United States Air Force

Scientific Advisory Board

Report on

Unmanned Aerial Vehicles in Perspective:

Effects, Capabilities, and Technologies

Volume 1: Summary (PR)
SAB-TR-03-01
September 2003

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Foreword

Unmanned Aerial Vehicles (UAVs) recently demonstrated complementary warfighting capabilities in the Afghanistan and Iraq theaters. In these operations, less expensive, limited capability UAVs were able to leverage the power of networked operations to accomplish complex and demanding missions. Innovative applications of UAVs demonstrated that persistence, coupled with precision, is an overwhelming advantage that leverages the full power of the combat air forces. UAVs are now integrated into the operational force and have become valuable contributors to the total force.

A team of talented professionals conducted this study – Scientific Advisory Board members and consultants, technical advisors and executive officers from the Air Force, and the staff of the SAB Secretariat. Their unmatched dedication and hard work made the study successful.

This report provides an SAB perspective for the Air Force Secretary and Chief of Staff regarding the future of Unmanned Aerial Vehicles.

Dr. Ray O. Johnson
Study Chair

June 27, 2003

Dr. LTG (Ret) Mal R. O'Neill
Deputy Study Chair

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Executive Summary

Introduction

Unmanned aerial vehicles (UAVs) are not new to aviation, the military, or the Air Force (AF). The first UAV was developed and operated by Samuel Pierpont Langley, in 1896. During World War I, two separate efforts were conducted to develop UAVs for surface attack. While neither effort was finished in time to see combat, the Sperry Torpedo and Kettering Bug both flew in 1918 as unmanned, automatically controlled bombers. UAV development stalled until World War II, when development was again too late to contribute to the war. The BQM-34 was developed in the 1950s and used operationally as a photoreconnaissance platform. More recently, UAVs have developed along two very distinct paths. Vehicles like Helios and Global Hawk have been engineered for extreme range and altitude, making them large. In contrast, the Black Widow, which has a wingspan of only six inches, was developed to be portable and travel to places where humans cannot go. The UAV is not new, and past experience can be used to chart the course for future development. Today the revolution in technologies such as signal and image processing and sensors can be leveraged to permit UAVs to assume a larger role in Air Force missions.

The Air Force is off to a good start as an operational user of UAVs. Ten types of UAV were used in OPERATION IRAQI FREEDOM. These UAVs performed traditional intelligence, surveillance, and reconnaissance functions as well as a range of more novel missions. One of the UAV's most used and desired attributes was persistence. The marriage of Predator to the Hellfire missile resulted in an unprecedented capability to hold targets at risk, with a level of endurance that made it difficult for the adversary to hide. Special Forces used portable UAVs to scan their areas of operations, enabling them to achieve tactical surprise.

This diversity of UAV sizes provides a wide spectrum of potential uses. Understanding the range of missions in which UAVs can contribute or providing perspective regarding the utility of UAVs was the purpose of this study. To accomplish this task, the Study addressed the following three focus areas:

1. *Provide notional mission concepts, to include innovative missions, for UAV employment in combat and non-combat roles*
2. *Delineate the evolution of roles and the appropriate synthesis of tasks for manned and unmanned aircraft over a spectrum of possible applications*
3. *Recommend air vehicle software technology and system capabilities for development and demonstration*

The Air Force is off to a Good Start

The Air Force has already studied the applications of UAVs, gained valuable experience in combat operations, integrated UAVs in networked operations, and identified key issues facing future UAV evolution. The Air Force has emerged as a knowledgeable proponent of UAV applications and appears prepared to leverage more UAV applications that support a range of Air Force missions.

Operations in both Afghanistan and Iraq demonstrated the value of UAVs in both Intelligence, Surveillance and Reconnaissance (ISR) and combat roles. UAVs were integrated into the operational force and became valuable contributors to the total force. The integration of weapons on the Predator provided significant armed reconnaissance benefits, especially in the case of persistent response to time-critical targets. The benefit of Predator as ISR support for the AC-130 gunship underscores the positive synergy between manned and unmanned systems.

The AF has acted upon previous Scientific Advisory Board (SAB) studies, which identified the need for persistent ISR and time-urgent threat response. UAVs have both designated targets for off-board weapons and engaged targets directly, which relates to the Suppression of Enemy Air Defense (SEAD)/Destruction of Enemy Air Defenses (DEAD) mission area identified in the 1996 SAB study. This study was also a catalyst for the recent USAF/Defense Advanced Research Projects Agency (DARPA) development of the Unmanned Combat Aerial Vehicle (UCAV), which may help transform the military aerospace landscape in both persistent battlespace presence and unmanned systems' integration with manned systems.

Other transformational concepts like Net-Centric Operations can be tapped to maximize the effectiveness of UAVs while saving significant costs. The characteristics of UAVs as platforms, which can run the gamut of onboard sophistication, suggest that they may be more flexible than manned systems in allowing the network to achieve greater system-level functionality. In fact, the idea of remoting the pilot function, as with Predator, demonstrates a degree of flexibility in the network that allows it to assume control of any UAV function by ensuring the development of an onboard processing package and validated flight software.

Despite this progress, the study identified several remaining issues associated with UAV systems. These include cost, flight safety, operator qualification, mission management technology, and the development of an integrated manned/unmanned architecture. The cost picture is unclear, primarily because of limited UAV experience and because procurement numbers are so low that per unit costs have remained high. Safety concerns regarding UAVs flying in the battlespace may force significant flight constraints that could curtail operational effectiveness, pending resolution of policy issues with the Federal Aviation Administration (FAA) and International Civil Aviation Organization (ICAO). A key technical area is mission management software, which Includes autonomy and human-system interfaces. Finally, UAVs should not be considered independent systems in the battlespace. They must be integrated into the overall architecture (operational, technical and system) containing manned and unmanned systems.

Do Things Differently

To get the most from UAV platforms the AF should make changes in the way it procures and operates UAV systems.

Net-Centric Operations (NCO)

Among the insights gained during this study is the realization that limited-capability UAVs can accomplish complex tasks by leveraging other systems in an integrated network. Similarly, manned systems benefit greatly from the data provided by UAVs. Unmanned vehicles must be a part of NCO, which involves integrating the vehicle communications into the command and control network and transmitting data and intelligence gathered from the UAV to the broader network to enhance situational awareness on the part of all other operators in the battlespace. The creation of a net-centric constellation of manned and unmanned assets will be a step toward the realization of Predictive Battlespace Awareness, the topic of last year's SAB study and an important AF organizational goal. Through this increased awareness and sharing of data, systems with limited capabilities will be able to perform complex tasks by leveraging the network.

Acquisition Strategy and Cost

The study concluded that both different acquisition concepts and cost-reducing measures must be implemented for UAVs to be procured in large numbers and escape the low-density/ high-demand space they currently occupy.

Current UAVs are being procured in small numbers, and this fact has resulted in high per-unit costs. Going forward, the number of systems procured will be highly dependent on their planned missions. To control life cycle costs, “requirements creep” must be controlled. The data show that UAVs manufactured to manned-aircraft standards of mission accomplishment, performance, survivability, and reliability will have procurement costs that are very similar to those of manned systems.

While procurement cost savings may be limited, substantial savings appear to be possible in operations and support costs. Since UAVs are operated remotely, the operator’s role in a mission can be completely replicated in a simulator without the need for training sorties. While some sorties for maintenance proficiency and interoperability with other platforms will still be required, substantial savings can be made by cutting actual flight operations. Deployment packages for similar mission capabilities can be substantially smaller for UAV systems, since in many instances, only launch and recovery teams need to be sent forward. UAV employment concepts may also reduce requirements for combat search and rescue, jamming escort, etc.

Do New Things

There are several new things that must be accomplished for the AF to realize the full potential that UAVs can bring to the battlespace.

The AF needs to invest in mission management technologies. While flight control and basic vehicle technologies are already well developed, the technologies to actually manage the mission (such as automation, human-systems interface and dynamic replanning algorithms) are the key limiting factors to increasing both the performance of UAVs and the vehicle-to-operator ratio. Although supporting work in mission management technologies was a recommendation of the 1996 SAB UAV Study, little work has been done in this area, and it remains a key area for focused investment.

The AF should procure the set of three present and planned systems (Predator, Global Hawk, and UCAV) as part of a family-of-systems concept. To realize the wide set of capabilities sought across the AF Task Force Concept of Operations (CONOPS), three new family members must be developed. The new systems are a survivable deep penetrating ISR, a survivable deep penetrating strike, and a set of small UAVs.

By analyzing the various CONOPS for needed capabilities and then comparing those capabilities to currently programmed systems, the study discovered that this limited set of vehicles is capable of achieving a diverse set of effects. Predator, Global Hawk, and UCAV are able to add value to five of the ten key missions identified for UAVs. Additionally, they are capable of accomplishing or enhancing 14 of the 27 missions. The recommended family of multi-functional UAV platforms, with modular payloads, can enhance the AF capability to achieve effects in 26 of the 27 mission areas. Procuring UAVs as a small family of fully interoperable systems will result in purchase numbers being sufficient to drive down costs, while supporting a broad range of capabilities.

Recommendations

The UAV Study is supportive of improved UAV capabilities and strongly encourages the acceleration of Air Force acquisition activities. UAVs have already emerged as working elements of the Aerospace Force. The study recommends that the Air Force:

1. Continue to procure Global Hawk, Predator, and UCAV, incorporating new capabilities through spiral development using open system architectures and modular payloads

2. Begin research and Analysis of Alternatives (AoA) on the Survivable High Altitude Endurance (SHAW) and Survivable Large (SL) systems

3. Develop a cross-cutting research initiative in Autonomy and Human-System Integration (H-SI) mission management technologies; integrate using a testbed environment

4. Develop an architecture and the associated standards that enable the integration of UAVs with manned and space systems

5. Initiate innovative research into small UAV platforms and the enabling technologies

6. Conduct near- and mid-term demonstrations of specific capabilities to integrate unmanned systems into the force structure

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Chapter 1: Introduction

In the past war, the nature of the weapons, the brilliance of our sources, and the mistakes of our enemies all weighed the balance in our favor. It may well not remain so in the future.

R. V. Jones, ***The Wizard War***

1.1 Overview

1.1.1 Study Charter

The goal of the 2003 Scientific Advisory Board (SAB) Summer Study is to take a considered look at the appropriate evolution of Air Force capabilities using unmanned aircraft. This study will build on previous SAB studies including ***UAV Technologies and Combat Operations*** (1996), ***Sensor Technology for Difficult Targets*** (2001), and ***Predictive Battlespace Awareness*** (2002), as well as two of the three current SAB studies, ***Technology for Machine-to-Machine Interface Management for Intelligence, Surveillance, and Reconnaissance***; and ***CONOPS and Technology to Support Long Range Strike Operations***. The study will:

- Provide notional concepts of operation that support the operational capabilities addressed in the study and address issues that may affect management processes or technology design and development.
- Consider innovative missions for unmanned aerial vehicles that are not just a replication of manned missions and the features that make unmanned aircraft superior to manned aircraft for specific missions.
- Consider the evolution of roles and the appropriate division of tasks for manned and unmanned aircraft over a spectrum of possible applications – from fighters and bombers to transports and reconnaissance aircraft in the near-, mid-, and far-term.
- Survey and recommend air vehicle platform and software technology needs and availability – such as avionics, propulsion, flight control, and stealth. Consider the flight management technologies and processes that are needed when unmanned aircraft are used in close proximity to manned aircraft.
- Consider how the Air Force (AF) measures the contribution of unmanned aircraft to warfighting capabilities including the development of the test and demonstration metrics.
- Recommend technology and system capabilities development and demonstration plans.

In reviewing these requirements and the recent use of UAVs in Afghanistan and Iraq, the study determined that the increased emphasis on UAVs raised the following key questions:

1. What effects are best accomplished by unmanned aircraft?
2. What are the features that make unmanned aircraft superior to manned aircraft for specific missions and what are those missions?
3. What are the appropriate roles of manned and unmanned aircraft to accomplish the desired effects?
4. What flight management technologies and processes are needed when unmanned aircraft are used in close proximity to manned aircraft?

5. What are the correct metrics to test the contribution of unmanned aircraft to warfighting capabilities?
6. What is the right path for the development and integration of unmanned aircraft into the force structure?

To answer these six questions, and fulfill its charter, the study focused on these three areas:

1. Provide notional mission concepts, to include innovative missions, for UAV employment in combat and non-combat roles
2. Delineate the evolution of roles and the appropriate allocation of tasks for manned and unmanned aircraft over a spectrum of possible applications
3. Recommend air vehicle platform and software technologies and identify system capabilities for development and demonstration

1.1.2 Study Organization

The study was organized into four panels. The Mission Concepts and Demonstrations panel analyzed the AF's needed capabilities and effects and developed measures for determining the value of manned and unmanned platforms in achieving these effects. From these measures, the panel established a long-term vision for roles in which UAVs would enhance the capabilities of the AF and suggested a series of demonstrations that could be the basis for system maturation and fielding. The Mission Management Panel examined UAV human-systems interface, and autonomous operating technologies related to command and control, platform operation, and payload employment. This panel then identified key operational constraints associated with current levels of technology, and defined a framework for understanding future needs, future trends, and potential solutions. The Vehicles panel defined the vehicle concepts and design needs, identified vulnerabilities and limitations unique to UAV vehicles, identified UAV vehicle cost savings opportunities, identified vehicle technology limitations, and developed an integrated plan for near-, mid-, and far-term UAV system capabilities and demonstration. The Executive panel integrated the efforts of the other three panels.

1.1.5 Structure of Volume 1

This volume is a summary of the study's findings and recommendations. It is intended to be an action-oriented document. Chapter One provides a summary of the study's results and discusses how a broad range of desired effects and capabilities can be achieved by a limited family of UAV systems. This introductory chapter provides study-level findings and recommendations associated with this family of systems and the recommended "path ahead." The subsequent chapters contain the discussion, findings and recommendations of each of the study panels. Chapter Two will detail the mission concepts and technologies needed to achieve desired capabilities and effects on-board the vehicles. Chapter Three will outline the family of unmanned vehicles that enables mission enhancement or accomplishment and the vehicle technologies necessary to bring this family into being. Chapter Four will discuss the human-systems interface and automation challenges that must be overcome to realize the potential of unmanned vehicles.

1.1.6 Structure of this Chapter

This chapter will first outline the history behind the development of unmanned vehicles. It will show the AF has done well to date in developing and fielding new UAV technologies and in using them in the Iraq and Afghan conflicts. It will then discuss some outstanding issues and macro-level conclusions that led to an examination of the UAV mission space. From this examination of the mission space, it will become apparent that a limited family of six types of UAVs can make significant contributions across a wide range of AF Task Force Concept of Operations (CONOPS) and missions. The chapter will then discuss some things the AF will need to do differently to realize these contributions, and some new things the AF must do to enable UAVs to contribute optimally to the force. Finally, the chapter will conclude with some specific recommendations required for the AF to field this family of systems.

1.2 Background

1.2.1 History of UAVs

The history of UAVs predates the history of manned flight. The first engine-powered heavier-than-air unmanned vehicle was designed and operated by Samuel Pierpont Langley over the Potomac River in 1896. While the flight of the Langley Aerodrome was short, only 1100 yards, it led the way for future developments.

During World War I, the unmanned vehicle development continued by Lawrence Sperry, who, in 1916 designed an unmanned bomb, the Sperry Torpedo. The vehicle first flew in March 1918, but did not finish developmental testing until the end of the year. This was followed shortly thereafter by the "Kettering Bug" which first flew in October 1918, and like the Sperry Torpedo, did not finish testing until after the end of the war.

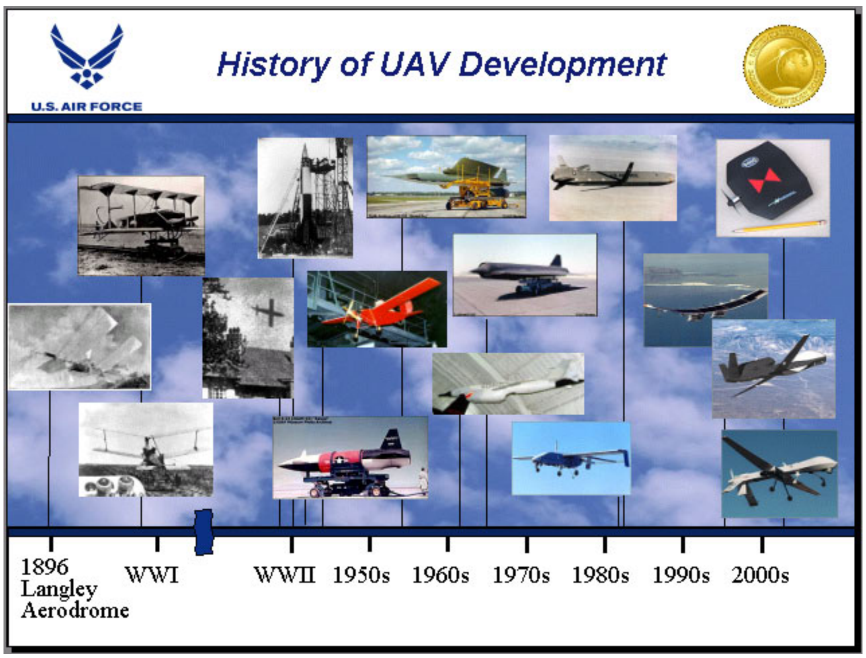

Figure 1-1. *History of Unmanned Vehicles*

World War II saw the development of a new set of unmanned weapons. Beginning in June 1944, Germany used the V-1 rocket to attack and terrorize the people of Great Britain. The V-1, an unmanned air vehicle was followed in September by the first use of the V-2, a ballistic missile. Germany's use of these devices prompted U.S. research efforts, which again came to fruition after the war. The Bell B-63 guided missile and the OQ-A Radioplane both were developed in 1946 and were never produced in mass quantity.

In 1960, the AF began another effort to build unmanned vehicles, this time for reconnaissance missions. The AQM-34 Ryan Firebee was an air-launched UAV and was the first attempt to incorporate low observable characteristics into an air vehicle. The Firebee had a screen which reduced the radar signature of the engine intake, and it was coated in radar-absorbing paint. Between October 1964 and April 1975, over 1000 Firebees would fly over 34,000 operational sorties in Southeast Asia, with an 83 percent mission success rate. In 1970, Ryan Aviation modified the Firebee for communications intercept work. The Ryan SPA 147 flew for the last five years of the Vietnam conflict.

More recently, UAVs have been built and designed in conformity to two different patterns. Systems like Predator and Global Hawk have been designed for long mission duration and for persistent intelligence, surveillance and reconnaissance (ISR). As a result, these platforms have been rather large; Global Hawk weighs over 25,000 pounds. Simultaneously, small UAV systems have also been developed. The Black Widow, pictured above, is among a set of unmanned platforms with a wingspan of less than a foot. These systems have a niche mission in that they can travel to places too small for manned aircraft to go. Thus far, over 1500 separate UAV systems have been produced, only a small fraction of which appear here. Together, they have made a substantial impact on combat operations through time, especially in OPERATION IRAQI FREEDOM.

