forerunner of a revolution in the military art. The cross-bow, the rifled barrel, the quick-firing gun, the submarine, the railway, and the motor-lorry--all these and others in their day have forcibly imposed important modifications in technique, and wrought great changes on the face of war. But all of them have had their counterpart in earlier ages, and none can really be said to have changed the nature of war.[1]
>
> Air Marshall Jack C. Slessor, *Air Power and Armies*

Following World War I, airpower theorists throughout the world began a great crusade in establishing the airplane as a new, revolutionary weapon that would change the nature of warfare forever. Italian Gulio Douhet, Englishmen Hugh Trenchard and J. C. Slessor, and American William "Billy" Mitchell all preached that the airplane could deliver the decisive blow against the enemy. Douhet held the passionate belief that airpower, and airpower alone could win a nation's wars. In his 1921 book, *The Command of the Air*, he provided a detailed listing on how a nation's air force could bring an enemy to its knees through the systematic use of airpower. Although most of his writings were based upon theories that had not been tested, the cornerstone of his theory was that a country that gained command of the air could not be defeated. In 1910 he stated, "The skies are about to become a battlefield as important as the land or the sea . . . only by the command of the air shall we be able to derive the fullest benefit from the advantage which can only be fully exploited when the enemy is compelled to be earth bound."[2] The arguments presented by these early aviation pioneers threatened each country's, well-established army and navy, and many military leaders viewed the growth of the air force as a threat versus an asset.

Many arguments made by the early airpower theorists parallel arguments made by some UCAV advocates today. It is easy to find information that either states or implies that the United States Air Force has a "propilot bias," and that this bias is what is preventing or delaying the development of a robust, UCAV force.[3] The arguments of a propilot bias do hold some merit, just as the biases held by many military leaders during the airplane's early development, but they do not impact this study. This study centers on whether the United States military should pursue a goal of replacing all manned, combat aircraft with UCAVs based upon the Air Force's needs and capabilities, not on why the UCAV's progress is challenged.

In an effort to analyze if the United States military should pursue a goal to replace all manned, combat aircraft with UCAVs in order to reduce the risk of human, combat losses, the analysis will follow a logical sequence. This study will first determine what capabilities the UCAV must possess and the tasks it must perform in order to accomplish the armed reconnaissance mission. The thesis will then reveal the UAV's current uses and capabilities within the military, and also the capabilities of the programs currently in the research and development process. Finally, this study will compare and contrast the strengths and weakness of conducting the armed reconnaissance mission using UCAVs and manned aircraft based upon criteria presented later in this chapter.

<u>Task and Capability Requirements</u>

The first step in determining the Air Force's needs in this study is to describe the tasks necessary to accomplish the armed reconnaissance mission. In order for it to replace manned aircraft, tasks that the UCAV must perform include self-protection, target detection, target identification, weapons employment, avoidance of collateral damage, and integration of attack operations with other air assets. This needs to be accomplished with sensor-to-shooter connectivity.[4] Information exchange between the UCAV and the controller provides the degree of flexibility needed in today's complex air war. "Having the right information in the right place and at the right time is one of the key prerequisites to accomplish complex missions successfully. While today's airborne information distribution is centered around systems like AWACS [Airborne Warning and Control System] and J-STARS [Joint Surveillance Target Attack System], modern information technology provides the means to go one step further by providing networks with alternative distribution paths." [5] UCAVs combined with the use of satellites and AWACS plus J-STARS provides multiple nodes for information distribution. "Even in dense conflict situations with the loss of some nodes, survivability of the network will be remarkably enhanced."[6]

Air superiority is another prerequisite to information distribution, and the UCAV will depend on other air and space assets to provide it. Air and space superiority is the United States Air Force's primary core competency. According to Air Force Doctrine Document 1 (AFDD-1), *Air Force Basic Doctrine*, the "core competencies are at the heart of the Air Force's strategic perspective and thereby at the heart of the Service's contribution to our nation's total military capabilities." [7] The core competencies are not doctrine themselves, but they are enablers of the Air Force's doctrine. They translate the beliefs on how best to use airpower into operational concepts. As the Air Force's primary core competency, air and space superiority "provides the freedom to attack as well as the freedom from attack. Superiority is that degree of dominance that permits friendly land, sea, and air forces to operate at a given time and place without prohibitive interference by the opposing force."[8] Therefore, air superiority will continue to be a precursor to effective operations in the future, and other air assets will provide it.

Current UAV Missions and Capabilities

In order to determine where the United States military needs to focus its UCAV research and development, this study will first examine the missions and tasks UAVs currently perform and the tasks performed in the past. Chapter 1 explained that UAVs performed photo reconnaissance, leaflet dropping, and signals intelligence missions during the Vietnam War, but the military also experimented with the use of UAVs in a combat role. Several demonstration programs used unmanned aircraft in flak suppression, chaff dispensing, target designation, and weapons delivery roles, but these missions were never performed operationally. There were tests of unmanned drone aircraft in air-to-air combat roles. The AQM-34 demonstrated dropping 500-pound bombs, dropping the Stubby-Homing Bomb (HOBO), and launching the electro-optically (EO) guided Maverick missile. Although these demonstrations were successful, termination of the Vietnam conflict ended the expanded roles of UAVs. The conflict's end also sparked a massive reduction in the number of United States military forces, and this included the elimination of Air Force UAV organizations in 1976.[9] Although many combat UAV technologies were not fielded, they offer a vision of future UCAV capabilities.

Many countries throughout the world currently field UAV systems. Except where design characteristics provide increased UAV capabilities, this study will mainly focus on the capabilities currently found within the United States. The United States military currently fields three major UAV systems: the Air Force operates the Predator; the Navy and Marine Corps operate the Pioneer; and the Army operates the Hunter. All three systems provide valuable information to tactical, operational and strategic commanders, and their use contributed to successful operations from Operation DESERT STORM through Operation ALLIED FORCE. In Kosovo, for example, UAVs were very effective in locating targets for strike aircraft.[10] During the air war in Kosovo, the Joint Forces Commander (JFC) held the authority to direct UAV assets for the overall support of the joint force, an authority outlined in Joint Publication 3-55.1, *JTTP for Unmanned Aerial Vehicles (UAVs).*

Joint Publication 3-55.1 contains guidance for the JFC on how to effectively employ UAVs. "When appropriately tasked, UAV units are capable of providing support to the JFC or other components of the joint force, during day and night operations on land, air, or sea."[11] The publication also lists the following UAV missions, but it does not limit the UAV's use to these missions:

1. Reconnaissance, Surveillance, Targeting Acquisition (RSTA) missions
2. Surveillance for search and rescue (peacetime and combat)
3. Deception operations
4. Maritime operations
    a. Naval surface fire support (NSFS)
    b. Over-the-horizon targeting (OTH-T)
    c. Ship classification

d. Antiship missile defense (ASMD)

e. Antisubmarine warfare (ASW)

f. Search and rescue

g. Mine defense support

5. Electronic warfare (EW) (including electronic attack (EA)), signals intelligence (SIGINT), and directed energy sensor reconnaissance

6. Nuclear, biological, and chemical (NBC) reconnaissance

7. Special and psychological operations

a. Resupply for special operations and psychological operations teams (scheduled and emergency)

b. Leaflet delivery and broadcast

8. Meteorology missions

9. Route and landing zone reconnaissance support

10. Adjustment of indirect fires and CAS

11. Rear area security support

12. Battle Damage Assessment (BDA)

13. Radio and data relay[12]

Although the above missions do not include combat uses, the conduct of these UAV missions provides insight into capabilities transferable to UCAV operations.

The current UAV systems are comprised of three main components: the air vehicle; a ground control facility; and a communications system to link the UAV and the ground control facility together. Although all three major UAV systems perform the missions described in Joint Publication 3-55.1, each service's UAVs were designed using slightly different requirements.

The Air Force's Predator UAV was developed to augment the Air Force's other reconnaissance assets. Program requirements and objectives for Predator included long-range and or dwell time, near-real-time tactical intelligence, RSTA capabilities, and BDA capability. Because of the requirement to supplement other Air Force reconnaissance assets, the Air Force required Predator to operate at or above 15,000 feet and at a 400-nautical-mile radius.[13] Actual Predator performance exceeds these requirements.

Figure 1. The Predator UAV

The Predator UAV is a spin-off of the Central Intelligence Agency sponsored Gnat 750 aircraft. Designed as a medium altitude endurance (MAE) UAV, it has a forty-hour endurance capability that gives it the ability to loiter over a target area for up to twenty-four hours. General Atomics Aeronautical Systems manufactures the Predator at a cost of approximately $3.2 million per vehicle. The Predator has a maximum ceiling of 25,000 feet, and its single, reciprocating engine gives it a cruise speed of 125 knots and a loiter speed of 75 knots. Its small size and lightweight design give the Predator a short takeoff and landing distance, and it has a 450 pound payload capacity. This payload capacity is used to carry the UAV's sensor suite equipment. It carries an EO and infrared (IR) sensor, and it has the capability to carry a synthetic aperture radar (SAR) sensor. These sensors enable the Predator to collect full-rate video imagery during daylight or night, and pass these images via data link. The Predator's near real-time data transmission enables commanders in the air and on the ground to make timely, critical decisions.[14]

The Department of the Navy purchased the Pioneer UAV to provide inexpensive, unmanned, over-the-horizon targeting, reconnaissance, and battle damage assessment.[15] The Pioneer also provides support to security operations (e.g., convoy escort, enemy avenues of approach and named areas of interest monitoring) and indirect fire adjustment capabilities for artillery and naval surface fire support. The design requirements of the joint U.S.-Israeli Pioneer program included a 100-nautical-mile operational radius at an altitude at or above 15,000 feet, and both EO and IR sensors to provide tactical commanders image intelligence capabilities. The Department of the Navy values the capabilities the UAV provides, and they funded the Pioneer program as an interim program until more capable UAVs could be developed.[16] The Pioneer program's success prompted the Army and Marine Corps to also purchase the system.


Figure 2. The Pioneer UAV

The Hunter UAV program was fueled by the need to provide the ground commander a means of collecting short-range intelligence information, and it was the first joint UAV program sponsored by the Department of Defense. The Hunter UAV program was hindered by the need to satisfy both land and sea operations, and this drove up design costs. Increasing costs caused an early program termination, but prior to termination the Army acquired seven Hunter systems. The Hunter UAV provides near real-time imagery within a 100-nautical-mile radius, and it operates successfully from unimproved airstrips.[17] "Hunters have been used in concert with J-STARS to provide more detailed surveillance of target areas identified by J-STARS' "big picture" system. The Hunter provides near-real-time BDA, precise targeting and adjustment of artillery."[18] It has the capability to support the ground commander at the forward line of troops, and it set the stage for further UAV development in the joint arena.

TABLE 1. OPERATIONAL FACTORS FOR DEPLOYED UAVs			
	Pioneer	Hunter	Predator
Radius (Kilometers)[a]	185	267	926
Endurance at Radius (Hours)	5	11	20 or more
Total Endurance (Hours)	7	14	35
Typical Operating Altitude (Feet)	3,000-8,000	10,000	10,000-25,000
Maximum Altitude (Feet)	15,000	15,000	25,000
Cruise Speed (Kilometers per hour)[b]	120	165	120
Dash Speed (Kilometers per hour)[c]	175	196	130
Types of Sensors	EO or IR	EO and IR	SAR, EO, and IR
Payload (Pounds)	75	200	450

Source: Congressional Budget Office based on data from DoD, the Army, and the Air Force
NOTE: UAV = unmanned aerial vehicle; EO = electro-optical (video); IR = infrared; SAR = synthetic aperture radar
a. Expected operating range.
b. Normal operating speed.
c. Maximum speed

UAVs are currently controlled from a ground control station (GCS) built within a thirty-by-eight-by-eight-foot, commercially available trailer. The trailer was not built with an emphasis on air mobility, but it can be transported on a C-130 or C-141 with special handling. “The trailer incorporates an integral uninterrupted power supply, environmental control system (cooling only), pilot and payload operator workstations, data exploitation,- mission planning,- communication (DEMPC) terminals, and SAR workstations. Power is supplied either by commercially supplied power or by dual external 35 kilowatt generators.”[19]

Figure 3. UAV Ground Control Station

The GCS is a key node in the UAV system because it links the operational requirements of the area commander to the capabilities the UAV provides. The PPO workstations provide the UAV controllers the primary means for controlling both the air vehicle and the sensor payloads. The controllers in a Predator GCS have the capability to record RSTA information for dissemination. This is critical because the Predator does not have the payload capacity to record information internally, so it must be recorded at the GCS. The DEMPC workstations take the information from the UAV and convert it into meaningful information. Data exploitation, mission planning, mission and payload monitoring, and system management takes place at the DEMPC workstations. The separate SAR workstation is responsible for monitoring and exploiting synthetic aperture radar information.[20] In order to link the UAV with the GCS, the UAV systems use two different types of communications networks. The key for using either system is line of sight (LOS). The GCS talks to the UAV by way of data link signals. These signals can either pass via ground relay stations or satellite.

The UAV, the ground control system, and the communications network make up the UAV system, and these systems work together in the conduct of the UAV's mission. A UAV controller, or pilot, can manually control the UAV from the GCS, the UAV can be programmed to fly a predetermined mission, or a combination of manual control and autonomous control can be incorporated. "Most UAV operations require manual launch and recovery. For multi-UAV operations, one UAV may be put in the preprogrammed mode to fly a specified course or to circle a designated target area while an additional UAV is launched and manually controlled."[21]

Typically, a UAV mission begins with a manual or autopilot climb to a predetermined altitude. Once at altitude, the UAV proceeds on a predetermined course to its area of responsibility and sets up an orbit. The UAV is constantly monitored by the GCS to ensure it maintains the programmed altitude and location. While in its orbit, the UAV's control can be passed to an airborne or ship borne control station for real-time data collection. Even if control is passed to another asset, the GCS continues to monitor the UAV's control parameters. Upon mission completion, the UAV flies a programmed route back to its recovery base where it is manually controlled for terminal approach and landing. One special feature of all UAV missions is a preprogrammed emergency flight mode called "return home." The sequence for return home is as follows: if data link is lost, the UAV automatically flies to a selected altitude and location and holds. When command is reestablished, the UAV continues the mission as planned. If command signals are not reestablished, the UAV will continue holding until running out of fuel.

Each flight includes planning for a remote recovery checkpoint located so that acquisition of the UAV by a control station is enhanced if return home is initiated."[22]

The number of UAV sorties flown in support of military operations has increased during the last decade due to improvements in UAV reliability and increased commanders' awareness of the capabilities UAVs bring to the joint warfighter. In Kosovo, the capabilities of the Predator were maximized, and innovative thought produced new uses for the Predator. Following the war in Kosovo, General Jumper stated to congress, "For the first time, we used the Predator Unmanned Aerial Vehicle (UAV) in a targeting role. During the air campaign, we reviewed Predator video in real-time and immediately provided pilots with the location of mobile Serb targets. Toward the end of the war, we equipped the Predator with a laser so that it could place a beam on a target--this identified it so a loitering strike aircraft could destroy it. We were able to successfully employ the Predator with laser only once before Allied Force ended, but in doing so, we developed a capability with great potential for rapid targeting."[23] Limited operator training prevented using the laser-equipped Predator to "guide in" the laser-guided munitions, but this scenario proved that it is possible.

Another first accomplished by Predator during Operation ALLIED FORCE was providing strike aircraft with detailed target locations. During the air war in Kosovo, real-time video imagery was fused with digital terrain data on the ground in Italy to produce highly precise target coordinates for precision-guided munitions equipped fighters. Target coordinates were passed to the fighters in a matter of minutes. The Air Force also conducted experiments on data fusion between J-STARS and the Predator.

These experiments lay the groundwork for future automated data correlation and exploitation.[24]

The United States Air Force is not the only service experimenting with UAV capabilities. The Marine Corps demonstrated the capability to directly uplink live Pioneer video to the cockpit of an airborne F/A-18 using Arid Hunter. This gave the Hornet real-time targeting information in the cockpit. Shortly after this demonstration, the Marine Corps used the Pioneer in a CAS role by providing strike aircraft real-time targeting information.[25]

The past ten years has seen a marked increase in the number of UAV sorties performed in support of Joint Operations, and this required an increase in integration efforts. The Joint Forces Air Component Commander (JFACC) is responsible for integrating air assets, and the JFACC is given this responsibility by acting as the airspace control authority (ACA.) "UAV operations must be coordinated with the ACA to provide safe separation of UAVs and manned aircraft and to prevent engagement by friendly air defense systems. The established principles of airspace management used in manned flight operations normally apply to UAV operations but may be waived by the JFC. UAV airspace requirements do not differ from other low performance aircraft."[26] UAVs perform both preplanned and immediate missions. In order to enhance integration, these missions are included in the joint force air-tasking order (ATO), special instructions, and airspace control order. This provides the opportunity for all participants within the theater of operations to have knowledge of UAV operations, and it alerts the UAV controllers to other air operations occurring within their sector.

During Operations JOINT ENDEAVOR and JOINT GUARD, the Predator UAV was placed on the ATO. Predator flights into Balkan airspace employed time-control and space-control procedures to ensure deconfliction with other air traffic. This was accomplished through the use of air corridors into and out of Bosnia, and the Predators used time and altitude deconfliction. The combination of established procedures, continued liaison with air traffic control authorities and real-time coordination of changes assured safety while covering the tasked targets.[27] This separation was required because the UAV is difficult to acquire visually and does not provide a clear radar picture like that of a manned aircraft due to the UAV's smaller size.

"Deconfliction depends on the command and control (C2) function and coordination between the joint force components. All aircraft working within a unit's boundaries will check in with the appropriate airspace control agency for that area upon entry and be advised of UAV status. The UAV mission flight crew will change the flight route, altitude, and location of the UAV, as necessary, to deconflict with other airspace users when directed by the appropriate ACA."[28] The unit that launches and recovers the UAV is responsible for the UAV's status information. Because the GCS continuously monitors the UAV's performance characteristics, it makes sense for the GCS to pass this information to supported unit or operational commanders and to the appropriate airspace control agencies. The airspace control agencies and airborne command, control, and coordination agencies pass the location and altitude of airborne UAVs to all manned aircraft during initial check-in.[29] These procedures, outlined in Joint Publication 3-52, *Doctrine for Joint Airspace Control in the Combat Zone*, provide for the UAV's seamless integration into the complex air battlefield.

Integration in the combat zone is not the only integration issues with which the UAV must contend. UAVs must also integrate with civilian aircraft outside the combat zone, and steps are being taken to ensure a smooth integration. The Air Force's Unmanned Aerial Vehicle Battle Lab (UAVB) at Eglin Air Force Base, Florida, flew a QF-4 drone with a Traffic Alert and Collision Avoidance System onboard to show UAV compatibility with airspace safety requirements.[30] This system is used in the commercial airline industry to alert airline pilots of potential midair collisions. The system operates off of cues from current identification, friend or foe (IFF) transponders, and it provides an additional, potential threat input to the UAV operator.

UAV Missions and Capabilities In Development

The United States Air Force's UAVB serves as the Air Force focal point for UAV issues. The UAVB is responsible for proposing and exploring new and innovative applications of UAV technology, and it works in concert with other commands to study the impact of the new technologies on doctrine, training, and operations. UAVB exploration efforts are concentrated in three mission areas including air vehicle improvements; intelligence, surveillance, reconnaissance, and combat applications.[31] The focal point for UAV combat applications within the UAVB is the Combat Applications Division. The Combat Applications Division explores ways in which UAVs can conduct strike, suppression of enemy air defense, electronic warfare and other innovative adaptations to support military operations worldwide.[32] This division and the other divisions within the UAVB are responsible for UAV and UCAV programs currently in development.

There are a number of UAV programs currently in development, and many of these programs are developing UAV combat capabilities. The Air Force's Global Hawk high altitude-endurance UAV is currently approaching the end of its advanced concept technology demonstration (ACTD), and a total of eight Global Hawk UAVs are planned for procurement through fiscal year 2005.[33] The Air Force requested $103.2 million for research and development for FY 2001 and $22.4 million for procurement.[34] The program requirements for Global Hawk center around increased range and altitude. The objectives for the program are twenty hours of flight time at 65,000 feet, and a 3,000-nautical-mile radius.[35] Global Hawk will have a 345-knot cruise speed. Based upon its range capabilities, it will be self-deployable. Command and control will be provided through LOS and satellite data link communications.

Like the Predator, Global Hawk will also include electro-optical, infrared, and synthetic aperture radar imagery (figure 4). Global Hawk will be able to carry all three sensors at once, making it more capable than the Predator. Another improvement over the Predator is the addition a moving-target surveillance capability. The moving-target surveillance capability provides the technology needed for the UCAV to acquire moving targets autonomously.[36] Once the Global Hawk detects a moving target, it could then use its other onboard sensors to identify the target.

Global Hawk is currently in a design update period, and two post-ACTD vehicles are nearing completion. During the demonstration phase, Global Hawk achieved over 27 hours endurance on a single flight, reached over 66,000 feet in altitude, and totaled nearly 500 hours of flight time. It also participated in several joint exercises, including an over-water flight to and from Alaska and transmitting imagery to Air National Guard, Air

Force, Navy ,and Marine Corps units. During an Air Force posture statement to congress, Air Force Chief of Staff, General Michael E. Ryan, reported, “The Global Hawk program will provide a cost-effective and useful system to the user at the earliest possible date through spiral development of platform, sensors, and other capabilities.”[37] Global Hawk’s interoperability will also be tested FY 2001, when it participates in its first outside Continental United States deployment. Global Hawk will deploy to Australia under a fifty-fifty cost share agreement with the Australian government. “This will be Global Hawk’s first opportunity to demonstrate its interoperability with a coalition ground exploitation system.”[38] This has sparked an interest in Global Hawk’s potential in other countries.

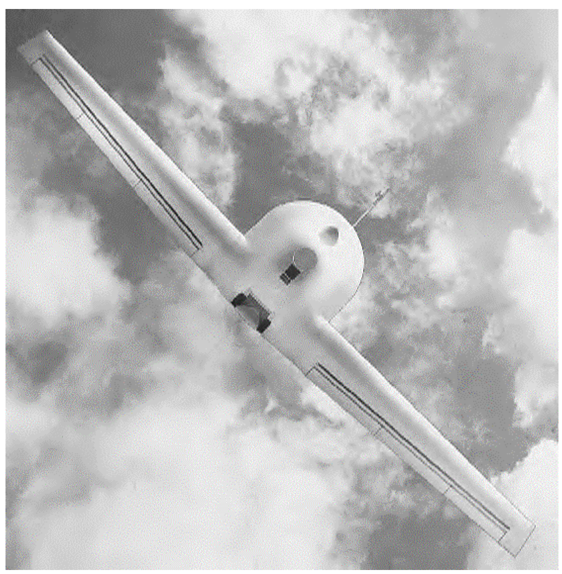

Figure 4. The Global Hawk UAV

The Global Hawk UAV system is focused on intelligence, surveillance, and reconnaissance capabilities, and this is prompting improvements in sensor capabilities. UCAV sensor development is currently making a lot of progress. In addition to IR, radio frequency (RF), and SAR imagery currently enjoyed by the Predator, the Global Hawk will incorporate an improved SAR sensor enabling it to see more clearly through cloud cover. “Cloud cover is a particular concern for [UAV] sensors because clouds are pervasive in the world-wide weather. Although a [UAV] usually operates at high altitudes above the weather, the sensor suite must be able to see ground targets through adverse weather. The global average cloud cover is about 61 percent, with an average cloud cover over land of about 52 percent and an average cloud cover over the oceans of about 65 percent.” Although current SAR images require thorough post-flight human analysis to identify targets and eliminate false returns, SAR sensors currently under development use improved techniques to provide more detailed imagery. This new imagery, combined with information from other sensors in the UCAV sensor suite greatly enhances the UCAV’s ability to automatically identify and track a target. Additionally, low-frequency sensors are also being developed for detecting, identifying, and targeting low observable targets in foliage.[39] “In the long-term, the Air Force expects to improve Global Hawk payload capabilities to the point where it could fulfill many missions now executed by U-2 and JSTARS.”[40]

Sensor improvements will give the UCAV the capability to detect and identify targets much more easily. The Global Hawk’s improvements concentrate on RSTA requirements, but its advanced capabilities will be of no use if they can not be available to all users. The interoperability of the UCAV is also important. In an effort to increase interoperability, a UAV Tactical Control System (TCS) is currently under development. The major focus of the TCS program is software. The software will provide the UAV operator the necessary tools for computer related communications, mission tasking, mission planning, mission execution, data processing, and data dissemination. The software will provide a high resolution, computer generated, graphics user interface that enables a UAV operator that is trained on one system to control different types of UAVs or UAV payloads with minimal additional training. The TCS will be in an open architecture and it will be capable of being hosted on computers that are typically supported by the using Service. The software developed will be Defense Information Infrastructure-Common Operating Environment compliant, nonproprietary, and the architectural standard for all future tactical UAVs.[41]