1.2.2 UAVs in Iraq

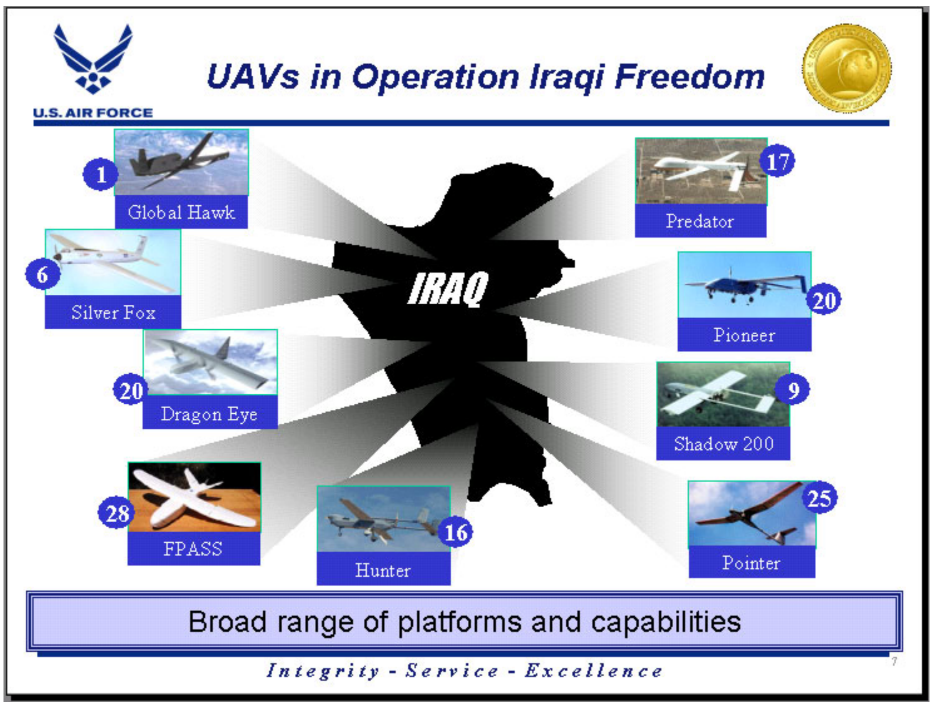

Figure 1-2. *UAVs Used in OPERATION IRAQI FREEDOM*

In OPERATION IRAQI FREEDOM, US forces used a variety of UAVs. In addition to the nine depicted above, ground forces also used several small UAVs that directly supported maneuver commanders. In general, the UAVs performed very well. Reachback for UAV operations enabled a reduced forward logistics footprint, which enabled more efficient deployment. UAVs provided persistent ISR over areas of interest throughout the battlespace and were synchronized with manned strike systems. This combination enabled the attacking of time critical targets at several points during the operation. Even though UAVs were preferred to manned systems in medium and high-threat environments, losses were lower than expected, with only three Predators and three Hunters lost in combat.

1.2.3 The AF is Off to a Good Start

The Air Force is already well on its way in defining future requirements for UAV systems. Several AF SAB studies contribute to this discussion including the 1996 study on ***UAV Technologies and Combat Operations***, the 2001 study on ***Sensor Technology for Difficult Targets***, the 2002 ***Predictive Battlespace Awareness*** study, and the 2003 ad hoc studies on ***Technology for Machine-to-Machine ISR Integration*** and ***CONOPS and Technology to Support Long Range Strike Operations***. The AF has also fully integrated UAVs into its Transformational Flight Plan.

Additionally, the AF has made considerable progress over the past ten years in UAV employment and research. In Iraq, the AF leveraged the UAV attributes of persistence, precision, survivability, flexibility, and lethality to strike time sensitive targets and create desired battlefield effects. The efforts of the UAV Battle Lab and Air Force Special Operations Command (AFSOC) are particularly noteworthy, as they developed innovative uses for a variety of UAVs. The integration of the AC-130 with Predator enabled persistent ISR over targets of interest, which denied the adversary sanctuary in an innovative melding of manned and unmanned technologies. These operations demonstrate that less expensive, limited-capability UAVs have been able to leverage the power of Net-Centric Operations (NCOs) to accomplish complex and demanding missions

1.2.4 Unresolved Issues

While the AF is off to good start, a number of unresolved issues remain. Among these are cost, flight safety and airspace concerns, force structure challenges, and technology needs.

Today, UAVs are expensive to develop, acquire, and operate, in part because of the relatively small numbers of procured systems. If UAVs are to be used in large numbers, then the AF needs a different design and procurement model.

UAVs must be flown with and around manned aircraft, as operations over Iraq and Afghanistan have demonstrated. A key challenge is getting people and machines to work together. While ad hoc arrangements worked in Iraq, more permanent concepts for airspace integration and deconfliction need to be developed. However, there is a second aspect of this problem. The civilian air traffic controlling agencies (the Federal Aviation Administration [FAA] and the International Civil Aviation Organization [ICAO]) continue to place restrictions on UAV operations, which can significantly constrain training and operations. Like the interoperability problem, this issue also needs to be resolved. To do this, an architecture that integrates UAVs with manned systems to realize complementary capabilities and leverage net-centric operations is needed. This architecture should include space systems as well.

In part because the AF's major UAV efforts today are technically Advanced Concept Technology Demonstrators (ACTDs), the force structure requirements to operate manned systems have been largely taken "out of hide." This manpower disconnect is putting strain on the rated pilot force. UAV programs need to account for manpower requirements and ensure sufficient qualified personnel are available to operate them. This raises a second issue in force structure. While many rated skills are applicable, UAVs are operated differently than manned aircraft, and thus require other skills as well. The optimum skill set (and thus the ideal method of training for UAV operators) is not yet fully understood.

In the same vein, there is not yet consensus on which systems should be automated and which should be left to the operator. As the SAB's 1996 study noted, significant technology needs exist in human-systems interface and in autonomous operations. These fields are still poorly understood. For example, field recommendations as to how many vehicles an operator ought to operate spanned more than two orders of magnitude. A greater understanding of these issues is necessary before the AF can reasonably move ahead.

1.2.5 Macro Insights and Conclusions

In performing its research, the study developed some macro-level insights. Principal among these was the realization that persistence is an overwhelming advantage when coupled with precision. This was the key to UAV performance in Iraq and Afghanistan, and the study believes this will continue for the foreseeable future.

UAVs are not one-for-one replacements for manned platforms. There is no production cost advantage if a UAV is designed to the same standards (performance, reliability, survivability, etc…) as manned platforms. Furthermore, as long as UAVs remain low-density assets, they will continue to be expensive. There may, however, be some operations and support cost savings in using UAVs.

A number of conclusions become evident as UAV operations to date are weighed. UAVs have made considerable contributions to AF capabilities, as operations in the Balkans, Afghanistan, and Iraq have demonstrated. The greatest contributions have come when people and machines worked in concert with one another.

Properly configured with modular payloads, a small family of UAV systems operating in concert with manned platforms can accomplish a wide range of missions and achieve a wide range of effects. To achieve this end, mission management technologies will need to advance significantly. Furthermore, the AF will need to do some things differently to realize the potential of UAVs, , and it will also need to do some new things.

1.3 Discussion

1.3.1. Defining the Mission Space

At the beginning of the study, the board began by analyzing the mission space critically. It became evident that each mission contained some tasks that machines do better than people, and some that people do better than machines. For example, machines have the advantage of long endurance and are able to handle large volumes of data efficiently. People, on the other hand, are better able to make complex, cognitive decisions rapidly and to infer, interpret, and synthesize contextual information. The challenge is therefore to integrate human and machine abilities optimally to leverage the full potential of UAV capabilities.

The study conducted an analysis of the AF Task Force CONOPs. From these it derived a set of desired effects and needed capabilities. These effects and capabilities were compared to existing systems to produce a list of shortfalls. These shortfalls were then compared to potential UAV missions to determine what roles UAVs might be able to perform in the future.

These UAV roles and missions were then plotted in a two dimensional space. The bottom axis, threat risk, delineates the level of danger to the system (manned or unmanned) performing the mission. The vertical axis, mission complexity, describes the relative level of difficulty associated with accomplishment of the described mission. This difficulty can come from the number of other systems with which the mission vehicle must communicate, the complexity of the task itself, or the detail of cognitive thought required to perform the task. While some minor disagreement is possible in the specific location of any individual item, the plot on the next page represents the consensus of the members of this study and clearly delineates the significant scope of the mission space.

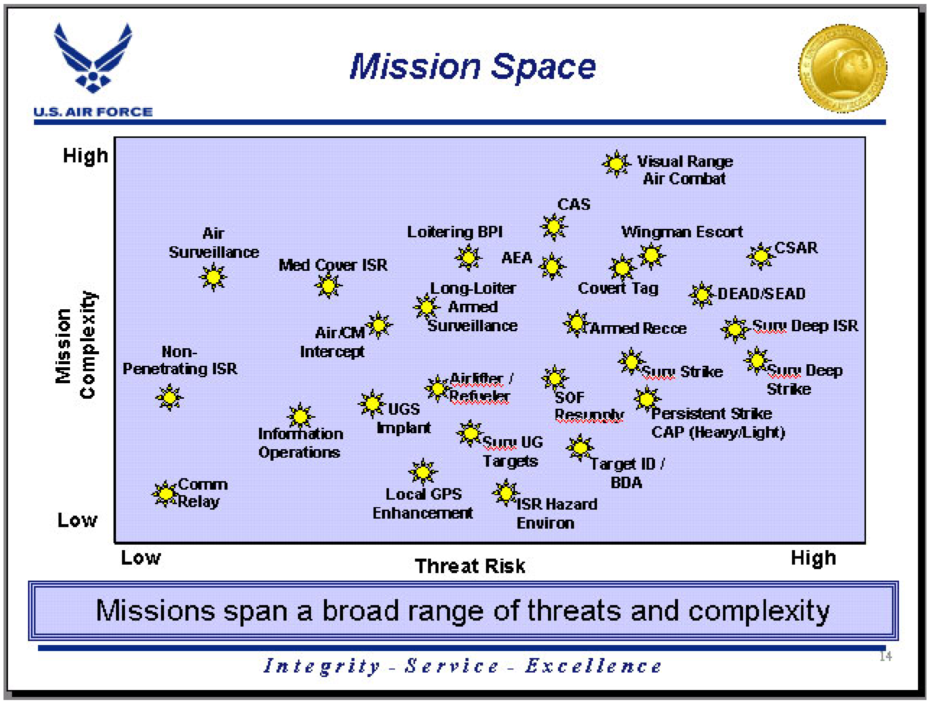

Figure 1-4. *Basic Mission Space*

1.3.2 UAV Attributes

The study examined the key attributes of unmanned vehicles. Among these are: a small forward logistics footprint, lower operations and support costs, responsiveness, attritability, global reach, reduced need for combat search and rescue, agility, and the ability to kick down the door in anti-access environments. The most important attributes were: persistence, precision, flexibility, lethality, and risk mitigation. The study viewed these attributes as complements to the capabilities and attributes of manned systems.

1.3.3 Key UAV Missions – Complementing Manned Systems

The study then took the desired effects and shortfalls identified, compared these to UAV attributes, and analyzed this combination in the context of the above-mentioned mission space. This revealed a set of ten key UAV missions that the study believed were the most important to the AF. These ten missions are:

- Deep coverage survivable ISR
- Armed reconnaissance
- Air surveillance
- Positive target identification and bomb damage assessment
- ISR of hazardous environment
- Survivable deep strike
- Airborne electronic attack
- Persistent strike combat air patrol (heavy)
- Destruction/suppression of enemy air defenses
- Airborne communications node

1.3.4 Capabilities of Current Programmed Platforms

The three current and programmed platforms (Predator, Global Hawk, and UCAV) are able to conduct the following five missions: armed reconnaissance, air surveillance, airborne electronic attack, destruction/suppression of enemy air defenses, and service as an airborne communications node. The study analyzed potential modular, missionized payloads appropriate to this set of UAVs to determine the other possible effects obtainable with these three systems. An important finding of the study was that with these modular payloads, the three currently programmed UAVs would be able to accomplish a range of missions and achieve effects across a wide range of the mission space. In fact, 16 of the 27 missions identified can be enhanced with the programmed set of UAVs. Additional missions that can be

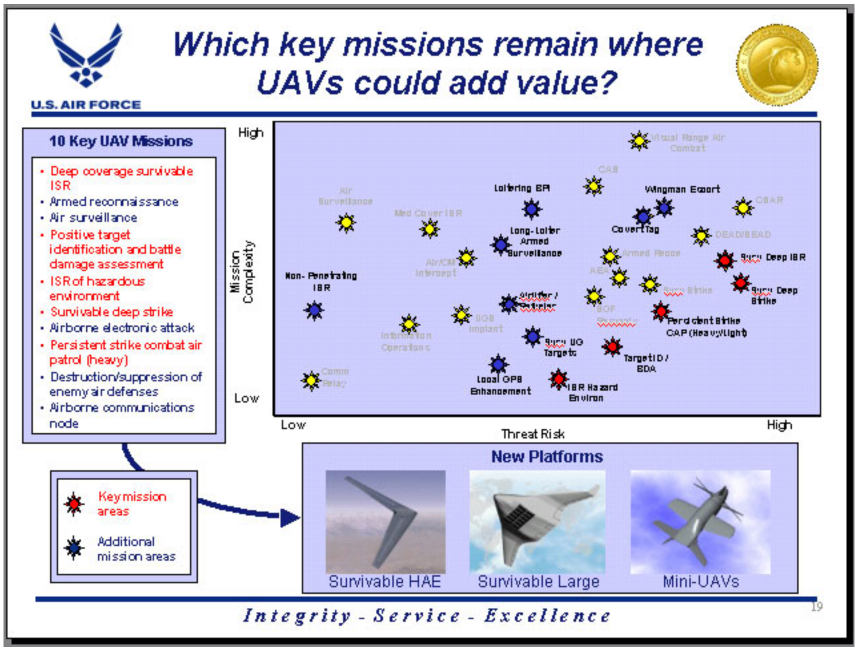

Figure 1-5. *Missions that Can Be Performed with Predator, Global Hawk, and UCAV*

accomplished or enhanced with these vehicles include medium coverage ISR, loitering boost-phase intercept of missiles, local GPS enhancement, close air support, combat search and rescue, survivable strike, persistent strike (light), and special operations resupply. It is important to emphasize that UAVs cannot totally accomplish all of these missions, but in each of these missions UAVs have attributes, such as persistence, that bring added value to mission accomplishment and achievement of desired effects.

The study then examined the missions that were not accomplished or enhanced by the three programmed unmanned systems. Among the ten key missions not met by the existing programs were: Deep coverage survivable ISR, positive target identification, bomb damage assessment, ISR in hazardous environments, survivable deep strike, and persistent strike combat air patrol (heavy).

1.3.5 Other Needed UAV Systems

To accomplish these key missions, the study determined that three new UAV systems (beyond the current program) are necessary. These systems are:

- Survivable high-altitude endurance UAV (SHAE)
- Survivable large payload UAV (SL)
- Miniature UAVs

The study then looked at the impact on the mission space assuming Predator, Global Hawk, Unmanned Combat Aerial Vehicle (UCAV), and the three aforementioned systems were procured with modular payloads appropriate to the desired missions and effects. As depicted below, this family of six UAV systems brings added value to 26 of the 27 missions in the mission space.

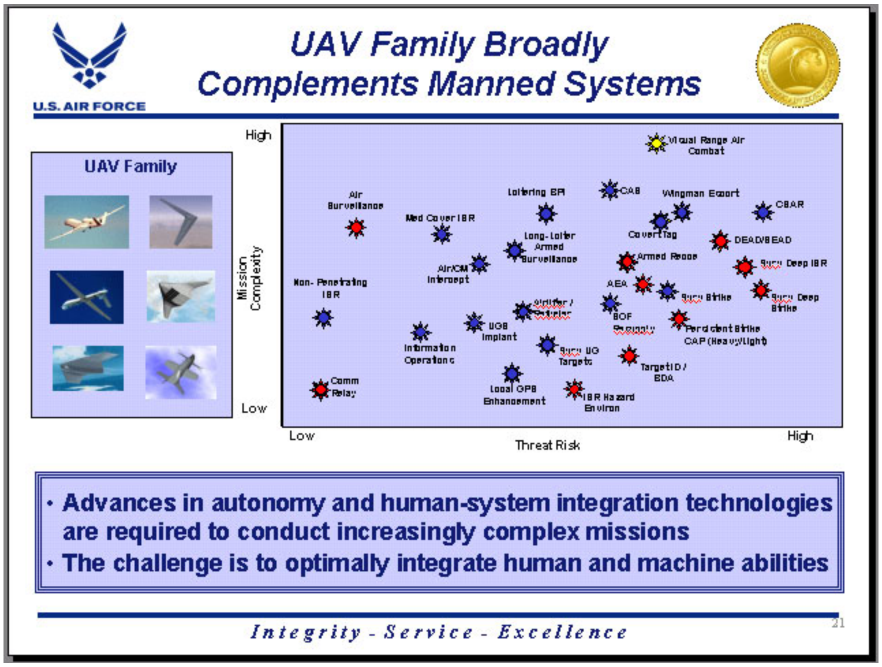

Figure 1-6. *Impact on Mission Space of Family of Six UAV Systems*

1.4 Findings

The major findings in this study can be broken into two major categories. In order to field the family of six systems and achieve the optimum contribution of UAVs to the force, the AF must: 1) Do some things differently and 2) Do some new things.

1.4.1. Do Some Things Differently

While the AF is off to a good start, the study identified several areas where there would be significant benefits in doing things differently. The first of these areas is cost reduction. In order to realize the true benefits of UAVs and to employ them efficiently and effectively, we must realize economies of scale by reducing their costs. Another area where we need to do things differently is in our systems architecture. Rather than continuing with our current paradigm of independent, stove-piped manned, unmanned, and space systems, we need to integrate all types of systems into mission architectures using a genuine system-of-systems approach. Finally, we must strive to improve the communications capabilities of UAV systems by optimizing the mix between data transfer and on-board processing.

1.4.1.1. Cost

Air vehicle cost drivers are payload weight, power, speed, altitude, maneuver, endurance, and survivability. Under current UAV low density/high demand (LD/HD) production practices, manned and unmanned vehicles will, given the same design requirements, cost about the same. Deleting typical "pilot" support and human system requirements save approximately five to ten percent, or approximately $1800 per pound.

Sensor payloads for ISR UAVs have become roughly 50 percent of the total system cost. These payloads, due to their very specialized nature and limited quantity production, result in costs of approximately $8000 per pound.

Since operations and support traditionally comprise over 50 percent of the life-cycle costs, it is important to look for savings in these areas. The potential for cost reduction is high, especially since aircrew training with UAVs may involve greater simulation and fewer actual flying sorties.

1.4.1.1.1 Acquisition Costs

There is an opportunity to reduce UAV acquisition costs through savings in both development and production.

Moving from a point design for a mission-unique vehicle and payload to a design for a family of systems should achieve development savings. Using a system of systems architecture, and some system commonality should result in lower costs. Furthermore, UAV design criteria can be changed to eliminate traditional manned aircraft requirements in areas as canopy resistance to bird strike, fan blade containment and maneuvering margins. Additional development savings may be possible in testing by eliminating or reducing live fire testing, and reducing static and handling qualities testing.

If UAVs are acquired with modularity and a family of systems in mind, then payloads can be inserted rather than built as part of the system. This allows the achievement of economies of scale that could reduce payload integration costs. By developing a "plug and play" architecture that supports affordable modular payload integration, the AF can gain great leverage across the family of platforms and can also take advantage of the potential benefits of spiral development in the design of mission-independent subsystems. This modular approach to a family of systems can take advantage of spiral development in payloads and sensors, allowing the technology within this family of systems to keep pace with advances like those due to Moore's Law.

1.4.1.1.2 Operations and Support Costs

While there are limited data to support precise cost estimates and many lessons remain to be learned, this study concluded that there are likely some savings achievable in operations and mission support costs over the life cycle of UAV systems.

Tailored training and operator proficiency requirements offer the greatest opportunity for cost savings. High fidelity simulation trainers can be used much more extensively in UAV crew training than in manned systems training, thereby reducing vehicle use costs. While there would be a need to participate in exercises and mixed-use training with other systems, the vehicles would be used less, and as a result the maintenance costs could also be less than those of manned systems.

One challenge to achieving operations cost reduction is the need to improve human-systems interfaces to reduce the accident rate of UAVs. Current data shows that 59 percent of Pioneer and 76 percent of Predator accidents are attributed, at least in part, to human factors-related issues, with 62 percent of Predator mishaps caused, at least in part, by the human-systems interface. Improvement in mission management technologies will allow for better reliability, improved operator situational awareness, and rapid evolution toward multi-platform control. The increased vehicle-to-operator ratio afforded by well-designed autonomy and human-system interface technologies means fewer operators and lower costs. When combined with reachback, which reduces the logistics costs of deployment, this evolution has the potential for further savings in Operations and Support (O&S) costs over the life of the family of systems.