The Army is currently working on a program to develop a small, tactical UAV, and the Navy and Marine Corps are developing a UAV with a vertical-takeoff-and-landing (VTOL) capability for employment from ships with small decks and for operation ashore in locations with limited landing facilities, including urban areas. Both of these programs' UAVs will incorporate the TCS, ensuring command, control, and communications interoperability in joint engagements. In addition, the TCS will be considered for retrofit on Predator endurance UAVs operated by the Air Force. Although acquisition of Predator systems concluded in FY 2000, procurement of attrition replacement UAVs will continue through at least FY 2005.[42]

The small, tactical UAV the Army is developing is the Outrider, and it is designed for both land-based and sea-based operations. Takeoff and landing accidents occur frequently with many of the current UAVs, so the Outrider incorporates an automatic takeoff and landing capability for short, unimproved ground surfaces or large-deck amphibious ships.[43] With a production cost for 100 Outriders at $300,000 apiece, the program requirements and objectives include a four-hour on station time operating at a

200-kilometer range, and it will perform reconnaissance, surveillance, tactical situational awareness, gun fire support, and BDA.[44]

The Defense Advanced Research Projects Agency (DARPA) and the United States Air Force are into the second phase of the UCAV Advanced Concept Technology Demonstration program. During the program's first phase, three industry teams completed exhaustive mission effectiveness and affordability trades to optimize their operational system designs, identified critical technologies and issues, and planned their phase II demonstration program.[45] The Boeing Aircraft Company unveiled the first UCAV to a crowd of more than 400 spectators at Lambert Field, St. Louis, Missouri, on 27 September 2000. Boeing's Phantom Works is developing the technologies required for a UCAV to perform preemptive and reactive SEAD missions. The SEAD mission involves neutralizing, destroying, or temporarily degrading surface-based enemy air defenses by destructive and or disruptive means.[46] It is considered the most difficult mission envisioned, technologically speaking, for a UCAV to perform outside of air-to-air combat. Therefore, demonstrating the SEAD mission capability with UCAVs means many other ground-attack missions can be more easily developed from a technological point of view. The system is also designed for a single controller to operate four UCAVs at once. The UCAV predominately operates under autonomous control, but operator inputs are possible to alter the mission profile. This is accomplished through a "rules of engagement" matrix built into the system. If the UCAV encounters a scenario that is outside the preset rules of engagement, then it queries the operator. The operator can then set new parameters if desired. This gives the operator and the UCAV its flexibility.[47]

Lieutenant Colonel Michael Leahy, DARPA and US Air Force UCAV program manager stated that Phantom Works' UCAV, "will help take care of some of the air to ground threats that we face right now and allow manned assets to do their jobs more efficient[ly] and safe[ly]."[48] The UCAV is only twenty-seven-feet long with a thirty-four-foot wingspan, and it is designed to carry a variety of weapons. The UCAV will be stored unassembled in a small container for up to ten years, and six UCAVs can fit inside a C-17 Globemaster III transport airplane. Each Boeing UCAV will cost approximately $10 million, and flight-testing is slated to begin in the spring of 2001 at Edwards Air Force Base, California. Lieutenant Colonel Leahy stated that the program's objective is to have all the testing completed by 2005, and if all goes well, field the UCAV by 2010.[49] "At present, the Air Force has committed $80 million across the [Future Years Defense Program] FYDP to support the Defense Advanced Research Projects Agency Phase II Unmanned Combat Air Vehicle Advanced Technology Demonstration, which is designed to answer multiple questions regarding the potential application of UCAVs throughout the spectrum of conflict."[50]

The United States Marine Corps is also in the developmental process of obtaining an improved UAV. The Coastal Battlefield Reconnaissance and Analysis (COBRA) is a standoff mine detection system designed to support amphibious and expeditionary operations in the littorals. It can also be employed to support inland operations. "COBRA is intended to detect surface and buried mines as well as detecting obstacles and fortifications in the surf zone (10 feet of water to the High Water Mark). The Marine Corps intends to procure 24 COBRA from FY04 to FY10."[51]

The Marine Corps also successfully shortened the traditional research, development and acquisition process with the Dragon Drone UAV program. The Dragon Drone provides day and night reconnaissance, surveillance, target acquisition, and the delivery of nonlethal weapons at a cost of between $45,000 and $90,000, depending on the configuration. This relatively low-cost system is possible because the Dragon Drone is an off-the-shelf system that has been modified for military use.[52] This cost-cutting, timesaving acquisition method provides some opportunities for future systems as well as system components.

Operation DESERT STORM exposed the difficulty in locating and destroying high-value, mobile targets, such as the Scud-B. These threats are difficult to pursue because the enemy typically hides these systems in protected and camouflaged sites, only exposing them for a very short period of time. In order to combat this, the SAR Target Recognition and Location System (STARLOS) program is focusing on the integration of an Automatic Target Recognition (ATR) capability into the UAV GCS that utilizes a highly capable imaging sensor onboard a UAV. The STARLOS system utilizes the synthetic aperture radar's fine-resolution capability to provide day or night poor weather imaging at wide area coverage rates to conduct an intelligent cued search for targets of interest. This imagery is analyzed by state-of-the-art algorithms, operating in a high performance ATR processing architecture, to automatically identify targets against challenging clutter backgrounds in realistic, tactical environments.[53]

Over the past five years, STARLOS successfully demonstrated the ability to detect, locate and identify up to six high-value mobile targets at a time. This process used a real-time, strip-map, fine-resolution SAR with onboard automatic target recognition. The latest generation of the STARLOS ATR processor combined with significant algorithm performance concentrate on techniques to counter camouflage, concealment, and obstruction effects. Although STARLOS is being developed as a UAV system, its airborne testing is conducted in a manned aircraft.[54]

In order for a UCAV armed reconnaissance mission to be effective, the UCAV must be able to find the target and then destroy it. This can only occur through the use of a highly accurate navigational system. Due to the limited field of view the UCAV provides the controller, the guidance function is critical in putting the UCAV in the correct target area. Currently, Daimier-Benz Aerospace AG Military Aircraft and Honeywell Regelsysteme GmbH teamed up for project RAPIN, so named for Reliable Autonomous Precise Integrated Navigation. Although this project was originally defined for a transport aircraft with low-level operation capability, the system design has high potential for UCAV needs. Project RAPIN fuses the use of the Global Positioning System (GPS), Terrain Referenced Navigation System, and Laser Internal Navigation System through one filter to provide the UCAV with highly accurate positional tracking.[55] This idea of fusing different position tracking systems through one filter is not new to combat aviation. Modern fighter aircraft fuse Internal Navigation System (INS) data and GPS data through a filter to maintain a high degree of positional accuracy. Using three systems provides the redundancy needed during times where data link connectivity is lost or compromised.

In addition to knowing where the UCAV is, the navigational system must also be able to determine where it is going and at what rate. The accuracy in determining this is also increased through project RAPIN. This information is incorporated into the

UCAV's weapon delivery system to ensure the target is hit. The RAPIN system, combined with SAR precision mapping, "has the potential to provide target location with an error less than 3 meters."[56]

The Predator UAV demonstrated flexibility during its use in the Balkans though the use of in-flight retasking. The tactical commander was able to direct the UAV and or its sensors by telephone, while watching its downlinked video. "Its imagery is disseminated by a Trojan Spirit II terminal through the Joint Broadcast System to theater and international command and control facilities. This provides near-real-time control of the UAV from virtually anywhere."[57] Requirements for the UCAV require real-time control of the weapons delivery platform, so improvements in data-link capabilities are needed. High data rate transfer rates are needed for the UCAV to provide real-time information to the UCAV controller. Phased array antennas are currently being developed to provide high data rate (approximately 600 Megabits per second) and flexibility for a UCAV to rapidly and efficiently communicate with satellites, ground stations, manned aircraft or other UCAVs. Boeing is developing a family of low-cost, high performance airborne phased array antennas.[58]

UAV and UCAV research and development programs contest with other Department of Defense programs for funding, and over the years many programs have been cut for a multitude of reasons. One such program, the Air Force's DarkStar UAV program, is worth mentioning because it provides a glimpse of some of the technologies available in the foreseeable future. The DarkStar program was terminated in January 1999 due to funding issues. The DarkStar's program requirements and objectives were RSTA with high-altitude, long range and long dwell time, and wide area surveillance capabilities. It also required an eight-hour on-station time at 50,000 feet and a 500-nautical-mile radius. The main developmental difference between DarkStar and other UAV and or UCAV programs was its use of stealth technology. The DarkStar program incorporated low observable technology to minimize the UAV's detectability. The vehicle had to sacrifice payload capability and vehicle performance for survivability features against air defenses.[59] Although the DarkStar program was terminated, the development of low observable technology may prove valuable in future UCAV designs.

UCAV Comparison to Armed Reconnaissance Requirements

In order for the UCAV to replace manned aircraft in the armed reconnaissance mission, tasks that the UCAV must perform include self-protection, target detection, target identification, weapons employment, avoidance of collateral damage, and integration of attack operations with other air assets. Again, this needs to be accomplished with sensor-to-shooter connectivity.[60]

Self Protection

The first area of interest is the UCAV's self-protection capability. Size and shape have a direct impact on the UCAV's detectability. The pilot's removal, along with the associated equipment needed to support the pilot, allows for a UCAV smaller than a manned aircraft. This reduced radar signature is the first step against detection by enemy forces, and this contributes directly to the UCAV's self-protection capability. The UCAV's small size combined with low observable technology, such as that used on DarkStar, would further enhance the UCAV's self-protection capability. Although the DarkStar program was terminated, its technological research combined with the technological capabilities found in manned systems supports the conclusion that these capabilities will be available to future UCAV systems.

UCAV self-protection is also currently provided by its mission profile. Pioneer, Hunter, and Predator are all susceptible to surface threats due to the altitudes in which they operate. The Global Hawk has already reached an altitude of 66,000 feet, and this puts it above the effective altitude of many current air defense systems. As engine designs and performance parameters continue to improve, UCAVs can expect to operate at altitudes well above those attainable by manned, combat systems.

A UCAV's strike package integration is necessary in today's complex air-combat environment, and the UAV currently possess many of the necessary tools in order to accomplish this. Command and control is the key in UCAV integration, and current military doctrine addresses the UAV's incorporation into today's combat missions. Joint Publication 3-52, *Doctrine for Joint Airspace Control in the Combat Zone*, sets the framework for UAV integration. By incorporating UAV missions on the ATO, the JFC can easily fuse UCAV capabilities with other assets in the air arsenal, and at the same time ensure deconfliction procedures are established and understood by all. As commanders continue to reap the benefits that UAVs provide and experience instances where UAVs can effectively integrate with conventional strike packages, their reluctance to use UCAVs as a future force multiplier will continue to fade.

Target Detection, Identification, and Collateral Damage Avoidance

As previously discussed, the primary mission of today's UAV force is RSTA. The capabilities in EO, IR, and SAR systems are improving at an increased rate, and this enhances the UAV's ability in target detection and identification. The sensor improvements described in the STARLOS program combined with data transfer rate, GCS and interoperability improvements provides all users the ability to effectively locate and identify targets. Once the UCAV locates and identifies a viable target, then it can transition to target destruction. Through proper target location and identification, target destruction is accomplished with little fear of collateral damage.

Weapons Employment

History proves that UAVs do have the capability to conduct weapons employment operations, and this provides the backdrop for future applications. As early as the Vietnam War, the AQM-34 demonstrated dropping 500-pound bombs, dropping the Stubby-Homing Bomb, and launching the electro-optically guided Maverick missile. The conclusion of the Vietnam War prevented operational employment of the Lightning Bug's capabilities,[61] but it does provide a foundation from which a UCAV force can be built. When the Predator was equipped with a laser designator during the air war in Kosovo, it proved that today's JFCs see an increased potential use for UAVs in a combat role. Today's leaders are willing to look "outside the box" for ways to effectively and safely conduct future operations.

The United States military does possess the ability to conduct the armed reconnaissance mission using current UAV systems combined with systems in development. The UAV and or UCAV systems presented here do possess all of the requirements necessary to conduct the mission, but the degree to which these requirements are satisfied impact the UCAV's overall mission effectiveness. Although each requirement is met, this study will now look at the synergistic effects of all the parts and compare its overall effectiveness to that of manned aviation.