Finally, UAVs require reduced support packages. The fact that these are uninhabited vehicles means there is no need for Combat Search and Rescue (CSAR) or escort packages. As a result, UAV missions may be less expensive than those conducted by manned aircraft.

1.4.1.2 UAV Systems of Systems Architecture

In order to achieve the most efficient employment of all vehicle systems (manned, unmanned, and space), they must all be incorporated into a single, integrated architecture: a system-of-systems. To achieve this, the UAV architecture must be consistent with existing architecture roadmaps. This will support interoperability among the systems, as well as tactical and operational control. Also, integrating open systems and interfaces for both payloads and mission management will achieve common mission management across all platforms, while remaining consistent with the reference architectures. The UAV communication network must be integrated with the data communications architecture and the Transformational Communications System (TCS) so that a rapid communication network configuration can be realized. Finally, a common mission management framework is needed which includes consistent human-machine interfaces across all systems while optimizing the assignment of UAV autonomy levels. A common architecture for UAVs, manned systems, and space systems will ensure the AF realizes their complementary capabilities while simultaneously leveraging the potential of NCO.

1.4.1.3 Communications Bandwidth

Communications became a major concern during operational use of a single aircraft sortie could saturate most of the available operational communications links. The UAV vehicle command and control takes a very small portion of the required data rate.

Providing UAVs with on-board processing capability, as would likely be required for weapons employment missions, would reduce the data transmission needs significantly. However, in order to maintain situational awareness with on-board processing, data must be communicated to and processed by the UAV, and the UAV must transmit its status and environment to the off-board control station. Additionally, off-board users may need the on-board data, thus negating some on-board processing benefits. Further analysis is still required to determine the optimum mix of on-board and off-board processing.

1.4.2 Do Some New Things

In addition to doing the above things a little differently, the AF will need to do some new things as well.

1.4.2.1. Mission Management

The vision of multiple UAVs operating in the battlespace alongside aircraft and in conjunction with space assets places great stress on mission management-related technologies. These technologies are the human-systems interface enabling operator control and operator situational awareness and the suite of technologies that enable autonomous operations. Additional research will be required to develop these interfaces and autonomous systems to best enable flight in close proximity to manned systems, avoid crashes, and communicate with all other members in the net-centric operations space.

As systems develop greater autonomy, dynamic planning and replanning cycles will speed up and operators will need to understand the vehicle's level of autonomy, trust it appropriately, and dynamically shift their control of the vehicle in response to these faster cycles. Methods of positive control of weapons will also need to be determined.

Figure 1-8. *Future Vision Stresses Mission Management*

To achieve effective mission management for future operations several key technology enablers must be addressed. Operator situational awareness needs to be enhanced. To do this, displays to support better awareness of the state of the vehicle within the context of its environment and mission need to be developed. These displays will need to compensate for losses in sensory information and the communications lag times associated with UAVs, especially in conjunction with reachback operations. As the operator to vehicle ratio increases through greater autonomy, display technologies to support "global" situational awareness across multiple vehicles and across a larger segment of the battlespace will be needed to help operators allocate attention and solve problems across the system constellation.

A key requirement is to develop better ways to integrate human operators with autonomous systems. The current practice of automating what you can and leaving the rest to the human does not work, and there are thirty years of research to proves it. The appropriate levels of task automation to keep the operator in the loop and provide effective human/system performance need to be developed. Developing methods for supporting human understanding in the face of rapid shifts in the level of automation need to be supported, as little research exists on how best to pass control back and forth from operator to automation over time. Methods also need to be developed to help operators understand predictively what automated systems will do under operational circumstances.

Emphasis must be placed on developing autonomy to enable lower operator to vehicle ratios and to reduce bandwidth requirements to support larger numbers of UAVs. Among the key technology developments that are needed are machine-based perception and integration to form machine situational awareness, dynamic replanning and handling of situation uncertainties (vice the tightly scripted methods used today), vehicle health management (to include diagnosing of multiple concurrent faults), and multi-vehicle coordination and cooperation.

Addressing these key issues in mission management will not only allow for the vision of using UAVs for a much wider variety of missions, but will have the added benefit of providing better support for the wider battlespace management problem. In doing this, methods to integrate UAVS with manned aircraft and the air operations centers need to be addressed. To accomplish this, a better understanding of how to best combine manned and unmanned assets for accomplishment of different mission objectives is needed.

All of these issues still require substantial developmental research.

Figure 1-9. *Mission Management Technology Development Testbed*

The creation of a dedicated UAV mission management testbed is essential to conduct this research in mission management technology. This test bed would allow for an objective evaluation of the effectiveness of new technologies and concepts, and enable integration of those concepts to form a mission management system that can support operations in a wide variety of situations and missions.

A feature of the testbed will be connections and interoperability with lab facilities within the Air Force Research Laboratory (AFRL), the AF Battlelabs and industry. This will allow for rapid development and prototyping of independent mission management technologies that can then feed and transition to UAV programs. This testbed may be able to serve as part of a distributed missions operation center to enable the evolution of CONOPs for mixed manned/unmanned system operations.

1.4.2.2 New Platform Technologies

There are several new platform technologies needed to enable new UAV systems development.

1.4.2.2.1 Propulsion

Specifically, future UAV systems need engines with reduced specific fuel consumption, reduced engine weight, and lower cost. High power extraction engines and systems for electrical energy storage also need to be developed. These engines need to be designed for durability when operated in UAV-specific duty cycles—long-duration missions with relatively few shutdown cycles.

1.4.2.2.4 Payloads

Enabling the envisioned family of UAV systems to enhance or cover the above-named missions will require several advances to be made to enable modular payloads appropriate to this larger UAV mission set.

New sensor suites that are substantially lower in cost, size, weight, and power must be developed.

Advancements are also needed in communications to support net-centric operations. These include establishing a network architecture, low-cost miniaturized terminals for connectivity to the new transformational communications architecture, and standardized communications relay packages for use on the UAV systems.

1.4.3 New UAV Concepts

The study recommended two novel applications of new UAV concepts to demonstrate capabilities that may be realized by achieving advancements in the above technologies.

1.4.3.1 Deep ISR with Deep Strike

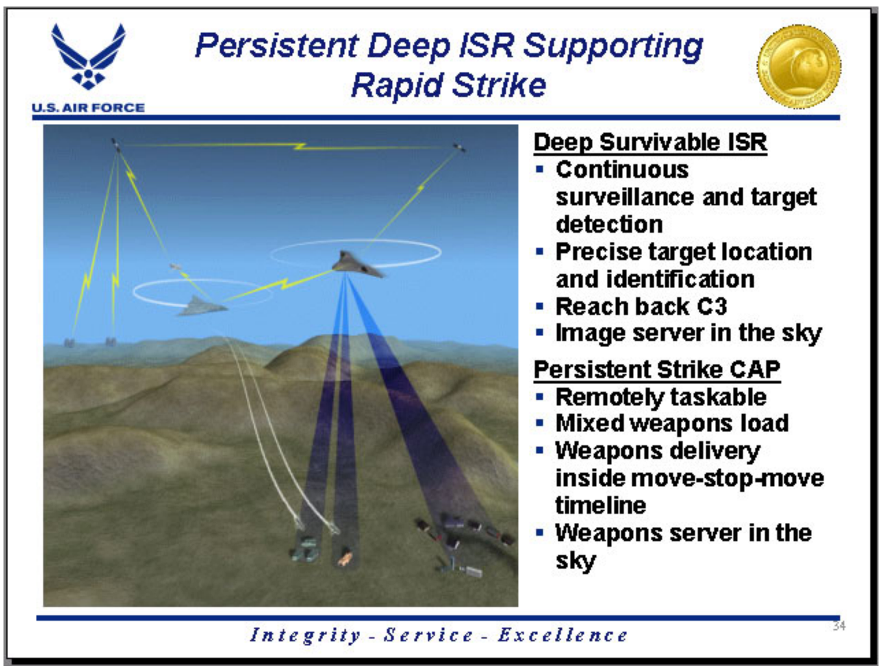

Figure 1-10. *Persistent Deep ISR Supporting Rapid Strike Application*

This first new application uses two new members of the recommended family of UAV systems working together to enable a broader range of effects on the battlefield. In this concept, the Deep Survivable ISR system would penetrate adversary airspace and provide continuous surveillance over critical areas of the battlefield. It would locate targets precisely and transmit this data back through the communications architecture. The Persistent Strike Combat Air Patrol (CAP) system, would then be taskable from reachback locations, and would discharge the appropriate weapons from its mix of on-board armaments to enable rapid target destruction. This would put all adversary systems at risk, including those able to move rapidly from one location to another.

1.4.4 UAV Demonstrations

In the conduct of this study, it became clear that UAV capability demonstrations have helped convince the warfighter of the value of these systems. To continue this progress, this study recommends two near-term demonstrations and one mid-term demonstration of UAV systems capability.

1.4.4.1 Flexible ISR – Near Term

This demonstration will integrate internet protocol-based command, control, and communications and dynamic image serving. The UAV system will demonstrate dynamic flight path replanning and sensor retasking, along with modular communications and sensor payload integration.

1.4.4.2 Multiple Target Engagement – Near Term

This demonstration will display the UAV system's ability to automatically cue and track targets, as well as autonomous tasking of mini-UAVs for close engagement of the multiple target set. This demonstration will also showcase an improved ground station human-computer interface.

1.4.4.3 Deep Suppression of Enemy Air Defenses (SEAD) – Mid Term

This demonstration will showcase next-generation enhancements integrated into the system and platform. The UAV will demonstrate manned-unmanned cooperative mission execution, to include air refueling of the UAV and weapons integration.

1.5 Recommendations

The following are this study's six top-level recommendations to the AF for the pursuit of UAV technology.

1. Continue to procure Global Hawk, Predator, and UCAV, incorporating new capabilities through spiral development using open system architectures and modular payloads

2. Begin research and Analysis of Alternatives (AoA) on the Survivable High Altitude Endurance (SHAE) and Survivable Large (SL) systems

3. Develop a cross-cutting research initiative in Autonomy and H-SI mission management technologies; integrate using a testbed environment

4. Develop an architecture and the associated standards that enable the integration of UAVs with manned and space systems

5. Initiate innovative research into small UAV platforms and the enabling technologies

6. Conduct near- and mid-term demonstrations of specific capabilities to integrate unmanned systems into the force structure

In summary, the AF Scientific Advisory Board 2003 Summer Study is very supportive of improved UAV capabilities and strongly encourages acceleration of Air Force acquisition activities. UAVs have already emerged as working elements of the Aerospace Force.

A family of UAVs should be developed, based on upgrading of existing systems, development of planned systems and preparation of the technology base for a few new systems that offer advanced mission capabilities. These systems will contribute to the manned force by adding persistence and reducing "detect and engage" timelines. New missions, including deep survivable ISR and Strike, and a number of mini-UAV applications must be supported.

Research activity should focus on improvements in mission management technologies, such as autonomy and human-system interfaces. Innovative technology programs focused on small UAV systems should also be initiated. These efforts will provide critical leverage for cost-effective accomplishment of key missions. Research in autonomy and human-system interface technologies should be supported. Architectures being developed for various Air Force CONOPS should integrate UAVs and eliminate the seams between the manned and unmanned segments of the force.

The development and deployment of Air Force UAVs will complement the manned and space forces by incorporating the advantages of unmanned systems to make the 21^{st} Century Aerospace Force much more capable.

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Chapter 2 MISSION CONCEPTS

2.1 Introduction

2.1.1 Panel Mission

The Mission Concepts Panel was formed to assess the operational and technical elements of AF roles as they apply to air missions suited to the employment of UAV's. The specific mission of the Panel was to derive the key UAV missions and requirements based on desired capabilities and effects and then translate those requirements to needed UAV characteristics and technologies. The Panel has defined a long-term vision, established new UAV vehicle needs, and proposed a series of capability demonstrations. Those demonstrations form the basis for UAV system evolution and fielding.

2.1.2 Approach

The Panel based the development of mission concepts on the evolving doctrine of "desired effects." Furthermore, consideration was given to the roles best performed by humans and the allocation of these "human-best" functions to a safe location (reachback and standoff). In addition to consideration of potentially beneficial unmanned alternatives to existing missions, the panel also defined new or modified missions that contribute to achievement of desired effects and identified missions that are not currently performed by manned aircraft. These considerations led to the panel's development of a set of UAV platforms, defined by the specific UAV attributes. The panel determined that modular payloads are a necessity for a platform-based approach, though it addressed this only superficially, as the SAB has recently completed independent studies in these areas. Figure 2-1 depicts the panel approach.

2.1.3 Vision

UAVs will complement USAF manned and unmanned systems by contributing unmatched battlespace persistence, situational awareness, rapid weapon delivery, operational flexibility, precision, survivability, and logistical supportability.

Improvements in microprocessing, data compression, communications and electronics will enable UAVs to do more of the missions that manned aircraft now perform for the Air Force. Indeed, there will be many new and unusual missions never yet undertaken with manned aircraft but suitable for UAVs. The UAV's enhanced continuity and persistence dictate that they will take their place in the AF inventory to complement and leverage manned air and space forces. UAVs will hold adversaries continuously at risk through persistence and precision.

Similar rapid advances in sensor and weapon technologies will further facilitate the UAV revolution through cost and weight reductions, while improving performance and reliability. These extremely rapid sensor and weapon technology advances will also create more effective products for the same investment in energy and mass. For purposes of endurance and effectiveness, fuel and payloads can be interchanged as the mission requires. Hence only a limited, optimized number of multifunctional UAV platforms with modular payloads need be developed, adapted, and deployed to accomplish a wide range of missions. The adoption of this approach will lower costs as higher numbers of vehicles are produced, thereby resulting in lower life cycle costs of UAVs relative to manned aircraft.

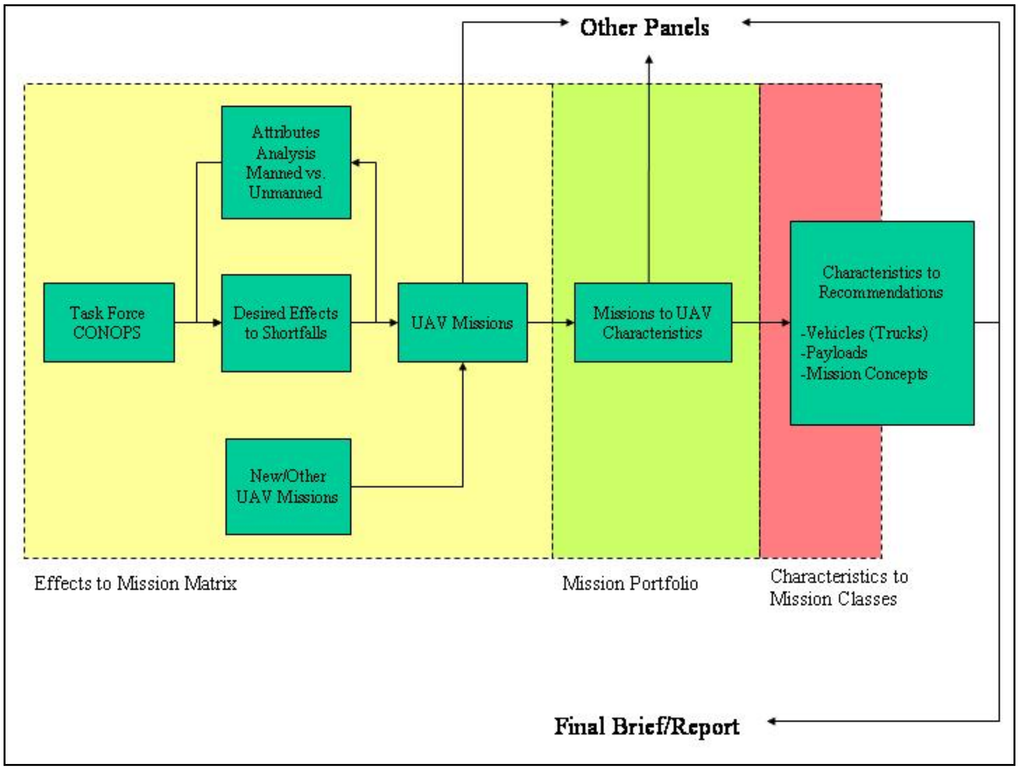

Figure 2-1. *The Mission Concepts Panel Process*

2.2 Discussion

2.2.1 CONOPS to Missions to Capabilities to Platforms

Evolving Air Force doctrine is transitioning from a platform-based garrison force to a capabilities-based expeditionary force. No longer platform-centric (F-15, E-3A, etc.), the Air Force is committed to using desired effects as a basis for all future operational, programming and budget decisions. Seven CONOPS, listed below, define the essential elements and capabilities required to accomplish future missions. These CONOPS cover the complete spectrum of warfighting capabilities (deep strike, information, urban and psychological operations, etc.), and will enable the Air Force to tailor forces (expeditionary wings, groups or squadrons) from existing Air Expeditionary Forces (AEFs) to meet the Combatant Commander’s requirements. They are:

- Global Strike (GS)
- Global Response (GR)
- Space and Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (Space and C4ISR)

- Global Mobility (GM)
- Nuclear response (NR)
- The Homeland Security (HLS)
- Integration

From these CONOPS, the panel identified shortfalls in our current ability to accomplish desired affects. The panel then derived potential missions that UAVs could execute to attain these desired effects. UAV characteristics were then assigned for each UAV mission concept. These characteristics included factors such as range, payload, speed and survivability requirements. The study identified a total of 26 missions that could be accomplished by UAVs that could assist in overcoming many shortfalls to achieving the CONOPS desired effects.

2.2.2 New/Key UAV Missions

The process of identifying missions for which UAV systems appear advantageous resulted in the selection of 26 missions. The Panel chose the ten most important and was able to achieve these missions with a set of six classes of UAVs, three of which already exist or are in development. The panel developed operational descriptions for each mission, identified the associated UAV platform and payload characteristics, and determined technology shortfalls.

The missions were parsed and prioritized into ISR, Strike, and Support macro-mission categories. For ISR and Strike categories, the general goal of holding the enemy at risk through *persistence* while aggressively shrinking the *detect-to-engage* timelines was emphasized. The support category captured those missions that are naturally suited to UAVs due to long mission duration or instances where it is imprudent to expose the crew of a manned vehicle. The ten highest priority missions are described below.

2.2.3 Mission Capabilities

2.2.3.1 Deep Coverage Persistent Survivable ISR

This mission features long range, long time on station and broadband communications connectivity to accommodate its communications-dependent ISR payload. It operates deep in enemy territory and loiters for 24+ hours to gather multi-INT data. Orbit(s) are pre-planned, but can be readily re-tasked as necessary. Some processing is done onboard for direct downlink to the theater users. All other data communications are uplinked to satellite communications (SATCOM) via RF or laser links. This UAV also has a server for access by small ground units and vehicles, other attack UAVs, command and control (C2) and other manned aircraft to provide processed information to a limited area. This UAV can relay attack air tasking from C2 centers and aircraft to attack aircraft, and can provide precision target location and identification.

2.2.3.2 Survivable Deep Strike (Survivable Large)

This UAV is self-deployable to the theater. Suitable operating bases can be very distant, but increases in transit time will reduce loiter. The mission is run autonomously, but operational control can be taken by a mission control element (MCE) for immediate re-planning to strike pop-up threats or targets. Target set will be high priority, heavily defended, and prompt attack targets and can evolve to include OCA capabilities.

2.2.3.3 Airborne Electronic Attack (UCAV+)

This system can self-deploy to theater. A variant of a strike UAV, it will incorporate active and passive Electronic Support Measures (ESM)/Electronic Countermeasures (ECM) modules and anti-radiation weapons. Operating in conjunction with manned aircraft, it will incorporate broadband connectivity to another manned air platform or the MCE where decisions will be made concerning sensor and weapon employment. Passive operations will be largely autonomous while active operations will require substantial human intervention.