TABLE 2. ARMED RECONNAISSANCE REQUIREMENTS AND ASSOCIATED UAV CAPABILITIES	
Requirements	UAV Capabilities
Self Protection	- UAV’s small size provides smaller radar cross section - Absence of pilot allows UAV to be more maneuverable - UAV flight profiles can be higher than effectiveness of modern defenses - Incorporation of stealth technology
Target Detection	- Electro-optical, Infrared and Synthetic Aperture Radar capabilities - Moving target surveillance capability
Target Identification	- Automatic Target Recognition capability - STARLOS system fusing ATR and SAR capabilities
Collateral Damage Avoidance	- Improvements in target detection and identification improves ability to avoid collateral damage
Weapons Employment	- Maverick missile firing and bomb dropping tests during Vietnam War (AQM-34) - Hellfire missile tests (Predator) - Development of Boeing Phantom Works’ SEAD UCAV
Integration	- ATO integration during recent military operations - IFF capabilities incorporated - Coordination with AWACS and J-STARS

Manned Aircraft versus the UCAV

When determining if the development of a new weapon system should be pursued, an organization must set criteria in order to prevent wasting resources on unnecessary research and development. The United States should not pursue a new weapon system just for the sake of new technologies. In order to justify the introduction of a new weapon system, the following criteria must be met:

> - New mission types can be executed that are required with respect to operational needs and that cannot be performed by current weapon systems, or an existing mission type can be executed more reliably.
> - Operational handling requirements imposed by the weapon system are adequate with respect to the environment and people's skills.
> - The technology is available or can be invented with reasonable effort.
> - The new weapon system is cost effective.[62]

This study uses the ideas presented above to develop a set of criteria to determine if the United States military should pursue a goal to replace all manned, combat aircraft with UCAVs in order to reduce the risk of human, combat losses. The criteria for this study are mission effectiveness, cost, feasibility, acceptability and suitability.

Mission Effectiveness

"Only two good reasons exist to introduce a new kind of weapon system. Either a specific existing mission can be accomplished more efficiently or a new type of mission is possible providing an advantage over an adversary."[63] This statement is the basis for introducing new weapon systems into the military's arsenal, because if a new weapon system can not perform a mission successfully then there is no reason to have it in the military. In determining the UCAV's mission effectiveness, this study will analyze the UCAV's reliability, survivability and flexibility with respect to the armed reconnaissance mission.

"Effectiveness is defined as being the level of impact of the performance of a system on a defined operational context, and is measured in terms of defined military goals (e.g., the destruction of tanks) rather than physical values (penetration of armor in millimeters). Effectiveness can be viewed as arising from the interaction between technology, tactics and environment."[64] Effectiveness also depends on the nature of the particular scenario in which you are using the system. For example, the United States military issued soldiers jungle fatigues during the Vietnam War so the soldiers could better conceal themselves in the thick, Vietnam jungles. Although these fatigues were quite effective in Vietnam, they would have been useless in the Middle Eastern deserts during Operation DESERT STORM.

There are many factors that contribute to a system's effectiveness, so there needs to be a limit on assessing what the effectiveness is measuring. Maintenance support, availability of munitions and fuel, and even rules of engagement all affect a system's overall effectiveness. Since these equally affect both manned and unmanned systems, they will not be included in this study to compare the UCAV's overall effectiveness with that of manned aircraft.

Because it is sometimes difficult to understand what is meant by the effectiveness of the system in conducting a mission, parameters known as Measures of Effectiveness are often established. These Measures of Effectiveness vary depending on the nature of the system being studied, and the purposes for which it is intended. "However, it is often in the case in combat modeling that military effectiveness is measured in terms of some combination of the following three factors; targets destroyed (or targets suppressed); own force losses; and collateral damage inflicted." Although other measures are often used when evaluating military effectiveness, in most cases they are fashioned from the criteria listed above. Of the three areas mentioned, the importance placed on each of the criteria changes from scenario to scenario. In a peace support operation, collateral damage may far outweigh target destruction or even friendly forces lost.[65] Since all three criteria listed above impact manned and unmanned vehicles equally, each criterion will carry equal weight.

The mission effectiveness of the UCAV depends first on its ability to get to the target area. Therefore, the UCAV's survivability is critical. A major argument supporting the survivability of the UCAV in a combat environment is based on the vehicle's size and its increased maneuverability potential. This study previously mentioned the advantages the UCAV's size provides with respect to its radar crosssection. Its small size is an inherent self-protection feature based on the absence of the pilot. "Removing the pilot from the vehicle eliminates man-rating requirements, pilot systems, and interfaces. The UCAV offers new design freedoms that can be exploited to produce a smaller, simpler aircraft, about half the size of a conventional fighter aircraft. Weighing about one-third to one-fourth of a manned aircraft, at 10,000 pounds they would weigh two to three times more than a Tomahawk missile."[66] This argument is valid for a UAV performing a RSTA mission, but the argument isn't as pronounced when the armed reconnaissance mission is examined.

Size and shape of the UCAV has a direct impact on its detectability; however, the current limiting factor with respect to the UCAV's size is its weapons load. This limitation should be eliminated within this study's time frame. Advances in small, smart munitions are currently in development, and they will have a great impact on both manned and unmanned flight. The goal of the Miniaturized Munitions Technology Demonstration is to produce a 250-pound munitions class capable of destroying a majority of hardened targets previously vulnerable only to 2,000-pound class munitions. These small, smart munitions will incorporate a GPS and or INS to provide precision guidance, and smart-fusing techniques will aid in producing a high probability of target kill.[67] These small, smart munitions will provide the opportunity for a smaller UCAV design, and at the same time they will provide manned aircraft the ability to carry a more lethal combat load.

In addition to weapons affecting the UCAV's size, the UCAV's requirement for self-protection also impacts the UCAV's design considerations. In order for the UCAV to operate in a combat environment it must possess self-protection capabilities. Self-protection is conducted by countering immediate threats, confusing enemy air defenses, or threat avoidance techniques. The basic technique in countering immediate enemy threats is through aggressive maneuvering. As stated previously, UCAV supporters argue that the UCAV is inherently more maneuverable than a manned aircraft because it lacks a pilot, and the pilot has physiological restrictions that limit manned flight's maneuverability. In theory this is correct, but based upon structural limitations with today's design materials, this is not necessarily the case.

A study conducted at the Naval Air Warfare Weapons Division looked into the feasibility of developing a highly maneuverable, lethal vehicle (HMLV) for conducting unmanned combat missions. Maneuverability and countermeasures were addressed to identify realistic design requirements needed to survive against an airborne threat. "The analysis showed that most current air-to-air missiles can be evaded, but advanced missiles with IR seekers cannot be evaded without using maximum g's on the order of 30 g's."[68] These high g missiles do not currently exist, but that is mainly due to the fact that they are not currently needed. If the HMLV is designed to pull thirty g's, then that will compel missile designers to design a missile that can withstand even greater g forces. If

UCAV designers develop vehicles capable of generating the maneuverability needed to outmaneuver an air-to-air missile, then the UCAV must become bigger in order to support the weight of the increased structural support the design would require. The increased size would directly impact the UCAV's overall cost and its radar cross section.

Another method of countering an enemy's airborne threat is to destroy the threat, but no current UCAV or UAV programs incorporate the use of air-to-air missiles. Although current designs do not incorporate air-to-air weapon loads in order to enhance self-protection, studies do indicate that incorporating these missiles is not technologically challenging. The addition of current air-to-air missiles would affect the UCAV's size, but advancements in technologies should allow for developing smaller missiles if needed. UCAVs equipped with long-range air-to-air missiles could protect themselves from known enemy airborne threats to avoid the maneuver requirements listed above, but they would need a reliable man-in-the-loop system to ensure engaged air threats are not friendly, support aircraft. Without the ability for the UCAV to positively identify an opposing threat, due to system malfunctions or enemy's self-protection capabilities, the UCAV must possess self-protection capabilities beyond the passive measures they already enjoy (e.g., small size and high altitude flight profiles).

The survivability of UCAVs requires the same characteristics required of manned flight. In order to reduce the UCAV's radar signature, emerging technologies, such as stealth, must be incorporated. In the near future, UCAV's will have the same radar detectability as similarly sized manned aircraft. Therefore, mission profiles must be altered in order to get the UCAV into the target area. UCAVs equipped with terrain-following radar can fly more aggressive, low-level profiles then manned aircraft due to their increased g-load capabilities.[69] These low-level tactics, however, make the UCAV much more susceptible to visual antiaircraft artillery and SAM defenses. This fact was demonstrated in Kosovo where twenty-four UAVs were lost, and it became apparent to commanders that the Serbian soldiers were quickly developing tactics to counter the UAV threat. The Serbian intelligence discovered the launch sites used by NATO's UAV units, and they used hand-held, heat-seeking missiles and guns to down the UAVs along likely avenues of approach.[70] This, therefore, pushes the UCAV back to high altitudes in order to avoid the surface threat.

"The typical UCAV will not be able to outrun or out-fly a fixed winged interceptor aircraft. Consequently, any avoidance strategy must rest upon avoiding detection by the long-range systems used to vector the fighters to their target, and upon detection by the fighters' airborne intercept radar and IR search and track systems. Ultra high operation is a possible strategy."[71] These factors make the need for stealthy technology much more important. Stealth technology combined with the use of off-board decoys and onboard electronic counter measures (ECM) will make the UCAV much more survivable. Confusion of air defenses could involve flying stealthy UCAVs with highly visible drones.[72] This combination would allow the UCAVs to get to the target area while the drones are engaged. It must be understood, however, that the addition of the stealth technology will drive up the UCAV's cost.

If the long range tracking of UCAVs by enemy ground based systems is avoided, then the enemy will have to resort to finding the UCAV with aircraft employing intercept radars. The UCAV then can use a threat-warning receiver to determine when it is being tracked. In order for the enemy to pose a viable air threat against a UCAV, it must possess a well-coordinated air defense network. In this environment, the UCAV's threat from manned aircraft is a considerable one. Enemy interceptor aircraft will most likely carry a mix of radar and IR guided air-to-air missiles, and these missiles will be effective from both medium and long range.[73] "The problems associated with protection against EO, IR and laser-guided threats are considerable. The bulk of such threats will not alert the UCAV in any way until a missile is launched or a gun is fired."[74] Short ranged threats include the enemy's gun and also the use of jet-wash to disrupt light air vehicles.[75]

Countermeasures to avoid defeat by enemy systems involve the exact same procedures as manned flight. Exploiting the radar's doppler notch, or "blind spot," combined with chaff and maneuver is a current method to defeat an airborne threat. The UCAV can use a threat-warning receiver to determine when it is being tracked. "The danger [interceptor aircraft] present may be reduced by presenting the [Air Intercept] AI radar with the minimum radial velocity. This may be achieved by turning to place the threat on the beam, and by flying the UCAV at its minimum airspeed. Some forms of ECM may also be appropriate."[76] These maneuvers can cause an enemy's radar to break lock, but they are not effective against other airborne tracking systems, such as the infrared search and track system (IRSTS), found in today's fighter aircraft. Therefore, the UCAV must be capable of defeating an enemy's air-to-air missile.

A common method used to defeat an enemy's air-to-air missile is through maneuver combined with the use of an onboard countermeasure system. The Naval Air Warfare Weapons Division's HMLV study included an investigation into the requirements needed for a UCAV to accomplish this self-protection maneuver. The conclusion made showed that maneuver combined with onboard countermeasures is workable, but the timing of each element is critical in the HMLV's survival.[77] Due to the inherent transport delays associated with the UCAV's digital tracking system, the UCAV's threat reaction sequence would need to be autonomous. In order for this to feasible, sensors would need to be developed capable of detecting inbound threat missiles at a range of about two-to-three-nautical miles within an accuracy of approximately $\pm$ 500 feet in range and $\pm$ 400 feet-second range rate.[78] Threat detection systems with this level of accuracy do not currently exist. This author, while researching this thesis, could not find evidence of any program to develop such systems.

"The mission effectiveness of current UCAVs has been demonstrated in low-density conflicts, like over Bosnia. Despite low reliability records, the survivability of the early designs in scenarios with strong air defense capabilities on the adversary's side is questionable." The slow flying speeds and predictable flight paths are the main reasons for the UAVs susceptibility to the enemy's air defense. Measures to enhance the UCAV's survivability include increased subsonic velocity levels, the use of less predictable flight paths by enhancing the UCAV's maneuverability, and development of signature reduction technologies.[79] Although additional functionality and more sophisticated onboard systems will compliment these improvements regarding sensor data processing as well as command and control, they will also increase the UCAV's overall cost.

The UCAV's ability to survive in the complex air arena depends on its ability to avoid the threat, confuse the enemy's air defense system, or react to the threat. Due to the limitations listed above, the UCAV's ability to conduct effective self-protection procedures requires the controller to interact with the UCAV. Controller interaction is also needed for safety reasons. “Restrictions must be placed on lethal UAVs because of the potential consequences of an accident or malfunction. Recent history has proven that the American public and the international community hold individuals and organizations accountable for decisions to use force. The downing of two US helicopters supporting Operation PROVIDE COMFORT in northern Iraq and the subsequent loss of twenty-four lives provides a vivid example of how the public will react to lethal force ‘accidents’ or ‘mistakes’.”[80] A man-in-the-loop feature provides the ability for the UCAV operator to make decisions affecting all aspects of the UCAV’s operation, and it provides the needed safety loop to help minimize catastrophic accidents, make critical employment decisions, and provide the flexibility required to adapt to the rapidly changing aerial battlefield.