2.2.3.4 Communications Relay (High) (Global Hawk+)

This UAV is characterized by palletized modular broadband communications and gateway/servers with RF and laser connectivity. It is capable of servicing ground networks, small units and other disadvantaged users. It has very long on-station loiter capability; it depends on altitude and standoff for defense. It acts as a server/router for IP-based network and can serve as relay for networks of unattended ground sensors (UGS), CSAR radio transmissions, and blue force tracking. Communications packages will be Joint Tactical Radio System (JTRS)-based where appropriate.

2.2.3.5 Persistent Strike CAP (Heavy) (Very Large)

This UAV self-deploys to theater and can loiter at long ranges for extended periods. Operating from high altitude, UAV is accessible from multiple ground, air and space platforms. UAV can operate autonomously against pre-planned targets, or a ground (MCE) or airborne (E-3A, MC-2A) controllers can also employ weapons. Controllers can pass target coordinates and/or guidance to the weapon onboard the UAV and can call for UAV weapon launch. The UAV adds persistence and weapons quantity to the Strike Coordinating Armed Recce (SCAR) role. The mission could also include a Defensive Counter Air (DCA) role with the addition of air-to-air defensive weapons.

2.2.3.6 DEAD/SEAD (UCAV)

This UAV deploys from a base in the theater and follows preplanned or controlled routing to attack pre-assigned or pop-up ground air defense targets. It is stealthy and maneuverable to be survivable in a high-threat environment. The platform will have air-to-ground search and track sensor suite [RF detection, radar, and/or electroptical (EO)/infrared (IR)] and weapons. Aircraft will be equipped to operate as a single aircraft or in a multi-ship formation. The UAV can be managed and tasked from manned aircraft or MCE to investigate sites identified or detected by other UAV's or manned aircraft in the region.

2.2.3.7 Armed Recce (UCAV/Predator+)

MCE launches and directs UAV to target area where a ground or airborne forward air controller (FAC) takes over operational control, receives imagery, designates targets, selects weapons, authorizes release, and performs battle damage assessment (BDA), serving in a SCAR-like role. Weapons delivery can be augmented from "very large" UAV, bombers, gunships, or other manned strike platforms.

2.2.3.8 Air Surveillance (Global Hawk+)

This platform is a very long-loiter survivable UAV with 360 degree air surveillance and multiple communications (RF and laser) paths to command and control aircraft or ground centers associated with airspace control and warning, as well as air battle management. The UAV has large airborne radar and an identification friend, foe or neutral (IFFN) system to identify and track all flying objects in the region. It provides early warning and positive air identification (ID) to friendly airborne assets and controls counter air operations. It can loiter at high altitude deep in hostile territory or around the US border to provide constant surveillance picture. Has the capability to serve manned air interceptors and air superiority aircraft data via fighter data links.

2.2.3.9 Mini-Investigator/ID and BDA (TBD)

This very small UAV will operate singly or as part of a larger formation. It can also operate in a pre-planned mode, under the direction of a manned airborne platform, or from the MCE. UAVs small size and low altitude mission profile will make it very difficult to detect either visually or by radar/optical sensors. Primary missions will be employment of optical/small radar sensors to gain precision ISR for localized ID or post-strike BDA. UAV would be capable, through modular swap-out, to incorporate specialized chemical/spectral/audio sensors for select missions. Communications will be line of sight to MCE, airborne command platform or communications relay sufficient for mission support and downlink of critical mission data.

2.2.3.10 Hazardous Environment ISR (TBD)

This very small UAV is kin to the mini-investigator, but is specially designed to operate in a hazardous environment [such as chemical, biological, or radiological (CBR)]. Given the sensitivity of collected mission data and potential for loss, direct downlink of data as it is collected will be the norm. The UAV will incorporate communications links suitable to mission control and sensor data transfer either to an air platform, direct to the MCE, or via theater communications relay. Survivability will be a product of small size and low altitude mission profile.

2.2.4 Platforms Concept

Analysis of the desired UAV characteristics indicated that the performance required to complete these missions was such that the following limited number of representative classes of platforms could perform most, if not all, of the currently feasible missions:

- Survivable High Altitude Endurance (SHAE)
- High Altitude Endurance (HAE)
- Survivable Medium Altitude Endurance (SMAE)
- Medium Altitude Endurance (MAE)
- Mini
- Survivable Large (SL)
- High Altitude Airship

An eighth class could possibly be added that represents special designs satisfying unique requirements at the small/micro end of the UAV platforms spectrum, particularly if they are highly attritable and/or vertical takeoff and landing (VTOL) platforms that may be developed by other services.

Review of the current UAV programs' plans and studies revealed a general concern that the cost and complexity of UAVs was increasingly to comparable with those of manned platforms. The current costs of UAV aircraft are being driven by unconstrained requirements growth, a conventional manned aircraft development/testing approach, low production rates, large payload costs and a lack of multi-year contracts. The panel concluded that the most appropriate solution to this problem was to define a limited number of platforms that would meet the general mission needs without making them mission-specific. This concept would lend itself to larger quantity production of the platforms to achieve cost reductions. The advances in miniaturization, processing, communication, weapons, and aperture designs will make platforms more effective without structural alterations. As some missions require stealth for survivability and persistence, while others do not, it is recommended that UAV development proceed along the lines of platform class, rather than mission-specific configurations.

2.2.5 Payloads

The realization of a state where UAVs operate over the battlefield to find, fix, track, target, engage, and assess targets will depend upon the integration with current and future generations of weapons, sensors, and specialized payloads. The AF must develop new payloads that are inexpensive, “plug and play”, modular, and miniaturized to fulfill the promise of UAVs.

UAVs properly equipped with these types of sophisticated sensor suites can fill intelligence gaps where stand-off and space sensors lack coverage and persistence. Other UAVs can navigate into close proximity of areas of interest to conduct localized, penetrating searches. UAVs will also need weapons that can capitalize on the collected sensor information. UAV weapons must be small, lightweight, and cheap [such as the Small Diameter Bomb (SDB)]. Other non-traditional and developing weapons may be more effectively paired with UAVs. Similarly, evolving information operations payloads may be delivered best by UAVs. This host of revolutionary payloads expands mission effects and provides greater standoff and reachback.

2.2.5.1 Payload requirements

Historically, sensor cost has been a major expense for manned aircraft and early indications suggest the trend is the same for UAVs. Reduced UAV cost will be a critical factor in the perpetuation of UAVs. UAVs are expected to conduct high risk and dangerous operations due to their attritability; however, without cheaper components for the UAV, the prodigious cost will preclude this attritability. The panel found that payload is the primary hardware cost driver for a UAV. Sensor systems comprise approximately 45% of a UAVs fly-away cost (47% for Global Hawk, 40% for Predator A, and 46% for Predator B). To drive this cost ratio down and meet future payload requirements a new generation of sensors and specialized payloads must be created.

2.5.2.2 Sensors

UAVs drive the need for development of substantially lighter-weight multi-function RF sensors so that platform endurance and range can be significantly increased while cost can be reduced. Integrating multiple RF functions previously performed by multiple multi-function sensors into a single sensor suite enables significant weight and cost reduction. An open architecture for UAVs will allow insertion of latest generation hardware and software upgrades by modular and scaleable methods without regression testing. Modular payloads can enable a single UAV platform to perform multiple missions.

Since UAVs are expected to be deployed to perform more dangerous missions than manned platforms, they are expected to experience higher loss rates. The sensor systems on UAVs must have significantly lower costs to achieve desired UAV affordability. Key RF technology enablers to achieve significant weight, volume and cost reduction while improving reliability are: wideband digital receivers, digital beam forming, adaptive processing, and automatic target cueing/recognition to reduce operator workload.

Though UAV losses are more acceptable, the vehicles are absolutely not expendable; survivability is a key asset in the viability of UAVs.

EO/IR sensors are evolving into multi-spectral sensors to greatly enhance target detection, reduce false alarms and improve target identification.

2.2.5.3 Weapons

Precision standoff weaponry has transformed air power. The pace of continued weapon evolution is a very important consideration in defining the consequent utilization of future UAVs. It is essential to design future aircraft, manned or unmanned, with consideration for the desired future weapon effects. With this in mind, the panel reviewed existing weapons and current roadmaps for future weapon development. The panel then considered potential weapon developments over the next 1 to 6 years that would most dramatically impact UAV mission effectiveness.

This analysis identified six cogent areas for UAV weapons development. The first is the development of a family of W*inged Glide Bombs* that are inexpensive, standoff precision glide bombs with various warhead sizes that incorporate low cost wing kits. Second, develop a family of *Powered Glide Bombs* with low cost jet engines to increase the standoff range beyond 100 miles. Third, development of a *Beyond Visual Range Air-to-Air Missile* (BVRAAM) to make UAVs survivable against a competent enemy air force; the necessary technology and the ability to create a BVRAAM weapon have already been proven. It consequently represents a low risk development effort. *Low Cost, Long Range Missiles* are the fourth weapon domain; they could deliver a 120lb warhead at ranges greater than 600nm in a low cost weapon. Variations on this theme could result in jet powered missiles that could carry warheads up to 500lbs from 200-800 miles at extremely low cost. A fifth UAV-enabling weapon class is *SEAD/DEAD Sensors and Weapons* – ongoing programs have successfully demonstrated precision emitters and are planned to be available in UCAV and UCAR, as well as on several manned aircraft. This technology enables rapid and precise location of *any* emitter and the development of a supersonic, long-range missile tailored to attack rapidly and destroy such emitters before they can move.

Development of these weapon classes would produce: 1) longer standoff ranges and more targets serviced by a family of smaller warheads, 2) a significant increase in survivability through use of a BVRAAM weapon to counter enemy aircraft, 3) a dramatic increase in SEAD effectiveness by rapid location and destruction of any emitter, & 4) a time-critical strike capability with a very high speed missile.

2.2.5.4 Other Payloads

The range of additional services currently envisioned for UAVs includes communication relays, psychological operations, battlefield delivery, and threat warning. Communication services will aid battlefield operations by expanding theater communications beyond line-of-sight (BLOS) through communication relays, establishing airborne area networks, and increasing capability through employment of laser communications. Information operations entail UAVs operating near the target area and require specialized payloads to accomplish information and psychological operations for broadcasting radio and TV transmitters covering HF, VHF, and UHF bands. Battlefield delivery is a potential mission for UAVs to transport items such as unattended ground sensors, mini-UAVs, weather dropsondes, and specialized container delivery systems for troop resupply. Detection and warning payloads can be carried on the UAV; a number of systems such as missile launch and approach detection systems, radar warning receivers, wideband radar warning systems, laser warning, and battlefield ordnance avoidance can enhance the survivability of both the UAV and manned aircraft operating in the area. The UAV can also provide GPS services as an airborne pseudolite. Mapping services may also be conducted through the use of LIDAR and other payload technologies.

2.2.6 Connectivity

Communications networks are an essential enabling technology for UAVs. Advances are required that will permit layers of self-forming, self-healing, secure, unjammable networks with sufficient bandwidth. There are minimal technical obstacles to achieving such a layered network; the real challenge is an accurate projection of the number of future aircraft, UAVs and weapon nodes to be serviced, the types of sensors and signal processing at each node, and the consequent desired data flows between nodes, portals and gateways. Another significant challenge is to ensure interface commonality of all program nodes in this future network. Under the TCA, current systems will be replaced with Wideband Gapfiller Satellites (WGS), the Mobile User Objective System (MUOS) for narrowband communications, and the Advanced Extremely High Frequency (AEHF) system in the protected arena.

Layers of this future network can effectively be divided into tactical and strategic layered networks. At the tactical level, UAVs, manned aircraft, and weapons will all be data-exchanging nodes in a very dynamic information grid. Some UAVs and loiter weapons will serve as communication relay nodes for over-the-horizon deployments, connecting the entire tactical network to surface and space-based portals. Theater-level networks will also consist of manned aircraft, UAVs, and weapon nodes, and will require high altitude UAV communication relay nodes to connect surface and space-based portals. The TOC is chartered with assuring the development of the space based layers to assure interoperability with the theater and tactical-level layers of the communications grid.

With the anticipated increases in the use of UAVs for military operations, there is a need for a network to allow these agents to communicate. An “internet in the sky” would enable distributed functionality such as mission planning and replanning, route planning, cooperative and collaborative mission execution, distributed decision making, and distributed real-time control. UAVs with capabilities similar to those of today’s manned aircraft can become nodes (hubs or routers) in a multihop internet in the sky. Small or less capable UAVs could form the edges of the airborne network. Such an airborne internet would allow the huge bandwidths and very low latencies needed to support UAVs for the set of envisioned missions.

2.2.7 System Demonstrations

Table 2-1 provides an overview of the proposed UAV classes, missions, associated characteristics, advantages, and technologies. In the *near term*, the Air Force should focus on a number of demonstrations to test and advance UAVs in its warfighting concepts of operations. The following five demonstrations have been identified as having high payoff:

Suppression of Enemy Air Defenses (SEAD): UAVs are well suited for SEAD operations as their attritability is a desirable attribute for this highly dangerous mission; it is mission area of national priority.

Communication Relay: UAVs could address the expected increases in demand for bandwidth and weapon mobility via a high altitude, long endurance air vehicle or airship equipped with radio payloads. The persistence HAE UAVs have combined with the “dullness” of the mission to suit the Communication Relay Mission ideally for UAVs.

Small Team Re-supply: UAVs can provide small team resupply through high and low altitude delivery, integrating a UAV configured with a specialized container delivery system, precision navigation, and communications.

Hen and chicks: Demonstrate the teaming of standoff manned ISR and battle management assets with multiple UAVs conducting ISR missions over the denied area. Capitalize on the UAV’s ability to penetrate the enemy’s airspace and operate in areas the “Mothership” cannot view because of terrain masking or sensor range limitations.

UAV Sensor-to-Weapon: Develop and demonstrate the capability for precision engagement of fixed and mobile time-sensitive targets using a single UAV to update precision standoff GPS weapons en route to the target. UAVs can provide greater flexibility in our targeting and weapons pairing options through their deployment and configuration in the ISR mission role.

In the **longer term**, the Air Force should focus on a few technically complex demonstrations advancing UAVs to aid in long range operations. The Mission Concepts panel recommends the following three areas for demonstration:

Unmanned Net-centric Constellation: Conduct a demonstration that exploits the operational synergies of large numbers and types of UAVs operating over denied areas and collaborating to conduct a variety of missions including *persistent surveillance, broad area search, target identification and designation for weapon employment, strike, battle damage assessment, and force protection.*

Deep Strike Operations: This demonstration will show UAVs in supporting roles for penetrating manned strike aircraft as well as performing strike operations in unmanned teams or solo operations. Key technologies to be demonstrated will include stealth, precision, advanced command and control, air vehicle range, sensor payloads, and weapons delivery.

UAV Air Refueling: As the definition of "long range strike operations" continues to be refined, and the desire for the persistent UAV missions (ISR, Communication Relay, etc.) to remain aloft longer increases, air refueling capabilities become a valid requirement. Demonstrate the ability for a UAV to refuel from a manned tanker aircraft.

2.3 Findings

After extensive interviews, briefings, and visits to industry and Air Force installations, coupled with the receipt of inputs concerning UAV development in the other armed services, the Panel has found that there is clear evidence of UAV utility. That utility was clearly demonstrated with great success in both Operations EnduringFreedom and Iraqi Freedom. The panel also reviewed AF CONOPS and their desired effects. On the basis of this fact-finding, the panel identified capability gaps that can best be addressed by UAVs.

UAV Successes: There are excellent examples of Air Force successes and ingenuity in the application of UAVs to military roles. The UAV Battlelab approach, with simplicity, autonomy and innovation, is commended for its goals and accomplishments in demonstrating new capabilities (e.g. FAC, SEAD). AFSOC is also commended for innovation, enthusiasm and *results* in the application of UAVs for combat missions (e.g. Predator to Gunship feed). Hellfire Predator was greatly facilitated by the Big Safari Program. The AFRL Munitions Directorate (AFRL/MN) is commended for its innovative work in micro-UAVs and integration of precision weapons with UAVs.

UAV Platforms and Payloads: Potential UAV payload technology is advancing independently, simultaneously and faster than platform development. Current UAV system development, however, is proceeding with platform and payload being in lockstep. The panel expects that this will constrain long-term UAV progress and proposes the adoption of a family of platform UAVs, with payload modularity, as a potential solution to achieving a range of missions without the need of "inventing" new UAVs for each possible mission. Predator, Predator B, and Global Hawk are clear current members of the family. UCAV is a strong candidate.

UAV Costs: The panel found UAV cost estimates irreconcilable and determined that existing cost models and analyses have substantial biasing assumptions and are of dubious accuracy. Rather than use those estimates, the panel instead chose to identify potential cost drivers and savings for UAVs. One cost driver, emphasized in the SAB's 1996 study on UAVs, is that unconstrained requirements growth is the greatest threat to program viability and cost effectiveness. It is a continuing problem for UAV development today, just as it is for manned aircraft. Furthermore, UAVs are currently acquired through short-term contracts with low rates of production, a most expensive acquisition option. UAV costs are often overstated by including the cost of the payload: Examples are: Global Hawk, with approximately 60% of the UAV cost in the payload, and Predator with more than 50% of the cost in the payload. The panel expects that cost savings for UAVs relative to manned aircraft can be realized through O&S costs. Simulation can be used to provide equivalent training and mission rehearsal for UAV skills, to a greater extent than would be the case for manned aircraft. Simulator flight hours are considerably less expensive than manned aircraft flight. Additionally, simulation can be used to speed development and evaluation for UAVs at significant cost savings.

The USAF has made great strides in its development and use of UAVs, as evidenced by the recent successes in Operations Enduring and Iraqi Freedom. Adoption of a platform-centric UAV "family" development concept will further exploit those successes. It will lead to larger UAV production volume and longer term contracts, thus creating acquisition savings in both time of development and cost. Payload modularity and increased simulation use will help insure that UAV platforms will not become quickly outdated. The panel's findings have led to a series of recommendations.

2.4 Recommendations

The panel derived three primary categories of recommendations – Platforms, Process, and Payloads. Specific recommendations on UAV platforms and their mission capabilities are found below in 2.4.1.1 and 2.4.1.2. Regarding process, the panel recommends a development and acquisition approach for UAVs and payload modules in 2.4.2. Finally, payloads are addressed in 2.4.3.1 and 2.4.3.2; sensors and sensor modular payloads are discussed in 2.4.3.1, and weapons and weapon modular payloads are discussed in 2.4.3.2. It should be noted that mission and system requirements (for example, payload weight, performance and power required, and platform range, endurance, speed, maneuverability, and supportability) will rapidly evolve as the Air Force gains experience with the potential, limitations, and costs of UAVs.

2.4.1 Platforms

2.4.1.1 Current UAV system concepts can evolve through the spiral development process to accomplish a large number of missions:

High Altitude Endurance UAV (e.g., Global Hawk X) with missions for Non-Penetrating ISR, Communications Relay, Air Surveillance, Medium Coverage ISR, and Loitering Boost Phase/Post Launch Intercept.

Medium Altitude Endurance UAV (e.g., Predator X) with missions for Non-Penetrating ISR, Armed Recce, Airborne Electronic Attack, Air/Cruise Missile Interceptor, Close Air Support, Communications Relay, Persistent Strike CAP, and Info Ops.

Survivable Medium Altitude Endurance UAV (UCAV is a candidate) with missions for Survivable Strike, DEAD/SEAD, Armed Recce, Airborne Electronic Attack, Medium Coverage ISR, Close Air Support, SOF Resupply, UGS Implant/Seeding, and Wingman Escort.

2.4.1.2 The Air Force should use the spiral development process to develop three new UAV platforms while concurrently developing operational concepts to meet high priority missions.

Survivable High Altitude Endurance UAV with missions for Deep Coverage Survivable ISR, and Local GPS/Differential GPS (DGPS) Enhancement.

Survivable Large UAV with missions for Survivable Deep Strike, Persistent Strike CAP, Long Loiter Armed Surveillance, Loitering Boost Phase/Post Launch Intercept and Airlifter/Penetrating Refueler.

Mini UAVs with specific missions for ISR of Hazardous and Confined Environments, Mini-Investigator for Positive ID/Bomb Damage Assessment, Local GPS Enhancement, Surveillance of Underground Targets, and Precision Covert Tagging.

Other Mini-UAVs, Micro-UAVs, and High Altitude Airships should be developed for specific new missions.

2.4.2 Process

Recommend concurrent spiral development be implemented for the next generation of UAV platforms, payloads, and operational concepts. The panel strongly believes that it would be detrimental for UAVs to enter the "normal" acquisition process. ***The process used for Global Hawk and Predator is exemplary; use the Advanced Technology Demonstrator (ATD)/Advanced Concept Technology Demonstrator (ACTD) process for the development of future platforms.*** These technology demonstrations can be used to develop CONOPS, plan for continued spirals or discontinue unsuccessful programs, and enter SSD of a streamlined acquisition process. However, we do recommend greater attention to mission management in future ATD/ACTD.

2.4.3 Payloads***2.4.3.1 Our recommended sensor roadmap builds on the science and technology base to focus on low-risk developments. It should be implemented to develop and field payload modules with:***

- ***Substantially lighter-weight, modular, low cost sensor suites***
- ***RF systems for highly survivable platforms***.
- ***Communications***

2.4.3.2 The recommended *weapon roadmap* ***builds on the science and technology base and focuses on low risk developments, some of which are already underway. UAV missions would benefit from:***

- A family of winged glide bombs with GPS accuracy and a range to complement SDB.
- A small, inexpensive jet engine that can push the range of the above family.
- A beyond-visual-range air-to-air missile.
- A family of low cost cruise missiles.
- A high-speed missile for attack on time-critical and SEAD/DEAD targets.

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Chapter 3 VEHICLES

CHAPTER 3 VEHICLES

3.1 Introduction

This chapter presents the Vehicles Panel mission, findings, and recommendations. It includes a description of useful operational capabilities and current state-of-the art vehicle technology. Note that vehicle missions and payloads/sensors are addressed by the Mission Concepts & Demonstrations Panel in Chapter 2, and onboard autonomy is addressed by the Mission Management Panel in Chapter 4.

3.1.1 Panel Mission

Within the overall context of the UAV Summer Study Terms of Reference (see Appendix A), Vehicles Panel members met with various Department of Defense (DoD) and private industry organizations in over a dozen different locations over the course of five months (see Appendix D). The Vehicles Panel used the following directives to collect, organize, and analyze UAV data:

- Identify vehicle characteristics that enable superior UAV system effects
- Identify vulnerabilities and limitations that are unique to UAV vehicles
- Compare UAV and manned aircraft system costs
- Identify UAV vehicle cost saving opportunities
- Identify platform technology limitations
- Define vehicle characteristics for missions defined by the Mission Concepts and Demonstrations Panel
- Recommend vehicle technology investments

3.1.2 Key Findings

The Panel has identified the following key findings:

- From an air vehicles technology perspective, UAVs can be a viable alternative for most Air Force missions within the time frame of this report, and in particular can provide persistence using practical air vehicle designs. UAV-unique vulnerabilities can be overcome.
- There are significant UAV propulsion system technology limitations, including low SFC engines optimized for UAV missions with extended hot periods, high power extraction requirements, and LO high bypass rate (HBPR) engine integration designs.
- Small UAVs offer expanding opportunities for new and unique capabilities at very low costs but introduce their own unique technological challenges.
- Medium and large UAV development and production costs will approach those of manned aircraft for equivalent mission requirements, production quantities, and procurement environments. The key to achieving lower UAV costs, therefore, will be to tailor requirements to optimize UAV capabilities and to produce them in larger quantities. UAVs have the potential to significantly reduce O & S costs.
- There are no technological barriers for aerial refueling of UAVs; it is primarily a development and confidence issue.

- Methodologies are needed for the automated testing and certification of large amounts of flight critical software and for the flight certification of multiple, cooperating aircraft.

Overall, this Panel found many technical challenges to executing the missions described in this study; see Section 3.4 for details. However, there are no insurmountable obstacles, and vehicle technologies are unlikely to retard an increased deployment of UAVs.

3.1.3 Recommendations

Based on the findings above, the Panel makes the following recommendations to the USAF leadership:

- Invest aggressively in the development of critical technologies required to achieve UAV capabilities, including LO designs with well-integrated, high-efficiency HBPR engines, aerial refueling, and methodologies for the certification of flight critical software and multiple cooperating vehicles.
- Institute detailed studies and analyses to determine whether large numbers of small UAVs can be more cost effective than small numbers of large UAVs.
- Continue innovative research into small UAV platforms and their enabling technologies.
- Aggressively manage UAV development and production costs by creating a family of modular platforms and reduce O&S costs by developing a tailored UAV operator and support personnel training and proficiency program.
- Aggressively tailor UAV design requirements and criteria to achieve a better balance between safety/reliability/risk and reduced development, procurement, and O&S costs.

These recommendations are discussed in greater detail in Section 3.4.

3.2 Background

Unmanned aerial vehicles were first flown in the early part of the twentieth century for research and development and as guided single-use weapons (i.e. Langley, Lillienthal, and Wright Brothers gliders; Kettering Bugs; Luftwaffe V-1s; and PROJECT APHRODITE B-17s). From the late 1950s to the 1980s, remotely-piloted vehicle development flourished in the ISR and drone target mission niches with advances in lighter weight materials, high speed aerodynamics, photo-optics, and electronics (consider D-21 supersonic drones, Ryan BQM-34 and other aerial targets, and Lightning Bug ISR drones). As communication, computational, and composite material technologies matured in the 1980s and 1990s, UAV capabilities and resulting mission applications grew to include artillery and laser-guided weapons targeting, BDA, FAC, mine-hunting missions, and near-real-time ISR platforms such as the RQ-1A Predator and RQ-2A Pioneer.

In the last ten years, the family of UAVs has greatly expanded to stretch from small and very inexpensive limited-use systems to large, complex, multi-mission platforms. Capabilities have also grown, allowing much greater persistence and contributing to all elements of the kill chain (see Figure 3-1). Current UAV scales, for example, range from 6-inch vehicles whose endurance is measured in minutes to the Global Hawk's 116-foot span and 30+ hour loiter time. Existing ISR UAVs such as Predator have been weaponized to embrace a wider spectrum of missions. The UCAVs recommended in the 1996 SAB report are being developed and demonstrated. New munition concepts such as Loitering EW Killer (LEWK) and Low Cost Autonomous Attack System (LOCAAS) have emerged with UAV-like persistence in the battlespace and autonomous target location and lock. Some UAVs can take off, land, and perform waypoint following with little or no human intervention. Contingency management algorithms automatically reconfigure the operation of the vehicle to account for lost communications links, inoperative sensors, failed actuators, even engine loss. Technology advances in many areas have transformed these UAV capabilities for the warfighter. Advances include GPS navigation-aiding, small-to-large-scale composite construction, EO and communication electronics miniaturization, encrypted ultrahigh frequency (UHF), SATCOM, and other line of sight (LOS) and BLOS communication systems, capable OTS engine cycles, and design and performance lessons learned from decades of RC-model enthusiasts. This trend is far from exhausted.

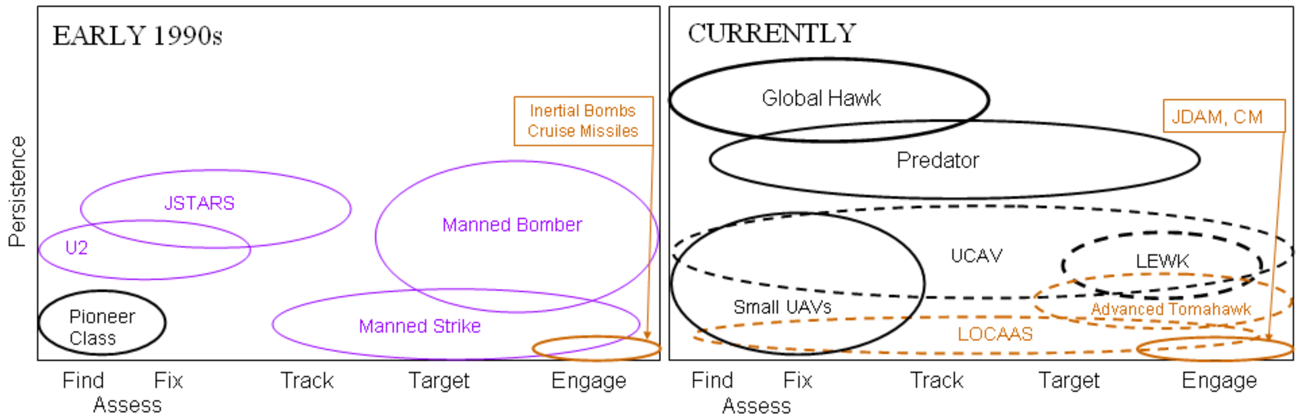

Figure 3-1. *Expansion of Vehicle Capabilities, 1990s – Present*

3.3 Key Findings

3.3.1 From an air vehicles technology perspective, UAVs can be a viable alternative for most Air Force missions within the time frame of this report, and in particular can provide persistence using practical air vehicle designs. UAV-unique vulnerabilities can be overcome.

Automation, Persistence, and Survivability

UAVs perform missions autonomously by placing operators in lower-risk "outer control loops" with acceptable communication delays. Automating the most compelling missions (ISR, SEAD/DEAD, and armed-reconnaissance) exploits the chief attributes of UAVs: persistence, tolerance of hazardous environments, and lower risk from severe, threatening defenses. Automation of other missions, such as aerial transport, is technically feasible but isn't as dependent on the chief attributes and is unlikely to provide meaningful cost savings. Autonomous close-in air-to-air combat is an example of a mission that may not be technically feasible within the timeframe of this study, considering the immediacy of response and visual perception required by the machine and operator.

The SAB 1996 UAV Study questioned FMS reliability, naming it a primary contributor to accidental losses. Since then, much progress has been made on autonomous reconfigurable flight control and contingency management systems. The Vehicles Panel no longer considers the FMS to be of concern. Currently, Global Hawk, UCAV, and Firescout are demonstrating high levels of FMS reliability.

Persistence is a particularly valuable UAV attribute. For missions demanding long ingress/egress and time and station (TOS) flight times, UAVs enable the vehicle duty cycle and the number of vehicles to be optimized without the constraint of airborne crew endurance (typically 12 hours or less for a single aircrew member). Persistence requirements for medium and large UAVs are highly mission-dependent. For ISR missions, where 24/7 operations are required, the per-vehicle endurance can be very high – 24 to 36 to 60+ hours. However, other considerations may drive the optimum endurance design point. For example, ground support personnel and duty cycle requirements for maintenance, flight, and mission operations including sensor utilization are critical considerations. Cost is also an issue: the sensitivity of empty weight to TOS for a conventional 24 hour HAE ISR UAV, for example, would be around 750 lb/hour, which at a nominal procurement cost of $1,500per pound, is the equivalent of ~$1.1 million per additional hour on station. At 36 hours, the sensitivity is about 1350 lb/hour, or around $2 million per additional hour TOS.

Based on a limited analysis of HAE ISR systems, optimum endurance points for ground personnel appear to be in multiples of 12 hours, with vehicle and mission considerations optimum at ~24 hours TOS for a 30-36 hour total mission flight time. This differs from the 1996 study, which recommended 60-100 hours endurance but did not consider operations and support issues. For other UAV missions such as strike or attack systems, the analysis is very dependent on specific mission characteristics such as target density. For small UAVs, technologies such as electrical power density will be limiting endurance factors.

Survivability, an additional design consideration for high endurance systems, imposes air vehicle signature and advanced countermeasures challenges beyond those currently employed in less persistent operationally-fielded vehicles. Survivability and persistence are rather contradictory design attributes and must be given detailed consideration when developing the vehicle, mission management, and supporting systems. As an example, future LO UAVs using high bypass cycles for efficient persistence will require larger and less easily integrated engine inlet designs.

3.3.2 There are significant UAV propulsion system technology limitations, including low SFC engines optimized for UAV missions with extended hot periods, high power extraction requirements, and LO HBPR engine integration designs.

UAV operational engine cycles include gas turbine (turbojets, turbofans, or turboprops) and IC engines. A major technology limitation for all vehicle size classes is the propulsion system fuel efficiency. The figure of merit for this efficiency is specific fuel consumption (SFC). For the particular case of small UAVs, the 2002 Office of the Secretary of Defense (OSD) UAV Roadmap cites a wide range of issues for various engine types and configurations. Technology issues for IC engines in particular are fully captured in the Roadmap and include the need to operate on common (heavy) fuels and to achieve much higher reliability and better SFC. Improvements in these areas require an integrated DoD working group approach as the current efforts are small and fragmented.

For larger UAVs (TOGW above 2,000 lbs), gas turbine engines (GTEs) are used for their higher specific thrust (thrust per unit of mass flow through the engine). Turbine technology challenges include decreasing thrust specific-fuel consumption (TSFC) and cost, and increasing power extraction and specific thrust. The current Integrated High Performance Turbine Engine Technology (IHPTET) development program, nearing completion, has achieved major advances in TSFC. The DoD-funded follow-on to IHPTET is the Versatile Affordable Advanced Turbine Engine (VAATE).

3.3.3 Small UAVs offer expanding opportunities for new and unique capabilities at very low costs but introduce their own unique technological challenges.

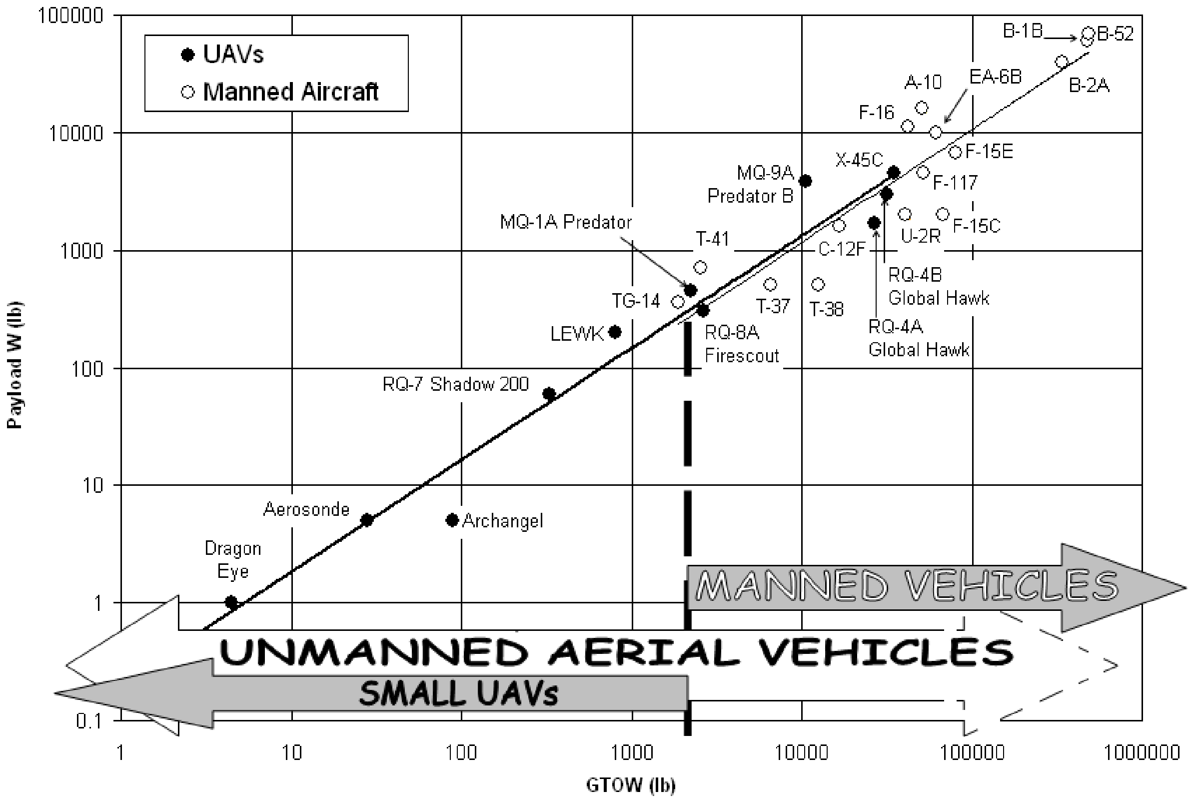

Figure 3-3. *Scales of Manned vs Unmanned Vehicles*

Figure 3-3 shows a range of manned and unmanned vehicles characterized by their GTOW and payload weight, indicating overall vehicle scale. The dashed portion of the arrow labeled “Unmanned Aerial Vehicles” indicates UAV scales that do not currently exist. This same arrow extends to the left of the origin to indicate scales for very small UAVs, commonly referred to as micro air vehicles. The vertical dotted line indicates the upper limit of the “small UAV” class, defined here as vehicles too small for human habitation. This includes the Mini UAV concept from Tables 3-1 and 3-2 (Section 3.3) as well as other small vehicles considered in the following discussion.

Table 3-3 lists effects (i.e. missions) potentially enabled by small UAV attributes. Furthermore, groups of small UAVs may offer cost-effective solutions for some missions currently performed by single high-value platforms (see Section 3.4.2). Small UAVs working synergistically with large manned or manned platforms, or in their own collectives therefore have the potential to enable new effects or provide lower-cost solutions for existing effects.

***Table 3-3.** Small UAV Attributes and Effects*

Attributes	Effects
• Low development, acquisition, and support costs • Ease of transport • Unit-level control • Ground and air launch options • Inherently low observable • Distributed sensors • Expendability	• Close-in, high-confidence target ID and tracking • Target tagging • Delivery of unattended ground sensors • CBR agent detection • Bomb damage assessment • Over-the-hill surveillance • Weather sonde delivery • Airfield perimeter surveillance • Low-cost, wide area EO coverage

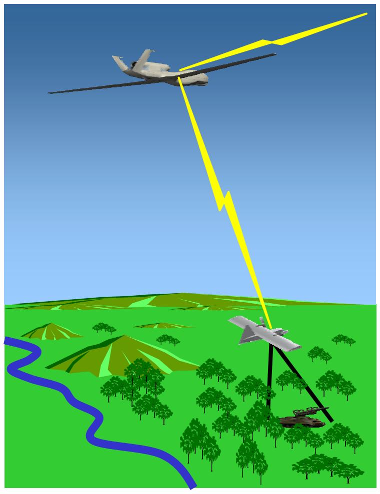

***Figure 3-4.** Hen and Chick Approach for NIIRS 9 Optical Resolution*

For wide-area coverage typically provided by current MAE ISR platform sensors, multiple small UAVs might be coordinated to achieve cost savings. A sample scenario and related first-order analysis, detailed in Volume 2, Chapter 4, compares one MAE flying at 20,000 ft to 16 small UAVs (10-ft wingspan) flying at 5,000 ft providing the same area coverage, each with an inexpensive COTS EO camera. The small UAVs can perform the mission for ~25% of the MAE airframe cost and ~40% of the MAE fuel cost. This first-order cost estimate does *not* account for more complex issues such as higher attrition rates for smaller UAVs flying at lower altitude or higher communications bandwidth.

Improving small UAV operational capabilities requires investments in:

- ***Low Re*** research to better understand unsteady aerodynamics at relevant small UAV scales
- ***Propulsion systems*** employing heavy-fuel IC and turbine engines with noise reduction technologies
- ***High-power density energy storage devices*** to extend vehicle range and/or payload capacity
- ***Multifunctional structures*** integrating vehicle subsystems to address volume constraints
- ***Microelectronics*** for miniaturization of avionics and sensors packages
- ***Flight stability and control*** for improved sensor pointing, enhanced image quality, and in-weather operations

3.3.3 Medium and large UAV development and production costs will approach those of manned aircraft for equivalent mission requirements, production quantities, and procurement environments. The key to achieving lower UAV production costs, therefore, will be to tailor requirements to optimize UAV capabilities and to produce them in larger quantities. UAVs have the potential to significantly reduce Operations and Support costs.