The rules of engagement provide the boundaries within which the United States conducts military operations, and the UCAV’s man-in-the-loop feature is paramount in operating within these constraints. “Parallels may be drawn with cruise missiles and stand-off weapons dispensing sub-munitions, however there is an essential difference. Stand-off weapons are dispatched against a specific target or target area, implying that the surveillance, identification and acquisition tasks have already been carried out and confirmed, and that the mission has been judged safe in terms of its potential for endangering civilians or allied assets. The UCAV, in contrast, is one of surveying an unknown area, identifying and locating targets, then attacking.”[81] In its simplest forms a UCAV could be controlled entirely as a remotely piloted vehicle, but this is deemed impractical. Although it would give flexibility in maneuvering the UCAV, it would be too dependent on data link, operator workload would be high, and the ability of the controller to maintain situational awareness would actually be reduced. In a sense, UCAV operation would become less flexible.[82]

"The man-in-the-loop feature is very important since there is always the possibility of an unknown or unforeseen event (in flight emergency, target not where or what it was supposed to be, hostages chained to the target, etc)." The extent to which artificial intelligence or preprogrammed logic can accommodate unknown or unforeseen events has not been established. To compare man-in-the-loop systems to artificial intelligence or preprogrammed logic systems is therefore not possible. The man-in-the-loop feature must be incorporated into the UCAV to provide the flexibility needed to account for the changing complexity of the battlefield. "In the case of a UCAV with weapons onboard, this man-in-the-loop feature permits the remote operator to make a rational, judgmental and moral assessment of the situation before the automatic weapons delivery"[83] UCAVs depend on data link to provide its required man-in-the-loop capability, but there are inherent limitations with data link communications.

The biggest concerns within the UAV community with data link communications are long connectivity lapses due to distances between ground relay stations and/or satellites, loss of UCAV control due to enemy jamming or signal manipulation, and the limited number of frequency bandwidths available to accommodate large numbers of secure links for multiple UCAV operations.[84] These concerns impact the UCAV's ability to conduct the armed reconnaissance mission effectively, and they are being addressed within the UAV and or UCAV community.

Long connectivity lapses due to distances between ground relay stations and or satellites affects the UCAV's ability to pass real-time information. Improvements in high data transfer rates currently in development are helping to eliminate these connectivity lapses. This will enhance the UCAV's ability to pass real-time information to the battlefield commanders, and it will aid the controller in self-protection requirements and battlefield situational awareness. These improvements directly improve the UCAV's mission effectiveness.

The loss of UCAV control due to enemy jamming or signal manipulation is a major threat to the UCAV's use. This could be easily avoided if the UCAV is preprogrammed to fly its assigned mission without communication with the GCS, but this is impractical due to the safety concerns stated previously. Continuous communication with the UCAV was also previously addressed concerning operator workload and flexibility requirements, so UCAV developers are designing systems that eliminate the need to interact with the UCAV constantly.

A way to avoid the need to interact with the UCAV continuously is through a combination of autonomous control and remote control. The UCAV could be programmed to fly certain profiles to get to the target area, and then when it is time for a critical decision to be made, the operator will then communicate with the UCAV.[85] This would offer two advantages. The first advantage is that the UCAV wouldn't continuously radiate electronic energy that could be exploited by the enemy. This would increase the UCAV's survivability. The second advantage is that it would reduce the dependency on the number of frequencies needed for UCAV communications.

Minimizing the UCAV's need to transmit increases its survivability. "In principle, all antennas are susceptible to detection by the adversary's surveillance and reconnaissance systems or by electronic supporting measures, especially when transmitting. Therefore, active sensors should not be operated in continuous modes but only when operationally required."[86] All electronic devices are threatened by EW and informational warfare, and each system that interacts with the outside world is susceptible to attack. Although countermeasures exist to protect systems from attack, they work mainly to limit the attack's severity or duration. System redundancy helps to minimize the impact electronic warfare has on a system. "However, it is unlikely that the data link will operate without timely limited disturbances not only caused by electronic warfare, but also as a result of geographical conditions or meteorological anomalies. Consequently, continuous data transmissions with high real-time requirements should be avoided."[87] This is accomplished through the combination of autonomous and remote control.

The need to minimize the number of frequencies UCAV's use is also important. There are a limited number of frequencies available to transmit data link information to the UCAV. In order to maintain a high degree of certainty and reliability of information being passed to and received from the UCAV, designers must minimize the conditions that cause data link losses. The two main categories of losses are propagation losses and losses due to rain, clouds or fading. Propagation losses are losses due to the spherical propagation of the RF signal, and these losses increase with increasing range. To offset these two losses, UCAV designers must boost the transmitted RF power and or use larger antennas. Certain frequencies minimize these losses, and based upon the degree of accuracy needed for real-time UCAV control, this minimizes the usable frequency spectrum available.[88] Current technological advancements in this area are having a positive effect on the development of viable, secure systems.

In addition to affecting the UCAV's ability to operate in the combat arena, data link delays due to system limitations and or EW effects have an impact on the ability to safely recover the UCAV. One way to overcome this situation is to incorporate a "safe termination" function into the system. The basic idea of this is to incorporate a predetermined landing location that the UCAV will automatically land at in case data link is severed. In order for this idea to be feasible, the UCAV's navigational system needs to be highly accurate.[89]

There are some differences in navigational system accuracy requirements between manned and unmanned flight. There are typically five phases in a military mission: start; cruising to the operational area at high altitude; ingressing to the target at low or high altitude; cruising back to the home base or alternate recovery site; and approach and landing. For manned missions, the navigational system requirements are driven by the low-level and approach and landing phases. In addition, if the navigational system loses its accuracy or "drifts," the pilot can manually update the system or he can simply take over the navigational duties. The UCAV does not have that luxury. The UCAV's navigational system is driven by all five military mission phases, therefore it depends on an accurate navigational system for a much longer period of time. Combine this with the fact that UCAVs provide the opportunity for much longer mission endurance, system redundancy and accuracy is imperative to ensure mission success.[90] The RAPIN system provides the accuracy needed for this level of navigational control.

Another factor that can affect the UCAV's mission effectiveness is weather, and UCAVs are susceptible to severe weather patterns in most cases just like manned aircraft. An area where weather affects the use of UCAVs differently is its data link requirement.

“Adverse weather conditions and faulty satellite communication links created integration problems in the European theater during Operation ALLIED FORCE in Bosnia.”[91] If the weather is too severe for the UCAV to fly, then it is obvious there is no need to ensure the data link system is impervious to weather. The LOS data link requirements are achieved through the use of satellites or radio relay systems. Satellite systems are not as effective as GCSs if high-data rate or high-update rates are required, because of the complex relay links required by satellite. Yet, high-data rates are required if real-time control of the mission is needed. A GCS is more susceptible to weather interference, and relay stations are required to ensure continuous line-of-sight connectivity.[92] Although weather conditions may be fine at the launch location and in the target area, weather patterns between the two may impact the GCSs.

In an address to Congress following the war in Kosovo, General Jumper stated, “We must fully develop the technology and tactics to rapidly strike targets. Ultimately, our goal is to reduce the time from target identification to target destruction from hours and days to minutes.”[93] General Jumper highlights one of the major advantages UAVs have over manned aircraft, and the same will hold true for UCAVs. With today’s air refueling capabilities, combat aircraft have an unlimited range. Without air refueling capabilities, UCAVs can have a greater range due to replacing the pilot with fuel. In addition, there are no crew rest limitations with the UCAV, and the UCAV can’t get fatigued.[94] The on station times stated earlier in this study describes the opportunity for UCAVs to provide twenty-four-hour target area coverage, and this is critical when trying to locate the armed reconnaissance mission’s mobile targets.

The armed reconnaissance mission is an extremely difficult mission for both manned and unmanned aircraft to perform. Mission effectiveness depends on the ability of the vehicle's operator to maintain awareness of the situation in order to complete the mission. "In most current manned air platforms, situation awareness exists almost entirely in the pilot's mind. Some elements of it exist within the various sensor and effector subsystems, but the pilot alone must perform the overall data fusion task: filtering, summarizing and prioritizing what he sees. In a UCAV, situation awareness must be implemented as a subsystem, performing data fusion at all levels."[95]

Situational awareness is the cornerstone in many aspects of the UCAV's required criteria, but they are most prevalent in flexibility and survivability. This is the area where artificial intelligence will become most important. Since it is the pilot who accomplishes the data fusion in manned aircraft, the UCAV will need to incorporate a method to fuse data to respond to external influences. There exist a variety of methods and algorithms for the implementation of data fusion, but the observe, orient, decide, act cycle provides the framework from which a responsive system can be designed.[96] The end product of the data fusion is for the UCAV to develop machine-held situational awareness. This situational awareness exists only to be used by routines that will control the UCAV's responses to a given situation. "The principle response packages include: mission re-planning and re-routing to avoid threats while still accomplishing the mission; tactical maneuver control combined with employment of onboard countermeasure systems to avoid the detection and/or destruction by the enemy; targeting, allocation, firing and control of weapons; and reporting the situation back to the UCAV's command and control center." In order to ensure flexibility and controllability, a manual system override must be included in the design, and this is provided by the man-in-the-loop requirement stated previously.[97] All of these requirements increase the UCAV system's complexity, and this directly affects the system's cost.

Cost

The cost associated with developing and maintaining a viable military is continuing to climb, and a weapon system's cost effectiveness is a major driving factor in its procurement. The cost savings the UCAV provides is by far its strongest selling point, and the savings are measured in dollars as well as in human lives. "That UCAV losses are not coincident with loses of pilots' lives makes them suitable for dangerous missions with a high loss probability and situations in which human loses are not acceptable for political reasons."[98] As was previously stated, the senior military leaders knew that the political climate of the Kosovo operation included extreme sensitivity to casualties. This attitude did have a negative impact on the NATO alliance. "If NATO wants a military victory in Yugoslavia, the only way to get it is to risk pilots now," said Maurizio Cremasco, a former general in the Italian air force. "They [did not] do this for the same reason the Apache helicopters [were not] utilized--because low-altitude flying still involves the risk that pilots and crews will get shot down and killed."[99]

Many people believe that the recent push for UCAV use is due to the fact that the American people cannot accept the loss of human life in combat. In reality aircraft have always been designed in order to increase pilot survivability. Improvements in aircraft performance, self-protection systems, stealth technology, and standoff weapons capabilities are all geared towards increasing survivability in the combat arena. Tactics have even evolved in order to maximize the effectiveness of standoff weapons. The problem is that in order to increase our standoff capabilities, the cost of the weapon systems needed to accomplish this continues to increase at an incredible rate.[100]

The United States military employs many weapons today that provide standoff capabilities to keep friendly forces out of harms way. The cruise missile is a relatively inexpensive weapon system capable of striking enemy targets deep in enemy territory. Cost arguments favor the use of cruise missiles overmanned aircraft, but reusable UCAVs are more economical than cruise missiles. UCAVs can hit targets currently not feasible for today's cruise missiles. Cruise missiles cost roughly 1.1 to 1.2 million dollars apiece.[101] Although cruise missiles can attack targets without placing a pilot at risk, the UCAV participates in the target acquisition process by identifying and attacking targets. This makes its use more flexible than the cruise missile.[102]

Another aspect of cost deals with the age of the fighter force. Over the past twenty-five years, the percentage of the budget dedicated to fighter production has been relatively low. Downsizing of the military combined with increased fighter capabilities has hidden the effects of the lower production rates, but now fighter production can barely keep up with fighter attrition. Over the past twenty-three years, fighter procurement averaged 2 percent of the total Department of Defense budget. Over the past ten years it was 1 percent, and its average over the past five years was 0.3 percent. Based on current spending levels, fighter availability will begin to decline, and by 2020 it may not be able to support even a fifteen fighter wing equivalent level. Solutions to this problem include increasing the service life of the current fighter force and the development of the Joint Strike Fighter.[103] These each have their flaws, so this is why low cost UCAVs may be viable as a cost-effective means of providing combat airpower in the near future.

The unit cost for UAVs varies widely, and it is dependent on the system type and the number procured. One measure of cost is an airframe's "flyaway" cost. Flyaway costs exclude the cost of procuring associated launch and recovery platforms, transports, and other ground support equipment. The expected flyaway cost for the DarkStar (terminated) was $10 million as compared to a $16 million flyaway cost for the F-16.[104] Research and development costs traditionally run up the cost of many weapon systems. In an effort to minimize UCAV costs, the Department of Defense is evaluating off-the-shelf UAV technologies, like the Marine Corps Dragon Drone UAV.[105]

The unit flyaway costs for a UCAV capable of flying in a well-defended target environment will approach the flyaway costs of a conventional fighter. If the military considers using UCAVs to accomplish the armed reconnaissance mission, then system reliability becomes a major issue. The flexibility required to carry out the mission requires increased system complexity, and that also drives up the cost. "Especially in the case of complex functions, system integrity aspects have a far ranging influence on mission accomplishment rates and affordability."[106] If the military pursues the development of a UCAV capable of increased maneuverability in order to ensure survivability, then the unit cost for the vehicle would be as high as manned aircraft due to system complexity and size requirements needed to support high-G flight. Cost savings, however, would occur in the operation, maintenance and support of these systems.[107]

"Typically 80 percent of the useful life of today's combat aircraft is devoted to pilot training and proficiency flying, requiring longer design lives than would be needed to meet combat requirements. Without the requirement to fly sorties to retain pilot proficiency, UCAVs will fly infrequently."[108] In addition to the costs associated with maintaining pilot proficiency, pilot crew rest limitations limit the number of sorties each pilot can accomplish in a given day. Therefore, a typical fighter squadron requires more personnel to accomplish the same number of sorties as a UCAV squadron. The UCAV squadron also has a much lower maintenance personnel cost because the UCAVs are stored until needed, while the UCAV operators conduct the vast majority of their training in simulators. The cost savings generated when comparing UCAV operating costs to manned aircraft operating costs is substantial, and this makes the UCAV an attractive means for conducting aerial warfare. A weapon system's cost also impacts its acceptability as a viable warfighting alternative.

Acceptability

Joint Publication 1-02 defines acceptability as, "The determination whether the contemplated course of action is worth the cost in manpower, material, and time involved; is consistent with the law of war; and militarily and politically supportable."[109] The previous discussion pertaining to the UCAV's cost benefits explained that the UCAV is worth the cost in manpower and material because of the savings it generates. The UCAV is also acceptable with respect to time because of its ability to quickly strike a target once an armed reconnaissance mission target is identified. This rapid strike capability is provided by the UCAV's ability to loiter over the target area. Where the UCAV faces acceptability issues is within the laws of war and its military and political supportability.

This study is intentionally focused on the UCAV's technological aspects to determine if it can replace manned aircraft performing the armed reconnaissance mission. Through researching this aspect of UCAV employment, this author did discover volumes of information concerning the UCAV's use with respect to the laws of war and both political and military supportability issues. Weapon system limitations are nothing new to the American military. Project Aphrodite was terminated during World War II due to the British fear the German's would retaliate in kind due to the "terror" nature of the weapon. Recently, the Predator's Hellfire missile test was delayed due to possible cruise missile treaty violations. These two examples highlight the fact that the UCAV's acceptability is in question in areas outside the scope of this study, and this area must be addressed in future studies. The UCAV does meet the criteria of acceptability within the context of this study, however, due to its cost analysis with respect to manpower, material and time.

Feasibility

The concept of feasibility is also described in Joint Publication 1-02, and it states that a concept is only feasible if the assigned tasks can be accomplished by the available means.[110] In this study, the assigned tasks involve the tasks required to accomplish the armed reconnaissance mission outlined earlier in this chapter, and the available means is provided through the UCAV's use. As was previously presented, the UCAV does possess the capability to conduct all of the tasks required to carry out the armed reconnaissance mission, but limitations in survivability and flexibility affect the UCAV's effectiveness in accomplishing the mission.

Survivability and flexibility are provided through the use of the UCAV's man-in-the-loop system, and it was proven earlier that the man-in-the-loop system is required. The UCAV's man-in-the-loop system depends on data link, and this dependency is a major weakness due to limited, usable frequency bandwidths and susceptibility to electronic warfare. During the 1997 UAV symposium, Dr. D. Scheithauer stated, "The availability of a reliable, jam-resistant real-time data link providing the necessary throughput capacity is paramount to accomplish such missions successfully."[111] Even if reliable, jam-resistant data link is developed within the timeframe of this study, data link transport delays limit the UCAV's self-protection capability in a visual, air-to-air fight. According to Dr. Scheithauer, "In visual-range combat, transport delays from digital processing limit tracking performance. Unless sampling rates will be significantly increased, manned aircraft will be superior to UCAVs in this role due to better situational awareness of the pilot."[112]

Literature reviewed while conducting this study indicates that technological improvements will be made with respect to data link sampling rates, reliability and security, but technological improvements will also occur to counter these data link improvements. Therefore, it is not feasible to replace all manned, combat aircraft with UCAVs when conducting the armed reconnaissance mission in a heavy electronic combat environment. Manned aircraft mission effectiveness rates are superior to UCAV rates due to the better situational awareness the pilot in the cockpit provides. It is feasible, however, to employ the UCAV in scenarios where EW does not pose a significant threat.

Suitability

If the method of conducting a mission results in successfully accomplishing and meeting its specified objectives, than the means for the mission's conduct is considered suitable.[113] The UCAV is suitable in conducting the armed reconnaissance mission because it has the ability to detect, identify and destroy a target. Sensor suite improvements, like the improvements the STARLOS system provides, enable the UCAV to detect and identify targets by fusing synthetic aperture radar information with moving target surveillance data. The triple-redundant navigational system provides the operator the certainty that he/she is in the correct target area, and this enables the UCAV to destroy a target while minimizing the chance of collateral damage. Due to the nature of the armed reconnaissance mission, mission success depends on employing the correct weapon in a timely manner.

History has proven that UAVs can be used to deliver weapons effectively, as was previously discussed while describing the UCAV's feasibility. Current manned aircraft systems can carry larger payloads than the UCAVs described in this study, but this does not limit the UCAV's suitability in conducting the armed reconnaissance mission. Improvements in small, smart munitions will allow the UCAV to employ weapons with effects equal to today's larger munitions. Pinpointing these munitions' effects through the use of technological improvements in accuracy will allow the future warfighter to achieve the desired effects necessary to meet the mission's overall objectives. If its use results in meeting the mission's overall objectives, then the UCAV is suitable for conducting the armed reconnaissance mission.

114

---

[1]Jack C. Slessor, *Air Power and Armies* (London: Oxford University Press, 1936), 200.

[2]Phillip S. Mellinger, *The Paths of Heaven* (Maxwell Air Force Base, Alabama: Air University Press, 1997), 2.

[3]Bruce W. Carmichael et al., *Strikestar 2025* (Maxwell Air Force Base, Alabama: Air University Press, 1996), chap. 4, 1.

[4]B. D. Stewart, "The Operation Effectiveness of UCAVs in Mobile Target Attack," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997 (Defense Technical Information Center, Record accession number ADA351279), 1.

[5]D. Scheithauer and G. Wunderlich, "System Integrity Considerations for Unmanned Tactical Airlift," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997 (Defense Technical Information Center, Record accession number ADA351279), 4.

[6]Ibid.

[7]U.S. Department of the Air Force, Air Force Doctrine Document 1, *Air Force Basic Doctrine* (Washington, DC: Government Printing Office, September 1997), 27 (hereafter cited as AFDD 1).

[8]AFDD 1, 29.

[9]Air Force Scientific Advisory Board (SAB) SAF/PA 96-1204-1996, *UAV Technologies and Combat Operations*; available from http://www.fas.org/man/dod-101/sys/ac/docs/ucav96/chap1.pdf; Internet; accessed 14 January 2001.

[10]J. R. Dixon, "UAV Employment in Kosovo: Lessons for the Operational Commander" (Research paper, Naval War College, Newport, RI, 8 February 2000), 6.

[11]Department of Defense, JP 3-55.1, *JTTP for Unmanned Aerial Vehicles (UAVs)* [CD ROM], (Washington, DC: Government Printing Office, 27 August 1993): Chap. 2, II-1

[12]Ibid.

[13]Office of the Under Secretary of Defense (Acquisition & Technology) (OUSD(A&T)) Defense Airborne Reconnaissance Office (DARO), Document 1, *UAV Annual Report, FY 97*, 1997 (Washington, DC: AD-A336710), 21.

[14]Carmichael et al, Chap. 2, 3.

[15]Ibid.

[16]Office of the Under Secretary of Defense, 21.

[17]Sharon L. Holmes, "The New Close Air Support Weapon: Unmanned Combat Aerial Vehicle in 2010 and Beyond" (Master of Military Art and Science Thesis, U.S. Army Command and General Staff College, Fort Leavenworth, KS, 1999), 23.

[18]Office of the Under Secretary of Defense, 25.

[19]Federation of American Scientists, FAS Intelligence Resource Program, "UAV Ground Control Station (GCS);" available from http://www.fas.org/irp/program/collect/uav.gcs.htm; Internet; accessed 13 January 2001.

[20]Ibid.

[21]JP 3-55.1, Chap. 2, II-15

[22]Ibid.

[23]John P. Jumper, "Statement of General John P. Jumper, Commander, United States Air Force Europe, United States Air Force," (26 October 1999); available from http://www.house.gov/hasc/testimony/106thcongress/00-10-26jumper.htm; Internet; accessed 19 October 2000.

[24]General Michael E. Ryan, USAF, "AF Posture Statement 2000;" available from http://www.house.gov/hasc/testimony/106thcongress/00-02-10ryan.htm; Internet; accessed 5 January 2001.

[25]Office of the Under Secretary of Defense, 5.

[26]JP 3-55.1, Chap. 2, II-6.

[27]Office of the Under Secretary of Defense, 5.

[28]JP 3-55.1 Chap. 2, 11-8.

[29]Ibid.

[30]Office of the Under Secretary of Defense, 13.

[31]Federation of American Scientists, FAS Intelligence Resource Program, "Unmanned Aerial Vehicle Battlelab (UAVB);" available from http://www.fas.org/irp/agency/usaf/acc/awfc/53w/uavb/index.html; Internet; accessed 13 January 2001.

[32]Ibid.

[33]William Cohen, "Annual Defense Review," Annual report to the President and the Congress [Database on-line]; available from http://www.dtic.mil/execsec/adr2000/index.html; Internet; accessed 5 January 2001.

[34]Floyd D. Spence, Chairman, Press Release--House National Security Committee, 23 October 1997, Conference report for the National Defense Authorization Act for FY 98; available from http://www.house.gov/hasc/openingstatementsand pressrelease/105thcongress/fy98ndaapr.pdf; Internet accessed 5 January 2001.

[35]Office of the Under Secretary of Defense, 21.

[36]Cohen.

[37]Ryan.

[38]Ryan.

[39]E. L. Fleeman, “Sensor Alternatives for Future Unmanned Tactical Aircraft,” Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997 (Defense Technical Information Center, Record accession number ADA351279), 7.

[40]Ryan.

[41]Federation of American Scientists, FAS Intelligence Resource Program, “UAV Tactical Control System (TCS);” available from http://www.fas.org/irp/program/collect/ uav_tcs.htm; Internet; accessed 13 January 2001.

[42]Cohen.

[43]Office of the Under Secretary of Defense, 26.

[44]Office of the Under Secretary of Defense, 20.

[45]Office of Assistant Secretary of Defense (Public Affairs), “DARPA and Air Force Select Boeing to Build UCAV Demonstrator System,” (News Release 24 March 1999); available from http://www.defenselink.mil/news/Mar1999/b03241999_bt123-99.html; Internet; accessed 14 January 2001.

[46]Ibid., 435.

[47]Stanley Kandebo, “SEAD, Other Ground Attack Capabilities Planned for UCAVs,” *Aviation Week and Space Technology*, 2 October 2000, 2, [Database on-line]; available from http://ca.dtic.mil/cgl-bin/ebird?doc_url=oct2000/s20001005sead.htm; Internet; accessed 5 October 2000.

[48]Oshawn Jefferson, “Boeing unveils UCAV,” *Air Force Print News*, 28 September 2000; available from http://www.fas.org/man/dod-101/sys/ac/docs/man-ac-ucav-000928.htm; Internet; accessed 14 January 2001.

[49]Ibid.

[50]Ryan.

[51]Brigadier General Jan C. Huly, Director Plans, Policies and Operations Division, Headquarters Marine Corps, Testimony to Congress; available from http://www.house.gov/hasc/testimony/106thcongress/99-03-09huly.htm; Internet; accessed 6 January 2001

[52]General Charles C. Kurlak, Commandant of the Marine Corps, Testimony to Congress on 12 March 1998; available from http://www.house.gov/hasc/testimony/ 105thcongress/3-12-98krulak.htm; Internet; accessed 6 January 2001.

[53]Federation of American Scientists, FAS Intelligence Resource Program, "UAV Ground Control Station (GCS);" available from http://www.fas.org/irp/program/collect/ uav.gcs.htm; Internet; accessed 13 January 2001.