Development Costs

Medium to large UAV development costs will not differ significantly from those of manned vehicles designed to the same requirements in the same acquisition environment. Small UAV development can be done much more rapidly and at lower relative cost due to minimal on-board software and COTS parts.

Over the past 10 years, UAVs have been developed and acquired outside of the DAB structure as a technology push to the Services, which have exploited their capabilities only after operational demonstrations. Of note to the USAF: Predator, Global Hawk, and UCAV were joint programs led by another Service or Agency. A key tenet of these systems' development was a minimum set of requirements and a very focused team of engineering and acquisition personnel. Development cost to reach first flight is shown in Table 3-4 for three ACTD programs, compared to similar manned platforms. For two mission classes, Reconnaissance and Attack, the data is widely scattered and shows opposite trends. The variations are likely driven by the different levels of program management and requirements stability experienced by the individual programs.

Development costs for medium to large autonomous UAVs are dominated by software development [i.e. flight controls, guidance, navigation and control (GN&C), redundancy and contingency management], avionics and propulsion unit costs, and system integration requirements. Autonomous systems, for example, require system redundancies and contingency management logic that is significantly greater than that required by "equivalent" manned systems. These development costs are offset by a lack of manned platform onboard pilot infrastructure and pilot safety qualification testing. More specifically, significant development cost savings may be achieved in the mission management and communications segments by establishing a common infrastructure between Global Hawk and the Survivable Persistent ISR platform and between the UCAV and the Persistent Survivable Deep Strike platform. However, lessons learned from the USN TCS and CDL/TCDL programs must be heeded while establishing the programmatic and requirement framework.

GTE development costs are typically cited as a major issue when justifying compromises in the mission performance of off-the-shelf (OTS) engine cycles. In fact, significant cost savings are achievable (about 50% of the total engine development cost) by the use of derivative engines. The Air Force VAATE program cost reduction component includes a significant focus on the use of a versatile core concept that wraps new engine capabilities around a common high pressure engine spool (core compressor, combustor, and turbine).

Production Costs

Current medium and large UAV production costs approach those of manned aircraft for equivalent mission requirements, procurement quantities, and procurement environments. Early expectations assumed the elimination of air vehicle subsystems associated with pilots and other aircrew would enable significant reductions in overall UAV procurement costs. However, cost comparisons from the 2002 OSD UAV Roadmap show manned and unmanned air vehicle procurement costs, measured in terms of dollars per pound empty weight, are comparable at about $1,500/lb. Explanations for this include:

- Aircrew-related subsystems generally represent a small fraction (10 to 15%) of the overall vehicle empty weight [i.e., an unmanned F-16 weight savings is only 5% of gross takeoff weight (GTOW)].

- Early studies that projected substantially lower UAV costs took credit for subsystems that were incompatible with UAV CONOPS as contributors to cost reduction (i.e., removing the gun from the unmanned F-16).
- Current generation UAVs still carry requirements "baggage": systems such as propulsion continue to be designed and certified to manned aircraft specifications.
- Manned aircraft against which UAVs are typically compared have been produced in larger quantities than UAVs. The Northrop Grumman Global Hawk, for example, is identified in the DoD Roadmap as costing $20 million, or about $2,200/lb. To date, however, only seven Global Hawks have been produced. By comparison, a typical fighter such as the F-16, over 4,000 of which have been produced worldwide, costs about $1,500/lb. Consider instead the 7,000 BQM-34 target drones Northrop Grumman has produced over a period of 60 years; they currently cost less than $500/lb. Clearly, if Global Hawk were produced in quantity, its cost per pound would decrease significantly as the production and associated tooling move down typical cost "learning" curves.

Therefore, the key to achieving lower UAV production costs will be to tailor requirements to optimize UAV capabilities, and to produce them in larger quantities.

Operations and Support Costs

O&S costs have the highest potential for reducing "total ownership" costs for almost all systems. For example, the typical annual O&S cost for an aircraft system is 10-15% of initial procurement cost. Assuming a nominal 20% development cost and 20 years of life cycle costs, cumulative O&S costs constitute 2/3 to 3/4 of total ownership cost. Clearly, O&S cost is a high leverage cost consideration.

There are many reasons why UAVs are projected to have substantially lower annual O&S costs than an equivalent manned aircraft. First, UAVs typically fly longer duration missions than manned aircraft; since maintenance actions are traditionally flight-cycle versus flight-hour driven, long endurance aircraft require less maintenance per flight hour. Second, a vast majority of manned aircraft peacetime flight operations are executed to maintain high levels of pilot proficiency; these requirements are less demanding for UAV operators due to the higher automation levels inherent in their tasks. For example, a cost comparison between experienced U-2 and Predator pilots (detailed in Volume 2, Chapter 4) shows annual operator flight proficiency maintenance costs of $1 to $2.7 million per year for a U-2 pilot versus about $90,000 per year for a Predator operator. These differences will become even more dramatic in the future as UAV simulators come on line and actual airborne flight hour proficiency requirements are further reduced.

Finally, reachback UAV operations reduce forward deployment and airlift requirements. Both Predator and Global Hawk have demonstrated that about 50% of the personnel involved in UAV operations can remain in CONUS when operations take place overseas. Forward deployment of O&S equipment can similarly be reduced. For example, during recent operations, Predator reach-back reduced *per system* deployment requirements by 40 personnel and 1.5 C-141-sized loads.

Actually achievement of lower O&S costs requires an operator training and proficiency CONOPS tailored for UAV operations. UAV operators need to be rated pilots, but not in the traditional manned aircraft sense. UAV operators have to exercise the responsibilities of Pilot-in-Command of their platform in the same CONUS and OCONUS airspace as civil and military aircraft. Therefore, by federal regulation, they must be certified by the USAF to have the equivalent of a pilot certification and type rating. However, operating a UAV does not require the same physical skill sets of a traditional USAF pilot. Because of the high level of automation inherent in UAV operations, their hand-eye coordination skills are not as demanding as those of a manned aircraft pilot. Their airspace awareness and procedures skills, however, are almost identical. Therefore, their skill requirements are probably closer to those of a Navigator or Weapons System Officer than a traditional pilot. In addition, their ability to operate safely in the airspace while relying solely on 2-D situation displays requires a skill set typically associated with Air Traffic Controllers and/or Air Battle Managers.

3.3.5 There are no technological barriers for aerial refueling of UAVs; it is primarily a development and confidence issue.

Unmanned refueling technologies include accurate relative positioning of aircraft, identification, localization, physical link-up, and separation with the boom or drogue, and contingency management procedures to allow the aircraft to quickly and safely separate if necessary. AFRL has an ongoing 6.2 program in Automated Aerial Refueling (AAR) that is developing requirements based on computational fluid dynamics (CFD) and wind tunnel testing for aerial refueling. Flight demonstrations are planned for FY04-06 and could be inserted into UCAV Spirals 2 and 3. All work to date supports the finding that air-to-air refueling is technically feasible for UCAV-class UAVs. Probe and drogue refueling is likely to be more challenging than boom refueling, but is being investigated by AFRL.

The Panel is not aware of any completed studies on the use of unmanned tankers, refueling of small UAVs, or the use of drogues for UAV refueling. The use of unmanned tankers should not present significant difficulties for automatic refueling of other aircraft in terms of guidance, navigation and control. Procedures need to be developed for insuring safe breakaway maneuvers during contingencies, but the level of technology required is within current UAV C2 capabilities. Refueling of small UAVs has not been studied in detail; likely limiting factors are the authority and bandwidth of the UAV control system in the presence of unsteady aerodynamic forces, either from atmospheric turbulence or unsteady flow behind the tanker. For the mission scenarios considered in this study, aerial refueling of small UAVs is not required.

3.3.6 Methodologies are needed for the automated testing and certification of large amounts of flight critical software and for the flight certification of multiple, cooperating aircraft.

As autonomy levels of UAVs increase, on-board software quantities will increase as well. Much of this additional software will be flight critical (i.e. failure of the software to perform its intended function will result in the vehicle loss). Estimates for future UAVs include 500,000 to one million flight-critical software lines of code (SLOC), compared to about one hundred thousand flight-critical SLOC for current manned aircraft. Even at lower current SLOC levels, software design, coding, and (particularly) validation are often the critical milestones on the path to first flight. Unless substantial improvements are made in the methodologies for software design and validation, flight-critical software will drive substantial increases in system development cost and time to first flight. A second challenge in the certification of future UAV software is that it may in some cases, contain non-deterministic features, so identical inputs can result in differing outputs. Methodologies will be needed for the certification of such software.

Another challenge in software-intensive systems certification is the amount of post-modification regression testing required. Modifications will become unaffordable if the entire system must be retested each time a software change is made. The solution is modular software development, including appropriate isolation from other modules, to minimize the amount of required regression testing. Incorporating mission modular payloads in “plug and play” architectures is a prime example of this approach.

The operation of multiple UAVs in cooperation with each other and with manned aircraft further increases flight certification challenges. Multiple UAVs making autonomous decisions (e.g. on task assignments) based on shared group information will need to be certified as *one system*. This is a new requirement; for manned aircraft, safety of flight of multiple aircraft is achieved through individual aircraft certification and pilot training. The methodologies for hardware-in-the-loop and flight testing of systems of air vehicles have yet to be developed.

3.4 Recommendations

Based on the findings above, the Panel makes the following recommendations to the USAF leadership:

3.4.1 Invest aggressively in the development of critical technologies required to achieve UAV capabilities, including LO designs with well-integrated, high-efficiency HBPR engines, aerial refueling, and methodologies for the certification of flight critical software and multiple cooperating vehicles.

- ○ **Improved Engine Technologies**
- **UAV Refueling Issues**: Continue programs such as the AFRL AAR investigation, including research into refueling capabilities (limits) for medium and small UAVs, and confidence-building demonstrations of operations mixing man and machine (especially exercising contingency management).
- **Flight Critical Software**: Develop methodologies for testing large amounts of flight critical software efficiently and autonomously, considering the rapidly increasing amount of SLOC and their critical impact on program time and cost to first flight.
- **Certification of Multiple Cooperating Vehicles**: Develop methodologies for the certification of systems of multiple cooperating UAVs. These systems present a new flight certification challenge for which no appropriate methodologies exist.

3.4.2 Institute detailed studies and analyses to determine whether large numbers of small UAVs can be more cost effective than small numbers of large UAVs.

Detailed studies and simulations are needed to explore this concept from cost effectiveness and feasibility standpoints. The Panel found no studies identifying whether large numbers of small UAVs are more cost effective than small numbers of large UAVs and, if so, for which missions this savings holds true. Results from a simple first-order analysis indicate significant potential cost savings.

3.4.3 Continue innovative research into small UAV platforms and their enabling technologies.

Ensure the critical technologies required to support small UAV applications are developed either by the services or other agencies and transitioned to the warfighter for operational evaluation as rapidly as possible. The low costs and short development cycles of small UAVs lend themselves to rapid experimentation and early operational exploitation. AFRL/MN and UAV Battle Lab are developing low-cost technologies and exploring new operations and effects. Transition to the warfighter has been rapid and commendable. This provides a natural process for technology evaluation and selection based on utility. Other service branches and agencies have spent considerable effort in small UAV technology development. The USAF should track these technology developments and exploit them when possible and appropriate.

3.4.4 Aggressively manage UAV development and production costs by creating a family of modular platforms and reduce O&S costs by developing a tailored UAV operator and support personnel training and proficiency program.

Contain UAV development and production costs by building a small number of platforms to accomplish a wide range of missions and by avoiding requirements creep during the development phase. Requirements must be carefully analyzed and managed to avoid point designs incapable of satisfying broad mission objectives. In addition, UAV O&S costs can be dramatically lower than manned platforms if operator requirements are carefully analyzed and matched with the needs of unmanned, remotely operated systems. Pay particular attention to operator initial flight training (IFT) and required aircrew proficiency (RAP) CONOPS. Maximize the use of simulation for IFT and RAP maintenance; focus actual flight hours on multi-functional exercises and other integrated force enhancement activities.

3.4.5 Aggressively tailor UAV design requirements and criteria to achieve a better balance between safety/reliability/risk and reduced development, procurement, and O&S cost.

Establish a focused program to assess UAV design requirement, criteria-driven costs, and weight impacts and develop strategies to balance desired levels of safety, durability, operability and risk against development, procurement and O&S cost reduction goals. Make particular efforts to eliminate requirements and criteria that trace directly or indirectly to manned rating issues such as engine throttle excursions, upper-left hand corner maneuver excursions, and pilot rated handling qualities, and similar matters.

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Chapter 4 MISSION MANAGEMENT

4.1 Introduction

Current UAV systems have been very successful in High Demand, Low Density (HDLD) roles. To build upon these successes and realize the benefits of UAV systems in more demanding roles, significant advances need to be made in mission management technologies. Many of the technologies required to manufacture a wide range of UAVs and to control their flight systems are relatively mature. However, the technology required to assist decision makers in managing their missions, and to detect and respond to anomalies automatically, to respond to unexpected events in the environment, and to exploit opportunistic re-tasking has yet to be demonstrated. This has been a major limitation with current UAVs operating in an HDLD role, and will, if not corrected, become a major problem as increasing numbers of UAVs are assigned more complex missions and are integrated more thoroughly into Air Force operations.

There are two basic paradigms currently employed to manage UAV missions, and neither will scale up as UAVs become more common. The first, used by Predator, is “teleoperation,” whereby humans interact with the vehicle and its sensors at various levels of autopilot control. Humans, however, are fundamentally limited in their ability to share attention across multiple displays, maintain constant situation awareness, and deal with multiple competing high-priority cognitive tasks. This basic operating paradigm will therefore not scale well as missions become more complex, UAVs become more numerous, and operators are expected to “control” multiple UAV missions. This paradigm is also limited by communications bandwidth limitations.

The other paradigm, termed “supervisory control,” is to operate the UAV in a highly automatic mode, with responses to some contingencies pre-scripted by the operators. Global Hawk currently uses this mode of operation. Such automation is largely based on execution of a limited set of fixed scripts for a number of pre-selected (“anticipated”) contingencies, which may or may not be applicable to the wide variety of situations that the UAV actually encounters. Contingency planning software attempts to meet the need for some situational flexibility, but has proved too complex, due to the combinatorics involved, to work well even for the limited number of simple single-vehicle missions currently flown. In the multi-vehicle case, complexity increases exponentially with the number of vehicles, since plan deviations by one vehicle need to be responded to by the others. To cope with this, UAVs of the future must be capable of greater autonomy: that is, they must be able to detect and respond to vehicle/platform anomalies or plan deviations with little or no human intervention, and to surprises in the environment (e.g., pop-up threats) which were not anticipated during the mission planning phase. At a minimum, UAVs must be able to recognize that a plan deviation has occurred and initiate and conduct a safe mission abort. Ideally, they should be able to take advantage of unplanned opportunities presented to them, and should act appropriately to satisfy the mission objectives.

4.1.1 Panel Mission

The panel’s mission was to consider mission management (MM) from the perspective of enabling the introduction of UAVs into the force structure in a manner that takes full advantage of current and envisioned system capabilities, while ensuring effective human-system integration (H-SI) across a broad range of potential operational concepts and missions. The panel was assigned the following tasks:

- Review past and current studies related to UAV mission management
- Review current and projected USAF UAV operations, platforms, payloads, C2 systems, and MM systems

- Identify key MM issues and needs associated with current and envisioned operations and projected technology trends
- Identify potential technology-related solutions or ameliorating approaches to these issues, based on current technology trends and state-of-the-art practice in closely related disciplines
- Define a framework for understanding UAV MM issues, future trends, and potential solutions
- Approach

The panel was well-suited deal with the broad mission, being composed of experts in autonomy, H-SI, software design, training, and operationsissues. The panel began by identifying the following key questions:

- What is the state-of-the-art in UAV mission management?
- What are the fundamental H-SI issues involved?
- What are the key technology options that might be considered to address these issues?
- What are critical operational constraints that have to be taken into account?
- Can we develop an overarching framework for understanding the MM problem and for providing design and operational guidance for future UAV systems?

Findings relative to these questions were collected at numerous site visits and briefings (summarized in the next section), and then collated into technological issues and operational constraints. Recommendations were generated by topic area and then fused into a final set.

Data collection, assessment, and generation of recommendations were predicated on the belief that mission management needs to be viewed holistically and from a human-centered perspective. As shown in Figure 4-1, UAV mission management must be viewed in the larger context of battlespace management, and encompasses more than just on-board and ground-based software and hardware. Mission management transcends the full ensemble of mission, team, platform, payload, and ground control stations (GCS), and it helps humans to work effectively with all of these components. In keeping with this theme, the panel considered the command/control/communications (C3) links and the interface with the Air Operations Center (AOC), since these are critical to achieving net-centric operations. In addition, we reviewed the organizational implications of mission management for the operator population, as well as operational considerations such as flying in civilian airspace.

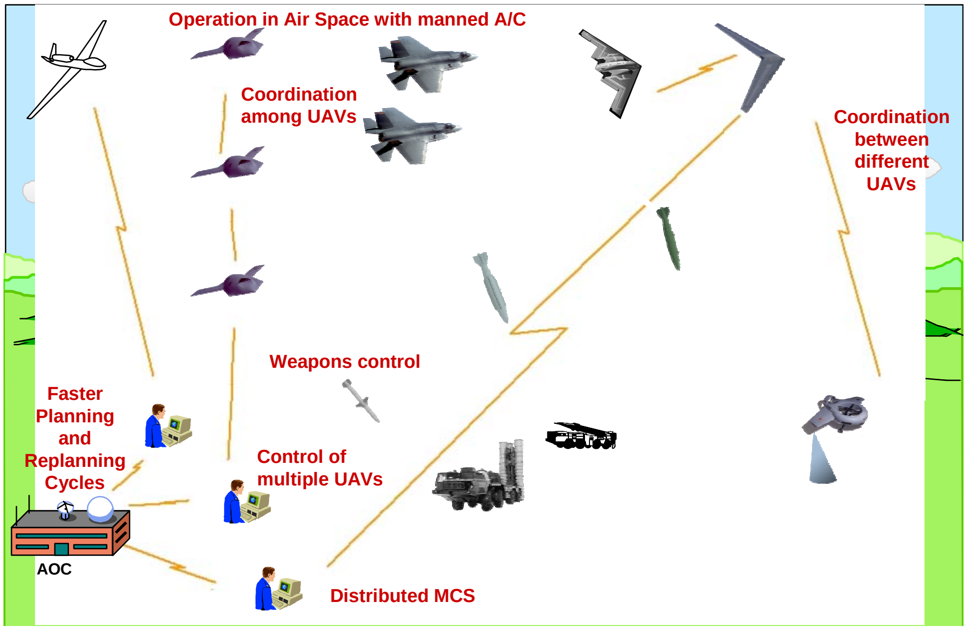

Figure 4-1. *UAV mission management as an integral element of theater battle management and mixed-fleet operations*

Mission management is an activity that requires significant capabilities in situation awareness, reasoning, and problem solving which are unlikely to be fully automated within the reasonable future. Rather than identify a set of technologies that would enable a UAV to execute some aspects of mission management and leave the remaining responsibility to the humans, the panel chose to look at the technologies that enable the UAV(s) and human operator to work at their best levels as an integrated team to accomplish HDHD missions.

4.1.2 Visits and Briefings

The panel collected data about mission management for UAVs by conducting highly focused fact-finding visits and reviews with USAF (including AFRL/HE, VA, and MN; the UAV Battlelab, and the C2TIG), UAV and related technology contractors (including Boeing, Lockheed-Martin, Northrop Grumman, Raytheon), research agencies with relevant programs (including DARPA, ONR, and NASA ARC), and operational units (including 11RS, 15RS, 17RS at Nellis AFB, and 12RS at Beale AFB).