[54]Ibid.

[55]Thomas Kohler, Franz Tumbragel, and Jurgen Beyer, "Reliable Autonomous Precise Integrated Navigation RAPIN for Present and Future Air-Vehicles," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997 (Defense Technical Information Center, Record accession number ADA351279), 1.

[56]Fleeman, 12.

[57]Office of the Under Secretary of Defense, 5.

[58]Fleeman, 10.

[59]Office of the Under Secretary of Defense, 21.

[60]Stewart, 1.

[61]Air Force Scientific Advisory Board, 1-1.

[62]Scheithauer et al.,10.

[63]Ibid., 2.

[64]Stewart, 2.

[65]Ibid.

[66]Federation of American Scientists, Military Analysis Network, "X-45 Unmanned Combat Air Vehicle (UCAV);" available from http://www.fas/org/man/dod 101/sys/ac/ucav.htm; Internet; accessed 14 January 2001

[67]Ibid.

[68]George M. Palfalvy and David K. Andes, "Highly Maneuverable Lethal Vehicle (HMLV) Concept," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997 (Defense Technical Information Center, Record accession number ADA351279), 6.

[69] Scheithauer et al., 7.

[70]J. R. Dixon, "UAV Employment in Kosovo: Lessons for the Operational Commander" (Research paper, Naval War College, Newport, RI, 8 February 2000), 7.

[71]S. J. Langham and P. M. Zanker, "Unmanned Tactical Air Vehicles-An Electronic Combat Perspective, Paper presented at the Mission Systems Panel 8th Symposium, Athens,

Greece, 7-9 October 1997 (Defense Technical Information Center, Record accession number ADA351279), 7.

[72]Ibid.

[73]Ibid.

[74]Ibid.

[75]Ibid.

[76]Ibid.

[77]Palfalvy et al., 4.

[78]Ibid., 6.

[79] Scheithauer et al., 3.

[80]Carmichael et al., Chap 4, 3.

[81]Langham, 8.

[82]R. A. Frampton, "The Challenge of UAV Supporting Offensive Air Operations," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997 (Defense Technical Information Center, Record accession number ADA351279), 4.

[83]Leleand M. Nicolai, "Design Guidelines and Considerations for the UTA," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997 (Defense Technical Information Center, Record accession number ADA351279), 1.

[84]Mark Thompson, "Grounded in Kosovo," *Time Magazine* 153, no. 21 (31 May 1999): 11, Article on-line; available from http://www.pathfinder.com/time/magazine/articles/0,3266,25695,00.html; Internet; accessed 20 October 2000.

[85]Armand J. Chaput, "Design Considerations for Future Uninhabited Combat Air Vehicles," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997 (Defense Technical Information Center, Record accession number ADA351279), 5.

[86]Scheithauer et al., 9.

[87]Ibid.

[88]L. Bianchi, G. Battaini, G. L. Scuzzola, and E. Crovari, "Integrated Data Link for UTA Applications: Design Considerations and Development Results," Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997 (Defense Technical Information Center, Record accession number ADA351279), 8.

[89]Kohler, 1.

[90]Ibid., 3.

[91]Keith Lymore, “Lessons Learned from Predator Peace Keeping Mission in Bosnia,” (Research Paper, United States Air Force Institute for National Security Studies, March 1997), 23.

[92]Bianchi, 2.

[93]Jumper.

[94]Thompson, 11

[95]Langham, 8.

[96]Ibid.

[97]Ibid.

[98]Scheithauer et al., 2.

[99]Thompson.

[100]Chaput, 2.

[101]Thompson, 16

[102]Scheithauer et al., 4.

[103]Chaput, 4.

[104]Steven M. Kosiak and Elizabeth E. Heeter, “Unmanned Aerial Vehicles – Current Plans and Prospects for the Future” 11 July 1997 [Database on-line]; available from http://www.csbaonline.org/4Publications/Archive/…/B.19970711.Unmanned_ Aerial_Ve.htm; Internet; accessed 26 October 2000, 14.

[105]Dennis T. Krupp, Major General, United States Marine Corps Director, Expeditionary Warfare Division Office of the Deputy Chief of Naval Operations (Resources, Warfare Requirements and Assessments), Testimony to Congress on 9 March 1999; available from http://www.house.gov/hasc/testimony/106thcongress/ 99-03-09krupp.htm; Internet; accessed 5 January 2001.

[106]Scheithauer et al., 1.

[107]Palfalvy et al., 3.

[108]Federation of American Scientists, Military Analysis Network, “X-45 Unmanned Combat Air Vehicle (UCAV);” available from http://www.fas/org/man/dod 101/sys/ac/ucav.htm; Internet; accessed 14 January 2001

[109]JP 1-02, 1.

[110]Ibid., 168.

[111]Scheithauer et al., 4.

[112]Ibid.

[113]JP 1-02, 433.

[114]

CHAPTER 5

CONCLUSION

> It was fortunate that the German Air Force relied too heavily on their initial advantage. For this reason they failed to develop, in time, weapons, such as their jet-propelled planes, that might have substantially improved their position.[1]

The United States Strategic Bombing Survey, 1945

Military leaders throughout history have always looked for ways to defeat an adversary while minimizing their forces' exposure to the enemy's combat power, and the UCAV's development is an example of this fact. The United States military must continue to develop systems that ensure American victories in the wars to come, because without this drive the United States can expect the same results the Germans achieved in World War II. The tank was developed in World War I in order to provide mobile firepower on the battlefield while, at the same time, providing protection to the weapon's operators. Throughout history, combat aircraft improvements have centered on increasing the aircraft's combat effectiveness and enhancing the pilot's survivability. Standoff weapon technologies combined with precision munitions accuracy provides the capability for today's pilot to destroy a target while minimizing his/her exposure to enemy defensive systems. The use of unmanned combat aerial vehicles takes this concept to the extreme by providing the pilot the ultimate "standoff" capability--the pilot remains outside the aerial battlefield. This raises the following question: Should the United States military pursue a goal to replace all manned, combat aircraft with UCAVs in order to reduce the risk of human, combat losses?

In an effort to answer the above question, this study focused on the UCAV's ability to replace all manned aircraft in conducting the armed reconnaissance mission. The criteria used to justify the findings included mission effectiveness, cost, acceptability, feasibility and suitability. Based upon the information presented in the first three chapters and the analysis provided in chapter 4, the United States military should not pursue a goal to replace all manned, combat aircraft with UCAVs in order to reduce the risk of human, combat losses. Although the UCAV's use is cost effective, acceptable and suitable within the context of this study, limitations in reliability and survivability affect the UCAV's ability to effectively conduct the armed reconnaissance mission. Table 3 summarizes this study's findings.

TABLE 3
UCAV CRITERIA ANALYSIS FOR THE ARMED RECONNAISSANCE MISSION

Criteria	UCAV Capabilities Meet Criteria?
Mission Effectiveness (Measured in terms of reliability, survivability and flexibility)	**NO** - Self-protection limitations in electronic combat environment - Self-protection limitations in visual, air-to-air combat environment - Severe weather limitations limit flexibility - Data transfer rate delays limit controller situational awareness
Cost	**YES** - Minimizes human exposure to combat environment - Unit flyaway costs similar for manned and unmanned systems - Great savings in operational costs
Acceptability (limited to cost in manpower, material and time)	YES - Cost arguments same as above - Long mission loiter times provides quick strike capability
Feasibility	NO - Survivability and flexibility limitations make an <u>all</u> UCAV force unfeasible
Suitability	YES - Sensor suite improvements provide navigational accuracy and weapons employment accuracy to ensure desired results - Small, smart munitions development will provide required combat firepower

The advantages the UCAV has over manned aircraft are noteworthy, and cost is the UCAV's greatest advantage. Although UCAV unit costs equal the costs of today's fighter aircraft when comparing relative firepower, the UCAV generates tremendous savings in operational costs. Current UAV squadrons use rated pilots to fly the UAV, so training costs for personnel are equal for manned and unmanned platforms. However, UCAV squadrons will be able to accomplish future combat missions with fewer operators because they will be able to control more than one UCAV at a time. This will lower overall manning requirements, which will, in turn, lower operating costs. Additionally, UCAV cost savings occurs by minimizing human exposure to the aerial combat environment. The United States military can attack targets deemed too dangerous for manned missions because UCAV's eliminate the fear of losing the pilot. Saving human lives is the biggest cost advantage gained through the UCAV's use, and the United States military must take advantage of the UCAV's combat capabilities. In doing so, however, the military must also realize the limitations associated with using UCAVs.

Current generation UAVs lack the mission flexibility possible with a pilot in the cockpit, and data link and sensor suite improvements will still result in mission flexibility shortfalls for future UCAVs. The UCAV's flexibility directly impacts its survivability, and limitations in self-protection affect the UCAV's ability to effectively conduct the armed reconnaissance mission. There is an inherent delay in the UCAV's man-in-the-loop system due to data transfer rate limitations. Therefore, in order for the UCAV to survive in an air-to-air engagement within visual range of the enemy, the UCAV must have a robust, autonomous threat-reaction capability. Current threat detection systems do not posses the precision necessary for UCAVs to effectively threat react autonomously, and future systems that provide the accuracy needed are not expected within this study's timeframe. Additionally, UCAV survivability and flexibility are questionable in an electronic warfare environment. The UCAVs man-in-the-loop system is dependent upon data link communications, and these communications are susceptible to jamming in an electronic warfare environment. This limitation makes the UCAV's use unfeasible in a heavy electronic combat environment, and electronic warfare is perceivable within this study's scenario.

Although the United States military should not pursue the goal to replace <u>all</u> manned, combat aircraft with UCAVs, this study shows that UCAVs do have a place in our military as force multipliers. UCAVs can accomplish the armed reconnaissance mission, and its relatively low cost combined with its extended battlefield loiter capability will make it extremely valuable to the future warfighter. The United States military should continue to research and develop combat UAV systems to employ in scenarios where the combat environment favors UCAV use, and emphasis should be placed on integrating UCAVs with the rest of the airborne force. UCAV research and development should not focus its effort on trying to replace the manned, combat force. Rather, it should focus on how to enhance the manned, combat force. There are many combat scenarios where the United States military will have to send in manned aircraft to ensure mission success, but there are also a number of scenarios where a UCAV's use can reduce the risk of human, combat losses.

---

[1]The United States Strategic Bombing Survey (Maxwell Air Force Base, Alabama: Air University Press October 1987), 40.

GLOSSARY

Anti-Aircraft Artillery: (AAA) Surface artillery used against an air threat.

Armed reconnaissance: A form of Air Interdiction that is planned against a particular area, rather than a particular target. The area may be defined by a box or grid, or may be defined as a stretch of an LOC such as a railroad, highway, or river. When specific killboxes are used for this purpose, the mission is sometimes known as “killbox AI.” Armed reconnaissance is normally flown into areas where lucrative targets are known or suspected to exist, or where mobile enemy surface units have moved to as a result of ground fighting (AFDD 2-1.3, 27).

Battle Damage Assessment**:** (BDA) The timely and accurate estimate of damage resulting from the application of military force, either lethal or non-lethal, against a predetermined objective (Joint Publication 1-02, 56).

Battlefield: In this thesis, the battlefield will be restricted to the airspace where the unmanned vehicles can expect to be engaged by the enemy. The enemy threat may be from the air or from the surface. Any airspace where offensive operations are conducted, with or without an opposing threat, will also be considered the battlefield.

Data Link: The means of connecting one location to another for the purpose of transmitting and receiving data. In this thesis, this will be the ability to pass targeting and threat information from a UAV or UCAV to other elements of a strike package or a ground station while airborne. In addition, data link will be used as a method to allow controller interaction with the UCAV (Joint Publication, 122).

High-speed Anti-Radiation Missile: (HARM) Air launched missile designed to suppress radar systems used for guiding enemy surface-to-air missiles (Joint Publication 1-02, 566).

Integrated Air Defense System: (IADS) This is a network of early warning and target tracking radars, communications equipment, command and control networks, and surface-to-air and air-to-air defense systems all orchestrated to accomplish the air defense mission.

Mobile Target: A target that is not fixed in space. Realistically, any target can be moved within a given timeframe. Therefore, for the purpose of this paper a mobile target is defined as a target that is moved within the time scale of the air tasking order's operation. A mobile target does not necessarily constitute a moving target, but rather a target moved within the time scale (DTIC, ADA351279, 2.).

Precision-Guided Munitions: (PGM) A weapon that uses a seeker to detect electromagnetic energy reflected from a target or reference point, and, through processing, provides guidance commands to a control system that guides the weapon to the target. In this thesis, weapon systems that incorporate technology that greatly increases the weapon's accuracy, such as GPS, are also included (Joint Publication 1-02, 351).