4.1.3 Vision

The panel envisions the next generation of MM technology enabling UAVs to quickly become part of the normal operations of the AF. The development and integration of human-centered MM software can have a profound and far-reaching impact on the types of missions that can be conducted to achieve the desired effects, the performance of those missions, and the cost of conducting a mission and developing new systems. A list of the major benefits of MM technology is as follows:

- Improved vehicle survivability and mission completion due to advances in on-board health management, vehicle autonomy and operator situation awareness
- Seamless interoperability of manned and unmanned vehicles in shared airspace (national, international and battlespace)
- Substantial reduction in mishap rates and probability of collateral damage in combat operations
- Reduced demands on communications resources

- Significantly reduced operator to vehicle ratio resulting from optimum division of tasks between humans and automation
- Rapid adaptation to mission changes, equipment failures, and/or or emerging combat opportunities
- Greatly increased mission flexibility to support effects-based operations
- Improved situational awareness for operators and commanders
- Extended population of candidate operators capable of working with unmanned systems beyond the current limits; improved retention and career progression for UAV operators.

4.1.4 Discussion

Based on the site visits, briefings, and assembled references, the panel identified mission management as the most significant technical challenge for future UAV systems, since it appears that most of the other enablers are sufficiently mature to support the proposed range of missions. The current state of the art of UAVs is a high degree of automation of flight control, such as seen with the UCAV, with mission management being handled by a combination of teleoperations and pre-scripted automation requiring extensive mission planning. Relatively little effort has been applied to the problem of establishing an appropriate allocation of functions between humans and automation or objective assessment of the operator workload and situation awareness. The panel identified four key mission management technology areas impacting UAVs (autonomy; human-system integration; personnel selection, training and proficiency; design methodologies and testing) and one organizational and infrastructure issue (operation in mixed-traffic airspace).

The panel also encountered numerous myths about UAVs that could negatively impact their development and deployment. Briefly summarized, they are:

- "*A UAV is just the vehicle.*" As noted by the panel's tasking and approach, UAVs are a system: the vehicle, the ground control station, the operator, flight control software, mission management software, the maintenance people, and the analysts, are all components.
- *"UAVs reduce the significance of operators."* The panel notes that operators are just as significant, they just aren't in the vehicle. MM software can assist and enable the operator to do more productive activities.
- *"UAVs are cheaper than manned systems."* The cost savings on the vehicle are currently exceeded by costs on the ground (ground equipment, net increase in people, training). MM software can help reduce these costs.
- *"Automate what you can automate, leave the rest to the human."* This is one of the most potentially damaging myths. Over 30 years of sponsored research (including that sponsored and conducted by the AF) shows this leads to poor performance and crashes. MM software can serve as the "middleware" between what vehicle automation can accomplish and what humans are good at. These gaps are, however, mission-specific and the software has to be co-evolved with the vehicle.
- *"Some missions are well-suited for unmanned systems and some for manned systems."* This implies that there is a right mission for UAVs. In reality, all missions will have roles for both humans and automation. The key technical challenge is to achieve an overall system solution that takes full advantage of the inherent capabilities of both.

4.1.5 State of the Art

UAVs have been deployed successfully in HDLD missions and have attracted great interest, but most deployments have been in highly predictable situations. This is because MM functionality has been largely limited to basic "housekeeping" functions of the vehicle (i.e., autopilot flight control; failure monitoring and detection, etc.) and simple mission planning/execution functions (e.g., pre-mission planning of the flight path; enroute specification of the sensor collection plan; pre-scripted contingency path planning; etc). In short, the state of the art vehicle flight control is highly automated and generally performs well, and that some rudimentary mission management functions can be done by a combination of on-board automation and comprehensive mission pre-planning with pre-scripted solutions to contingencies. Research is being funded on a limited basis to address some of the key areas that will ultimately enable a substantially greater level of vehicle autonomy.

Programmatically, UAVs are being promoted for high density/high demand (HDHD) missions. The state of the art in vehicle autonomy and human-system integration does not yet reliably support those missions. An expectation of a 1:4 or higher operator to vehicle ratio appears common, but this is far beyond the state of the art for the foreseeable future without a major shift in research focus and funding. As noted earlier, the current mechanisms for mission management will not scale up to support control of large numbers of UAVs by a small number of operators.

Research in key areas for autonomy provision and decision assistance is being conducted across a number of agencies and laboratories. University platforms such as the Berkeley Aerobotics Project, the Stanford Dragon Fly project, the Georgia Automated Rotorcraft project and Carnegie Mellon University have demonstrated landing capabilities for rotorcraft and fixed wing UAVs including vision based landing, coordinated operations such as formation flying for groups of UAVs, conflict detection and resolution among multiple UAVs, and coordination with Unmanned Ground Vehicles (UGVs) in pursuit evasion games. But there significant gaps remain. There is also much confusion over terminology and definitions for levels of autonomy. Some existing H-SI research has been conducted, but topics especially relevant for UAVs have been ignored and/or largely underfunded. Surprisingly, well-known current results in H-SI are not being effectively implemented in new systems such as UCAV.

The state of technology applied to the current generation of fielded UAV systems trails the current state of the art in mission management. Predator and Global Hawk were fielded directly from vehicle-focused technology demonstration programs without the benefit of USAF expertise and procedures in systems engineering and development. The human operator is responsible for mission management but is severely handicapped by the lack of design to support good human-system integration. For example, a typical mission plan for Global Hawk requires 8,000 mouse clicks (USAF AAIB Report, 1998) - it is complex, tedious, time consuming, and it is also as error-prone (leading to at least one accident and system loss). Programs that delay development of the human-machine interfaces until "later" may be understandable in the context of a "see if the plane flies" demo, but the lack of good interfaces is a significant causal factor in 59% of the crashes of the Pioneer (Seagle, 1997) and 75% of the crashes of the Predator (Draper, 2003). While some progress has been made toward effective human-system interfaces for UCAV, even this program was fettered by a primitive engineering-oriented Mission Control Station (MCS) design in the Block 1 demo, because of a philosophy that put human –system interface considerations low on the list of basic engineering design priorities. Some of the more challenging H-SI problems associated with operator awareness of highly autonomous UAVs, multi-vehicle control and mixed traffic operations have yet to be addressed by the development community.

4.1.6 Mission Management Technologies & Operational Constraints

There is an expectation that the addition of some form of autonomy on the vehicle and at the MCS will solve "the mission management problem" by replacing human-in-the-loop control and allowing the human operator to supervise larger numbers of vehicles operating at close quarters. The presumption of autonomy does not, however, eliminate the need to consider human-system integration, and the H-SI literature actually contradicts the assumption that autonomy improves human performance and overall system performance in mission management. Software cannot be safely and economically developed, validated, and verified without a design methodology and set of testing procedures that consider human-in-the-loop performance so that overall system performance can be optimized. Mission management software reflects a major change in how human operators interact with the system, making operator training and mechanisms for increasing proficiency a significant factor in the success of the software. From a larger perspective, advanced mission management software is expected to help resolve the tensions of flying UAVs near manned vehicles and in civilian airspace by enabling real-time de-confliction (Newcome, 2002)

4.1.6.1 Autonomy

Autonomy and automation are often used interchangeably, creating considerable confusion as to what mission management technologies might contribute. This report defines *automation* to mean that the vehicle or MCS can sense and act by following a script or computing directly from a perfect model of the vehicle, environment, and mission. Fly-by-wire flight control is an example of automation, with waypoint navigation and mission scripting as examples of the automation of extremely constrained mission management functions. *Autonomy* means that the vehicle or MCS can identify situations (or opportunities) outside of a pre-computed script, plan the appropriate response in real-time, and execute the plan. Tactical re-planning based on vehicle health management, adversarial intent, and pop-up threats is an example of an activity that necessitates autonomy and cannot be handled by automation. Another set of examples are those involving the dynamic re-tasking of the mission or changing the roles or composition of a team of UAVs. The flavor of autonomy is quite different than that of automation, and successful automation techniques (e.g., flight control technology) and programming methods (e.g., rule-based systems) do not extend well into autonomy. Since the long-term efficacy of mission management software will rely on advances in autonomy, not automation, it is clear that this is a critical enabler.

4.1.6.2 Human-System Integration (H-SI)

Human-System Integration (H-SI) allows human operators to effectively monitor and understand system status and behaviors and to effectively control or affect system behaviors in ways that meet mission goals. H-SI refers to not only the controls and displays provided to the operator (the human computer interface or HCI), but also the functional interactions between the human and the system actually performing the operations. For example, in a typical UAV MCS, the H-SI includes: 1) the visual, auditory and tactile displays for monitoring the status of UAV components, UAV flight parameters, environmental, geospatial and mission status information, and payload data acquired through the system; 2) controls provided for vehicle/payload operation (whether through a stick or computer based command inputs) and communications; and, 3) the logic or procedures required to interact with the system to perform tasks, the functionality assigned to human and machine components including any automation provided, and the means the operator has for intervening in autonomous system behaviors. In addition, the dynamic allocation of functions between the human and the system and the rules or methods guiding this allocation is fundamental to H-SI.

4.1.6.3 Selection, Training and Proficiency

For purposes of this study, UAV personnel will include the individuals and teams who control and operate the vehicle (this is independent of their status as pilots), who manage and control the onboard sensors/special equipment, and who plan and direct missions (i.e. mission commanders). Issues of selection and training of and achievement and maintenance of proficiency for these personnel have not yet been adequately addressed. *Selection* refers to the process by which personnel are identified from an

AF-wide population for UAV operations, which may involve a skills battery or specialized experience. *Training* then provides these personnel with a standard set of skills necessary to operate UAVs in the battlespace and in national and international airspace. Depending on the predefined set of incoming skills, operator training may involve simulator training, actual flight training, air traffic communication skills development, etc. Finally, for maintaining operator *proficiency*, continued operational experience in the battlespace and national/international airspace is desired. This may involve periodic evaluation, re-training/re-certification, and feedback to the UAV operators in the line. Additionally, career progression and retention issues must be addressed to assure that UAV assignments will continue to attract top-quality personnel.

4.1.6.4 Design Methodology and Testing

The Air Force has institutionalized processes and tools to address the effective integration of human and automated resources in operations of manned weapon systems. Comparable design methods and testing procedures have yet to be applied systematically to mission management of UAV systems. Because of the critical impact of human performance on system effectiveness *and* the novel functions anticipated for future UAVs, it is essential that the Air Force adopt and apply a *formal process* for UAV human-system integration. This process should require a thorough analysis of the functions to be performed in relation to the capabilities and limitations of the available human and automation resources. This methodology should be applied in a disciplined fashion from the earliest stages of system requirements definition through final qualification testing. Once the function allocation is established (and it is likely to be dynamic over the course of a mission), the operator interface design can be developed and refined through the application of established human engineering principles and rapid prototyping of display and control concepts. The utility of the final system (including hardware, software, and human elements) should then be evaluated using full-mission simulation, with representative operational personnel, realistic mission scenarios, and objective performance criteria.

4.1.6.5 Mixed Traffic Operations

As UAVs become a part of normal operations, the Air Force will no longer be able to contain all UAV operations within restricted airspace for training and testing. Deployment flexibility will also require more UAVs to be ferried, rather than crated and shipped. Mixed operations present challenges in three distinct types of airspace: battlespace, U.S. civil (“national”) airspace, and international airspace. Although there are substantial differences between them, the UAV is in each case expected to see and be seen by other traffic, as well as communicate its intentions sufficiently. In national airspace, this challenge is best characterized by the FAA requirement for pilots to “see-and-avoid” (S&A) other aircraft, with or without Air Traffic Control (ATC) services. Combat operations require traffic separation as well as IFF and weapons release de-confliction. Operations in other countries also require some form of collision avoidance once appropriate over-flight rights have been gained.

4.2 Findings

The findings of the panel are organized by mission management technology areas and issues. While the panel identified specific technology gaps by area, it also identified equally important issues in the software engineering process of creating effective mission management software.

4.2.1 Autonomy

Flight management is today largely automated, and it works well within a limited “sense-act” paradigm. Flight automation is, however, limited to mission scenarios in which there is a predictable ordering of actions and to contingencies that can be identified and planned for manually prior to the mission. As noted earlier, this makes the mission both *vulnerable* to human error in planning, and *brittle* due to an inability to deal with unanticipated situations. And this approach will not scale up as UAVs become more numerous and better integrated in the AF. Effective mission management (MM) will require autonomy (sense-plan-act) and a strategic investment by the AF to ensure fielding.

Current autonomy research results can now support limited vehicle functions, though (as would be expected for new research) these results are piecemeal and ignore system integration issues. Rudimentary system monitoring and health reporting functions are now available, though these methods are generally limited to complete failures (e.g., a report of sensor failure instead of a report noting that a sensor produces subtly anomalous readings) and assume the occurrence of only a single failure. The lack of system monitoring and health reporting also affects the logistic footprint of UAVs; the panel found that the Global Hawk currently requires 105-120 persons for 24/7 coverage, most of whom are associated with maintenance and support functions. Significant progress has been made in limited re-planning for known contingencies, particularly real-time flight path planning. The panel found that work in these areas should be continued. Navigation and sensor/payload management (tracking, viewpoint planning) are well understood and suitable for onboard autonomy.

The panel also identified areas in vehicle autonomy research that are not being adequately addressed. More work is needed to extend and develop autonomous methods for:

- ***Real-time detection, diagnosis, and recovery under multiple failures*** to achieve higher degrees of vehicle reliability. These methods will also aid with overall vehicle survivability and mission performance through the vehicle’s ability to reconfigure itself to deal with failures and proceed with the mission.
- ***Machine perception and situational awareness*** are critical attributes of mission management software. Advances in machine perception (whereby sensor data is transformed into actionable information that can be manipulated by computers or humans) are needed to support situation awareness. The panel notes that advances in sensors do not by themselves necessarily lead to advances in perception.
- ***Reasoning about unexpected changes and uncertainty software*** capable of handling unexpected changes in the operational environment (e.g., lost communications during severe weather). These problems are being explored by academic and commercial systems, but the issues of most relevance are being ignored. In particular, the USAF needs an uncertainty management calculus that allows the system to identify low probability, high-risk events While handling large numbers of variables in real time.
- ***Dynamic mission planning*** (e.g., opportunistically re-planning in response to a new threat or pop-up target) is a key area, requiring advances in automated machine perception, recognition, representation, and real-time planning under uncertain conditions.
- ***Multi-vehicle coordination and cooperation*** has been explored in academia, but often in low-fidelity simulations with unrealistic assumptions about communications and inter-vehicle sensing. The role of the human operator in coordination and cooperation with vehicles or agents operating with degrees of autonomy, as well as trust in those systems, is largely ignored.

The panel also found that there is an inadequate understanding of the trade-offs between on-board autonomy located on the vehicle and intelligent decision aids on the ground and their impact on performance. This is of fundamental importance, since it effects the overall design of the system, including communications, and the priorities for future research.

4.2.2 Human-System Integration (H-SI)

As shown in Figure 4-2, statistical data on UAV accidents and incidents highlights the contribution of H-SI design to operational safety. The panel found that insufficient attention to operator issues is the major limitation to current operations and will continue to lead to UAV incidents and losses if it is not explicitly addressed as part of a mission management system (note the growing trend over time shown in the figure). Currently, 59%-76% of current UAV losses can be attributed to "human error" or poor H-SI design. According to Seagle (1997), human factors problems contributed to 59% of Pioneer crashes, while another study on the Predator (Draper, 2003) found that 76% of the incidents reviewed involved human factors errors. While some may involve issues of operator training and experience, the vast majority can be traced to deficiencies in the interface.

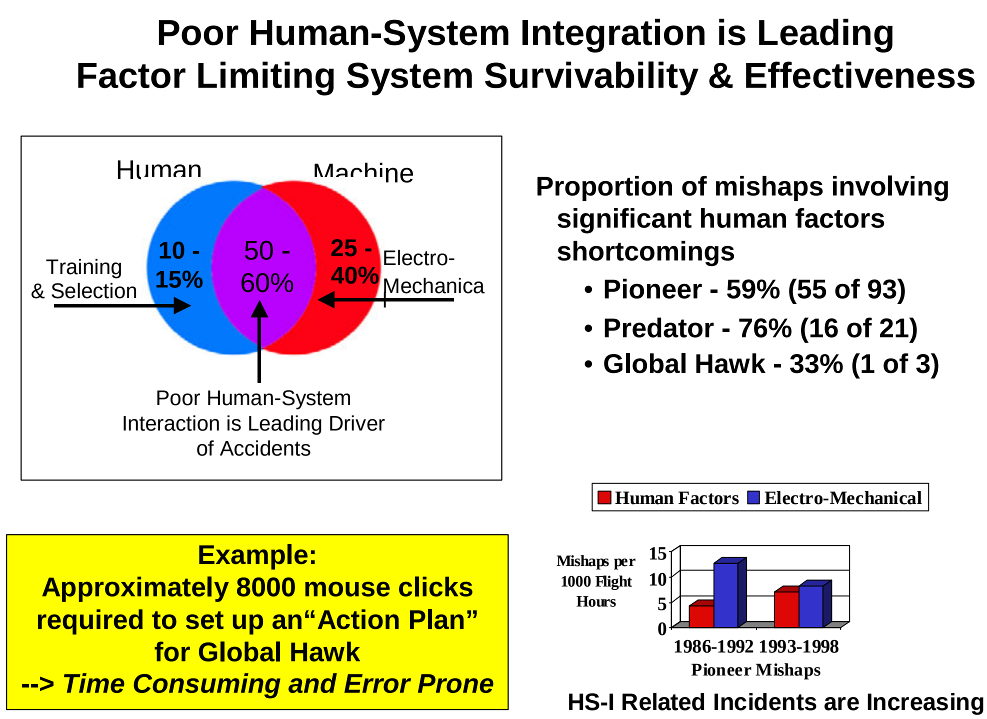

Figure 4-2. *Impact of human-system integration deficiencies on UAV mishaps*

Human operators and support personnel retain important roles for UAVs, and will continue to do so in the future, particularly with increased system autonomy. Since it is unlikely that fully autonomous systems will be developed in the foreseeable future, the partially autonomous systems that *are* fielded will still require the flexibility and ingenuity of humans to react dynamically to situational and mission changes. As long as human operators are required, whether just for pre-mission specification of UAV missions and priorities, or to provide supervisory control during mission execution, it will be necessary to insure that human operators are able to perform their role effectively. Any neglect of this important system component will lead to significant reductions in overall system survivability and mission effectiveness.

High levels of situation awareness (SA) are needed to control or oversee the mission performance of UAVs; this is, however, currently very difficult to obtain and will be even more challenging in the future with higher levels of mission complexity, system autonomy, and supervisory control of multiple vehicles per operator. Losses or errors in SA account for between 60 and 88% of human error in current *manned* aircraft systems (Prince et al, 1993, Endsley, 1995b). The SA requirements for a UAV are basically the same as those of a manned platform. However, visual, aural, and vestibular cues are degraded or absent for the UAV operator, posing significant hindrances to SA. As mission control software employs increasing amounts of automation and system autonomy to make possible lower operator to vehicle ratios, even greater challenges to SA will be encountered (Endsley and Kiris, 1995; Ephrath and Young, 1981; Wickens and Kessel, 1979; Young, 1969). Significantly new interfaces and H-SI approaches are needed to provide operators with the high levels of SA needed to monitor and interact with more intelligent and autonomous vehicles.

In addition to the individual findings, the panel found that the Air Force is not now addressing H-SI issues adequately in current system acquisitions or research programs. Current Predator and Global Hawk displays and operator stations do not meet basic human factors guidelines or standards; rather they appear to have been developed outside of state-of-the art cockpit design or human-systems engineering processes and standards. These deficiencies can be linked directly to many UAV losses. In one Global Hawk crash, for example, a programming error was faulted for causing the vehicle to taxi at too high a rate of speed. Deficiencies such as these can be easily prevented and operator error significantly reduced with adequate attention to the design of the human interface.