Strike: An attack which is intended to inflict damage on, seize, or destroy an objective. When the term "strike" is used as a mission type, it refers to the ability to deliver air-to-ground ordnance on a designated target (Joint Publication 1-02, 431).

Surface-to-Air Missile: (SAM) A surface-launched missile for use against air targets (Joint Publication 1-02, 436).

Suppression of Enemy Air Defense: (SEAD) That activity which neutralizes, destroys, or temporarily degrades surface-based enemy air defenses by destructive and or disruptive means (Joint Publication 1-02, 435).

Unmanned Aerial Vehicle: (UAV) A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semiballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles (Joint Publication 1-02, 473).

Unmanned Combat Aerial Vehicle: (UCAV) For the purpose of this thesis, the UCAV will have the same definition as the UAV with a few exceptions. The UCAV will carry a lethal payload, and all UCAVs will be recoverable.

BIBLIOGRAPHY

Books

Carmichael, Bruce W., Troy E. Devine, Robert J. Kaufman, Patrick E. Pence, and Richard S. Wilcox. *Strikestar 2025*. Maxwell Air Force Base, Alabama: Air University Press, 1996.

Dolgin, D., C. Hoffman, G. Kay, M. Langelier, and B. Wasel. *Identification of the Cognitive, Psychomotor, and Psychosocial Skill Demands of Uninhabited Combat Aerial Vehicle (UCAV).* Patuxtent River, MD: Naval Warfare Center, Aircraft Division, 21 June 1999.

Hall, Ellen M. and William C. Tirre. *USAF Air Vehicle Operator Training Requirements Study*. Brooks AFB, TX: Air Force Research Lab, Human Effectiveness Directorate, 1 February 1998.

Jackson, J. A., B. L. Jones, and L. J. Lehmkuhl. *2025 Operational Analysis*. Maxwell AFB, Alabama: Air University Press, June 1996.

Mellinger, Phillip S. *The Paths of Heaven*. Maxwell Air Force Base, Alabama: Air University Press, 1997.

Olsen, Jack. *Aphrodite: Desperate Mission*. New York, New York: G. P. Putnam's Sons, 1970.

Slessor, Jack C. *Air Power and Armies*. London: Oxford University Press, 1936.

Government Documents

Office of the Under Secretary of Defense (Acquisition & Technology) (OUSD(A&T)) Defense Airborne Reconnaissance Office (DARO). Document 1, *UAV Annual Report, FY 97.* (Washington, DC: AD-A336710), 21.

U.S. Department of the Air Force. Air Force Doctrine Document 1, *Air Force Basic Doctrine.* Washington, DC: Government Printing Office, September 1997.

________. Air Force Doctrine Document 2-1.3, *Counterland*. Publication full text. CD-ROM. Washington, DC: Government Printing Office, 27 August 1999.

U.S. Department of Defense. Joint Publication 1-02, *DoD Dictionary of Military and Associated Terms.* Publication full text. CD-ROM. Washington, DC: Government Printing Office, 12 January 1998.

________. Joint Publication 3-55.1, *JTTP for Unmanned Aerial Vehicles (UAVs).* Publication full text. CD-ROM. Washington, DC: Government Printing Office, 27 August 1993.

The United States Strategic Bombing Survey. Maxwell Air Force Base, Alabama: Air University Press, October 1987.

Papers

Bianchi, L., G. Battaini, G. L. Scuzzola, and E. Crovari. "Integrated Data Link for UTA Applications: Design Considerations and Development Results." Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279, 8.

Chaput, Armand J. "Design Considerations for Future Uninhabited Combat Air Vehicles." Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279.

Dixon, J. R. "UAV Employment in Kosovo: Lessons for the Operational Commander." Research paper, Naval War College, Joint Military Operations Department, Newport, RI, 8 February 2000.

Fleeman, E. L. "Sensor Alternatives for Future Unmanned Tactical Aircraft." Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279, 7.

Kohler, Thomas, Franz Tumbragel, and Jurgen Beyer. "Reliable Autonomous Precise Integrated Navigation RAPIN for Present and Future Air-Vehicles." Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279, 1.

Frampton, R. A. “The Challenge of UAV Supporting Offensive Air Operations.” Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279.

Gatti, A. “From Manned to Unmanned: A Viable Alternative to the Scrapyard.” Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279.

Gartner, Klaus-Peter, and Walther Kruger. “Investigation of Human Performance Monitoring an IR-Camera View from an Unmanned Tactical Aircraft.” Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279.

Holmes, Sharon L. “The New Close Air Support Weapon: Unmanned Combat Aerial Vehicle in 2010 and Beyond.” Thesis, Master of Military Art and Science, U.S. Army Command and General Staff College, Fort Leavenworth, KS, 1999.

Langham, S. J., and P. M. Zanker. “Unmanned Tactical Air Vehicles--An Electronic Combat Perspective.” Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279.

Keith Lymore. “Lessons Learned from Predator Peace Keeping Mission in Bosnia.” (Research Paper, United States Air Force Institute for National Security Studies, March 1997), 23.

Nicolai, Leleand M. “Design Guidelines and Considerations for the UTA.” Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279.

Palfalvy, George M., and David K. Andes. “Highly Maneuverable Lethal Vehicle (HMLV) Concept.” Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279.

Scheithauser, D., and G. Wunderlich. “System Integrity Considerations for Unmanned Tactical Aircraft.” Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279.

Sosa, A. J. "Unmanned Aerial Vehicles." Research Paper, Army War College, Carlisle Barracks, PA, April 1997.

Stewart, B. D. "The Operation Effectiveness of UCAVs in Mobile Target Attack." Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279.

Taylor, Thomas D. "Technical Evaluation Report." Paper presented at the Mission Systems Panel 8th Symposium, Athens, Greece, 7-9 October 1997. Defense Technical Information Center, Record accession number ADA351279.

Internet

Air Force Scientific Advisory Board (SAB). SAF/PA 96-1204-1996. *UAV Technologies and Combat Operations*. Available from http://www.fas.org/man/dod-101/sys/ac/docs/ucav96/chap1.pdf. Internet. Accessed 14 January 2001.

Cohen, William, Secretary of Defense. *Annual Defense Review*. Annual Report to the President and the Congress. Database on-line. Available from http://www.dtic.mil/execsec.adr2000/index.html. Internet. Accessed 21 October 2000.

Federation of American Scientists. FAS Intelligence Resource Program, "UAV Ground Control Station (GCS)." Available from http://www.fas.org/irp/program/collect/uav.gcs.htm. Internet. Accessed 13 January 2001.

________. FAS Intelligence Research Program, "UAV Tactical Control System (TCS)," Available from http://www.fas.org/irp/program/collect/uav_tcs.htm. Internet. Accessed 13 January 2001.

________. FAS Intelligence Resource Program, "Unmanned Aerial Vehicle Battlelab (UAVB)." Available from http://www.fas.org/irp/agency/usaf/acc/awfc/53w/uavb/index.html. Internet. Accessed 13 January 2001.

________. Military Analysis Network, "X-45 Unmanned Combat Air Vehicle (UCAV)." Available from http://www.fas/org/man/dod101/sys/ac/ucav.htm. Internet. Accessed 14 January 2001

Huly, Jan C., Brigadier General, Director Plans, Policies and Operations Division, Headquarters Marine Corps. Testimony to Congress. Available from http://www.house.gov/hasc/testimony/106thcongress/99-03-09huly.htm. Internet. Accessed 6 January 2001

Jefferson, Oshawn. "Boeing unveils UCAV." *Air Force Print News* 28 September 2000. Available from http://www.fas.org/man/dod-101/sys/ac/docs/man-ac-ucav-000928.htm. Internet. Accessed 14 January 2001

Kandebo, Stanley W. "SEAD, Other Ground Attack Capabilities Planned for UCAVs." *Aviation Week & Space Technology* (2 October 2000): 69-70. Database on-line. Available from http://ca.dtic.mil/cgl-bin/ebird?doc_url=oct2000/s20001005 sead.htm. Internet. Accessed 5 October 2000.

Kosiak, Steven M. and Elizabeth E. Heeter. "Unmanned Aerial Vehicles--Current Plans and Prospects for the Future," 11 July 1997. Database on-line. Available from http://www.csbaonline.org/4Publications/Archive/…/B.19970711.Unmanned_Aerial_Ve.htm. Internet. Accessed 26 October 2000.

Krupp, Dennis T. Major General, United States Marine Corps, Director, Expeditionary Warfare Division Office of the Deputy Chief of Naval Operations (Resources, Warfare Requirements and Assessments). Testimony to Congress on 9 March 1999. Available from http://www.house.gov/hasc/testimony/106thcongress/ 99-03-09krupp.htm. Internet. Accessed 5 January 2001.

Kurlak, Charles C., General, Commandant of the Marine Corps. Testimony to Congress on 12 March 1998. Available from http://www.house.gov/hasc/testimony/ 105thcongress/3-12-98krulak.htm. Internet. Accessed 6 January 2001.

Jumper, John P. "Statement of General John P. Jumper, Commander, United States Air Forces Europe, United States Air Force," 26 October 1999. Database on-line. Available from http://www.house.gov/hasc/testimony/106thcongress/99-10-26 jumper.htm. Internet. Accessed 20 October 2000.

Labs, Eric J., and Evan W. Christman. "Options for Enhancing the Department of Defense's Unmanned Aerial Vehicle Programs." Report submitted to the Congressional Budget Office, September 1998. Database on-line. Available from http://sun00781.dn.net/man/congress/1998/cbo-uav.htm. Internet. Accessed 26 October 2000.

Office of Assistant Secretary of Defense (Public Affairs). "DARPA and Air Force Select Boeing to Build UCAV Demonstrator System." News Release 24 March 1999. Available from http://www.defenselink.mil/news/Mar1999/b03241999_bt123-99.html. Internet. Accessed 14 January 2001.

Ryan, Michael E., General, USAF. “AF Posture Statement 2000.” Available from http://www.house.gov/hasc/testimony/106thcongress/00-02-10ryan.htm. Internet. Accessed 5 January 2001.

Spence, Floyd D. Chairman. Press Release--House National Security Committee, 23 October 1997. Conference report for the National Defense Authorization Act for FY 98. Available from http://www.house.gov/hasc/openingstatementsand pressrelease/105thcongress/fy98ndaapr.pdf. Internet. Accessed 5 January 2001.

Thompson, Mark. “Grounded in Kosovo.” *Time Magazine* 153, no. 21 (31 May 1999). Database on-line. Available from http://www.pathfinder.com/time/magazine/ articles/0,3266,25695,00.html. Internet. Accessed 20 October 2000.

Periodicals

Cooper, Pat. “Future UAVs May Drop Bombs, Fire Missiles and More.” *Navy Times* 46, no. 4 (28 October 1996): 33.

________. “The Digital Battlefield Revolution.” *The Army Times* 56, no. 50 (8 July 1996): 30.

Giscard, John C. “VMU.” *Marine Corps Gazette* 84, no. 5 (May 2000): 55-56.

McHale, John. “Unmanned Aerial Vehicle Programs Look to COTS for Future Upgrades.” *Military & Aerospace Electronics* 10, no. 6 (June 1999): 13-16.

McHugh, Jane. “UAV Downed Over Kosovo.” *Army Times* (19 April 1999).

McKenna, Pat. “Eyes of the Warrior.” *Airman Magazine* 42, no. 7 (July 1998): 28-31.

Walsh, Mark. “The Future Likely Hold Both Pilots and Drones.” *Air Force Times* 57, no. 40 (5 May 1997): 34.

Young, Peter Lewis. “Will the UAV Replace all Combat Aircraft Types?” *Asian Defense Journal* no. 4 (April 1999): 38-40.

Zolaga, Steven J. “UAV Military Future Deemed ‘Promising.” *Aviation Week and Space Technology* 146, no. 2 (13 January 1997): 89-90.

INITIAL DISTRIBUTION LIST

1. Combined Arms Research Library

   U.S. Army Command and General Staff College

   250 Gibbon Ave.

   Fort Leavenworth, KS 66027-2314

2. Defense Technical Information Center/OCA

   8725 John J. Kingman Rd., Suite 944

   Fort Belvoir, VA 22060-6218

3. Air University Library

   Maxwell Air Force Base, AL 36112

4. Captain Graham H. Gordon, USN

   Navy Element

   USACGSC

   1 Reynolds Ave.

   Fort Leavenworth, KS 66027-1352

5. Colonel Raymond O. Knox, USAF

   Air Force Element

   USACGSC

   1 Reynolds Ave.

Fort Leavenworth, KS 66027-1352

6. Rodler F. Morris, Ph.D.

   Center for Army Lessons Learned

   10 Meade Ave.

   Fort Leavenworth, KS 66027-1352

Insert CARL Form…