4.2.3 Design Methodology and Testing

In keeping with the holistic philosophy of the study, the panel considered how mission management is designed and tested. The panel found a disturbing lack of a coherent and systematic approach to H-SI design and testing, given the fundamental importance of H-SI to effective mission management. In particular, methods to establish a reasonable allocation of responsibilities between humans and automation remain inadequate for dealing with more complex automation and autonomy. Mission management software can not ultimately be effective or delivered on time unless the functional allocation has been established in the initial system design stages, taking dynamic reallocations that inevitably occur during complex mission execution into account, and taking the resulting impact on both operator situation awareness and workload into consideration. In practice, the lack of a principled approach to function allocation leads to a vacuum which is filled by a techno-centric approach in which engineers automate that which is easy to automate, leaving the rest for the human to handle. This approach has been shown through some three decades of research to be directly responsible for poor human performance in controlling and interacting with automated systems and resultant human-system failures, incidents, and accidents (Billings, 1987; Wiener & Curry, 1980). Beyond function allocation, the panel found evidence that lack of attention to established human engineering principles in the design of UAV mission control stations has contributed substantially to UAV mishaps (see Fig. 4-2).

The panel also found a significant under-utilization of human-in-the-loop simulation to objectively evaluate mission management components. Without objective evaluation under both normal and abnormal conditions, it is difficult to determine, for example, a realistic operator-vehicle ratio for a particular mission or a method to identify deficiencies in mission-management software to improve that ratio. Simulation could be used in most cases to establish function allocation between the vehicle, MCS, and human operator, the appropriate levels of vehicle automation and ways to support changes in those levels as the mission changes or progresses, alternatives for operator decision aids, and all aspects of the human interface design. Critical factors that must be evaluated objectively during such testing include operator situation awareness, workload levels, and performance in a wide range of tasks. Without a systematic application of such testing methodologies and processes, it is unlikely that many latent system problems will be discovered prior to critical human-system failures in actual operations.

Finally, the panel found that many software development advances and best practices have been largely ignored, perhaps because of the rapid fielding of technology prototypes. This impacts both costs and acceptance. For example, nascent efforts in designing common architectures could be exploited for cost effective and more capable software across vendors. The lack of a structured software development process poses problems for UAVs, which must have flight-critical software (in this case mission management) certified in order to fly over populated areas.

4.2.4 Mixed Traffic Operations

The panel found that UAVs will increasingly be operated with manned aircraft in the battlespace, and in national and international airspace. The problems in the battlespace are different from those of civilian airspace. In the battlespace, the technological issues are characterized by the need for adaptation and re-planning on the fly and operations under emissions control (EMCON) conditions. Problems in civilian airspace are less technological and more policy oriented. They are characterized by an air traffic system that mixes controlled traffic [primarily instrument flight rules (IFR)] and visual flight rules (VFR) traffic that may or may not be under Air Traffic Control. The FAA is currently imposing a “see and avoid” capability on manned traffic, which has serious limitations (Newcome, 1998, 2003; Matthews, 2001; Veillette, 1991). The FAA’s parallel imposition of “see and avoid” on UAVs extends these limitations, while simultaneously transforming a relatively simple technological approach to conflict detection into one that is difficult to achieve for UAVs *without* a real-time, low-latency, high-resolution wide field-of-view imaging system (and possibly a dedicated ground operator to monitor this imagery). A more qualitative finding is that pilots appear to resist broad integration of UAV operations in their airspace (especially in riskier missions). For example, in one operation, many U-2 pilots did not want to fly within 25-100 miles of a Global Hawk. Whatever approach the Air Force takes toward mixed traffic management, the panel believes it is likely that UAVs will be held to a much higher standard of flight safety than current manned operations.

Selection, Training and Proficiency

In 1996, the Chief of Staff of the Air Force affirmed a decision that only rated aviators could operate UAVs. However, little quantitative data exists that identifies the best qualifications for UAV operations and the recency and proficiency required for effective operations. A handful of research studies suggest that flying skills may be less important than other cognitive skills (e.g., Predator operations, Schreiber et al., 2002; Barnes et al., 2000), mission operation skills (Cornell University, 2003), or air traffic communication skills (Biggerstaff et al., 1998). This issue is further complicated by current federal regulations for various classes of UAVs. Tthe FAA, for example, does not regulate operators of very low altitude UAVs, but requires that operators of medium and high-altitude UAVs be IFR-qualified, certified pilots. A wide range of autonomous vehicles could potentially be operating at each of these altitudes, but right now there is a paucity of quantitative data which could serve as a more scientific basis for defining UAV operator qualifications and certification. The panel also found that accountability and responsibility for targeting and releasing weapons is particularly thorny. The Law of Armed Combat suggests that only a military member may be responsible for releasing weapons; precedence has, however, primarily assigned this responsibility to commissioned officers and the inertia may be difficult to overcome.

Training methods and mission management proficiency requirements for UAV operators are not known at this time. Predator and Global Hawk operators, however, can serve as useful starting points. “Stick-and-rudder” flying skills were more relevant to daily operations, especially with Predator. Interestingly, a study by Schreiber et al. (2002) suggests that civilian pilots and even non-pilots successfully used “stick-and-rudder” skills to fly a Predator simulator at levels comparable to highly experienced pilots (but not yet trained to fly Predator). As UAVs come into the AF inventory with greater levels of autonomy, “stick-and-rudder” flying skills will take a back seat to the cognitive skills necessary for understanding and operating them in the airspace (Schreiber et al., 2002; Barnes et al., 2000; Cornell University, 2003;

Biggerstaff et al., 1998). Furthermore, the autonomy of these UAVs is likely to vary dynamically over the course of a mission, making it particularly important for operators to be well equipped and trained to handle the changes.

In addition, the panel found that there is a lack of coherent and systematic approach to transfer lessons learned between platforms and from the field. Such approaches do exist; see, for example, Biggerstaff et al. (1998) for a study stating the importance of transferring lessons learned from experienced to novice operators.

Finally, the panel notes that career path and pay considerations have significant impacts on the ability to recruit and retain operators. There is no assured career progression for UAV operators comparable to that of manned aircraft operators and the retention rate is not known. Promoting experienced operators may or may not require a unique career field in the personnel system.

4.3 Recommendations

The panel recommends five actions to be taken to enable our vision for UAV mission management:

4.3.1 Immediately fix existing operator interfaces for currently fielded systems to incorporate current human engineering standards and best practices for supporting human performance.

Most Predator and Pioneer losses have been due to "human error", with most of those errors attributable to deficiencies in the operator interface (Seagle, 1997; Draper, 2003). Moreover, of the four Global Hawk losses that have occurred to date (out of 7 manufactured systems), one accident can be directly traced to H-SI deficiencies and one could possibly have been prevented with better feedback to the operator. As system-related faults are eliminated over time, it is expected that the proportional number of human factors related losses will increase, as has been the trend with other aircraft. The rate of UAV losses can be dramatically reduced within six months to one year by re-engineering the existing operator interfaces to meet current human factors standards, H-SI design methodologies, and best practices already used by USAF and the human factors design community. The Air Force system program offices (SPOs) for these programs should be directed to require such redesigns by qualified personnel employed by knowledgeable contractors. This is the single most important immediate step the Air Force can take to extend the life of its existing UAV fleet and reduce the likelihood of further vehicle loss and potential collateral damage.

4.3.2 Invest in a transition infrastructure specifically tailored for mission management S&T products.

Experience with currently fielded UAVs highlights the absence of an existing infrastructure for transitioning of mission management software. Under the current vehicle development model, mission management has not been considered an enabling technology component but rather something that a human does (unfortunately, not always well). Mission management software is integrative and requires a different supporting infrastructure. A mission management system will consist of many types of intelligent algorithms that must be harnessed to an operational system with sizeable human-system interaction. However, most software development facilities can only support unit testing, and no laboratory or university has a true systems-level testbed at the required level of fidelity. The concept of a dedicated testbed facility for development and transition of UAV mission management technologies is illustrated in Figure 4-3. The creation of such a testbed will help eliminate inevitable mis-matches in design assumptions, detect subtle software bugs, and provide rapid feedback from the field as to what really works, all in a manner that accelerates the transitioning of critical UAV MM technology to developing and fielded systems.

Figure 4-3. *Concept for a UAV Mission Management Testbed*

The panel's recommendation for establishing a transition infrastructure consists of two parts:

Host Dedicated ATD for Mission Management

An ATD dedicated specifically for mission management should be initiated within the next year to 18 months to determine the best design approaches and transition to operational systems. In addition, a UAV autonomy focus should be included in the next UAV-related ATD and autonomy should be evaluated in an operational exercise.

Establish Permanent Testbeds

We recommend that two mission management testbeds be established through a competitive procurement. The first testbed would provide an accelerated means to 'spiral' validated mission management technologies into operational UAV systems, and as such should be co-located with an existing facility such as a battle lab or the experimental Combined Air Operations Center (CAOC-X) at Langley. The second testbed would provide an operationally relevant but remotely accessible infrastructure, to focus the R&D community on critically needed mission management technologies. This would also provide a means to ensure the development and dissemination of reference architecture and more effective software development methodologies for ground and UAV systems.

4.3.3 Incorporate a process for current human engineering standards and best practices for supporting human performance

This recommendation can be broken down into two separate action items:

Enforce rigorous testing and prototyping with regard to human engineering in the acquisition process. The Air Force should use available simulation facilities (including the recommended testbed facility) for prototyping and simulation of alternative UAV mission management concepts and validation/qualification of MCS functionality. This should include exploration of mission management CONOPS, assessment of alternative human-machine task allocations, evaluation of emerging human interface technologies, and testing of optimum crew-vehicle operator ratios for multi-vehicle mission applications. These tests should use representative operational personnel in realistic mission environments. Evaluations should employ objective performance criteria along with subjective analysis.

Impose a Human Engineering/Systems Engineering process on the SPO. A formal human engineering program should be required for future AF UAV technology demonstrations and development/acquisition programs. The human engineering program should be structured according to MIL-H 46855 and tailored to provide the necessary flexibility to accommodate evolving requirements and/or emerging technologies consistent with a spiral/incremental acquisition strategy. This program should include requirements for objective testing and demonstration of H-SI effectiveness.

4.3.4 Develop a strategic research vision for MM and follow through by coordinating and investing in focused research programs on key technology enablers

Basic and applied research is needed to create the requisite vehicle autonomy and decision assistance required for mission management in HDHD operations. The panel, however, found that research programs in autonomy are often too broad or don't address relevant components. In order to bootstrap mission management development, the panel recommends that the Chief Scientist incorporate this study's autonomy research priorities into AF research agenda and fund through memoranda of agreement (MOAs) with DARPA. It is expected that the development of mission management software will lead to fundamental advances in vehicle autonomy and decision support, which can then be used throughout the AF.

Within the research agenda, the following technologies need considerable investment or a UAV focus with an experimental goal of transitioning to a permanent testbed:

- **Interfaces to support rapid shifts in control between human operator & autonomous system.**
- **Automation and autonomy approaches to support operator situation awareness at acceptable levels of workload.**
- **Methods and approaches for building human understanding of autonomous systems operations with appropriate levels of confidence.**
- **Interfaces to support SA of multiple vehicle operations at manageable workload levels, including monitoring, diagnosis and mission and payload management.**
- **Determination of the appropriate skills required for UAV operations, including cognitive abilities and requirements for interacting with other air vehicles and mission operations.**

4.3.5 Facilitate rapid integration of new UAV capabilities within the organizational and operational environment

Based on experience with current technology demonstrators, new UAV capabilities need to be usable within the operational environment, and organizational infrastructure. This recommendation could be accomplished through:

- **Aggressively participating in programs such as "Access 5" and NATO's Rights in Technical Data Working Group (RTWG) to allow safer integration of manned and unmanned platforms, and to overcome ATC procedure shortfalls.**
- **Promoting Blue Force Tracking in the battlespace and GPS-based tracking in civilian airspace for normal (unfailed) conditions and some means of secure communications of intended flight plans.** This is an action already in place, but it needs support. It should then be extended to battlefield airspace, with secure and non-secure communications and the possibility of non-cooperative targets.
- **Advocating standards and programs to build an "airborne Internet", providing a wideband communications capability with and between air vehicles worldwide.** NASA and commercial work on an airborne Internet establishes a baseline proof-of-feasibility but is insufficient. Military UAVs should form an ad hoc high-bandwidth, multi-hop airborne network, with each UAV serving as a hub and a subscriber to the network. This will allow the huge bandwidths and very low latencies needed to support UAVs for the set of envisioned missions.

Within the organization of the USAF itself, new UAV capabilities would be facilitated via the following actions:

- ***Base UAV selection, training, and proficiency requirements on data.*** This will improve performance and reduce training costs while increasing proficiency, and may aid with operator retention.
- ***Develop a system for recording/transferring lessons learned in the field to training programs and to other UAV programs [e.g., an analog to the Aviation Safety Reporting Service (ASRS)].*** This will greatly speed up the development of effective strategies and increase the overall expertise and effectiveness of UAVs.
- ***Ensure career progression and retention for UAV operators comparable to that of manned aircraft operators.*** This will aid operator retention and should encourage the acceptance of UAVs into normal USAF operations.

The recommendations address both tangible research objectives as well the infrastructure for, and process of, MM technology development. The benefits of these actions span the near-term to long term time-frame, with an expected immediate decrease in UAV incidents or crashes.

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References

Billings, C. E. (1988). Toward human centered automation. In S. D. Norman & H. W. Orlady (Eds.), *Flight deck automation: Promises and realities* (pp. 167-190). Moffet Field, CA: NASA-Ames Research Center.

Billings, C. E. (1997). *Aviation automation: The search for a human-centered approach*. Mahwah, NJ: Lawrence Erlbaum.

Burlingame, J. (2003), "Remote split operations and Predator operations center – Nellis" Briefing to SAB, 12 April.

"Detect, See and Avoid: Demonstration shows separation can be maintained", *NASA Dryden*, Press Release, April 2003.

Endsley, M. R. (1996). Automation and situation awareness. In R. Parasuraman & M. Mouloua (Eds.), *Automation and human performance: Theory and applications* (pp. 163-181). Mahwah, NJ: Lawrence Erlbaum.

Endsley, M. R., Bolte, B., & Jones, D. G. (2003). *Designing for situation awareness: An approach to human-centered design*. London: Taylor & Francis.

Endsley, M. R., & Kaber, D. B. (1997). The use of level of automation as a means of alleviating out-of-the-loop performance problems: A taxonomy and empirical analysis. In P. Seppala, T. Luopajarvi, C. H. Nygard & M. Mattila (Eds.), *13th Triennial Congress of the International Ergonomics Association* (Vol. 1, pp. 168-170). Helsinki: Finnish Institute of Occupational Health.

Endsley, M. R., & Kaber, D. B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. *Ergonomics, 42*(3), 462-492.

Endsley, M. R., & Kiris, E. O. (1995). The out-of-the-loop performance problem and level of control in automation. *Human Factors*, *37*(2), 381-394.

Endsley, M. R., & Selcon, S. J. (1997). *Designing to aid decisions through situation awareness enhancement.* Paper presented at the 2nd Symposium on Situation Awareness in Tactical Aircraft, Patuxent River, MD.

Endsley, M. R., Sollenberger, R., & Stein, E. (1999). *The use of predictive displays for aiding controller situation awareness.* Paper presented at the 43rd Annual Meeting of the Human Factors and Ergonomics Society, Santa Monica, CA.

Ephrath, A. R., & Young, L. R. (1981). Monitoring vs. man-in-the-loop detection of aircraft control failures. In J. Rasmussen & W. B. Rouse (Eds.), *Human detection and diagnosis of system failures*. New York: Plenum Press.

"Flying blind seems safe", *Nature*, 12 March 2002.

Fontejon, L. and Draper, M. (2001) Analysis of Predator mishap data. Unpublished report. Wright-Patterson AFB, OH: Air Force Research Laboratory.

Godfrey, J., Patrey, J., and Jones, K. (2003) The role of human factors in uninhabited aerial vehicle mishaps. Colorado Springs, CO: United States Air Force Academy.

Kibbe, M., & McDowell, E. D. (1995). Operator decision making: Information on demand. In R. Fuller, N. Johnston & N. McDonald (Eds.), *Human factors in aviation operations* (Vol. 3, pp. 43-48). Aldershot, UK: Avebury.

Layton, C., Smith, P. J., & McCoy, C. E. (1994). Design of a cooperative problem-solving system for en-route flight planning: An empirical evaluation. *Human Factors*, *36*(1), 94-119.

Matthew, R.C. (2001). "Characteristics of U.S. Midairs", FAA Aviation News, May/June, http://www2.faa.gov/avr/afs/news/archive/mayjune/Midair.htm.

McClumpha, A., & James, M. (1994). Understanding automated aircraft. In M. Mouloua & R. Parasuraman (Eds.), *Human performance in automated systems: Current research and trends* (pp. 183-190). Hillsdale, NJ: LEA.

Miller, C. A., Pelican, M., & Goldman, R. (1999). *Tasking interfaces for flexible interaction with automtion: keeping the operator in control.* Paper presented at the International Conference on Intelligent user interfaces, Redondo Beach, CA.

Newcome, L. (1998). "FAA-Type Regulations Will Allow UAVs To Grow" Aviation Week, http://www.aviationnow.com/content/ncof/ncfv18.htm.

Newcome, L. (2003). "OSD Support to 'See and Avoid'" Briefing to OSD, June.

Olson, W. A., & Sarter, N. B. (1999). *Supporting informed consent in human machine collaboration: The role of conflict type, time pressure, and display design.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting, Santa Monica, CA.

Parasuraman, R. (1993). Effects of adaptive function allocation on human performance. In D. J. Garland & J. A. Wise (Eds.), *Human factors and advanced aviation technologies* (pp. 147-158). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model of types and levels of human interaction with automation. IEEE Transactions on Systems, Man and Cybernetics,*30*(3), 286-297.

Pritchett, A. R., & Hansman, R. J. (1997). *Pilot non-conformance to alerting system commands.* Paper presented at the Ninth International Symposium on Aviation Psychology, Columbus, OH.

Sanders, M. S., & McCormick, E. J. (1992). *Human factors in engineering and design* (Seventh ed.). New York: McGraw-Hill.

Sarter, N. B., & Schroeder, B. (2001). Supporting decision making and action selection under time pressure and uncertainty: The case of in-flight icing. *Human Factors*, *43*(4), 573-583.

Sarter, N. B., & Woods, D. D. (1995). "How in the world did I ever get into that mode": Mode error and awareness in supervisory control. *37*(1), 5-19.

Seagle, Jr., J.D. (1997). *Unmanned aerial vehicle mishaps: A Human Factors approach*, Masters Thesis, Embry-Riddle Aeronautical University, Norfolk, Virginia.

Selcon, S. J. (1990). *Decision support in the cockpit: Probably a good thing?* Paper presented at the Human Factors Society 34th Annual Meeting, Santa Monica, CA.

Sheridan, T. (1992). *Telerobotics, automation and human supervisory control*. Cambridge, MA: MIT Press.

Sheridan, T. B., & Verplanck, W. L. (1978). *Human and computer control of undersea teleoperators*. Cambridge, MA: MIT Man-Machine Laboratory.

Smith, P. J., McCoy, E., Orasanu, J., Denning, R., Van Horn, A., & Billings, C. (1995). *Cooperative problem solving in the interactions of airline operations control centers with the national aviation system*. Columbus, OH: Cognitive Systems Engineering Laboratory, Ohio State University.

USAF Aircraft Accident Investigation Board Report RQ Global Hawk UAV, 98-2003, Runway 22, Edwards AFB, 06 Dec 1999

USAF Aircraft Accident Investigation Board Report, RQ4-A Global Hawk, 98-2005, Forward Operating Location, 30 Dec 2001

Vakil, S. S., & Hansman, R. J. (1998). *Operator directed common conceptual models for advanced automation.* Paper presented at the 17th Digital Avionics Systems Conference, Seattle, WA.

Veillette, P. (1991) Study performed for Transportation Research Board.

Wickens, C. D. (1992). *Engineering psychology and human performance* (2nd ed.). New York: Harper Collins.

Wickens, C. D., & Kessel, C. (1979). The effect of participatory mode and task workload on the detection of dynamic system failures. *IEEE Transactions on Systems, Man and Cybernetics, SMC-9*(1), 24-34.

Wiener, E. L. (1985). *Cockpit automation: In need of a philosophy.* Paper presented at the 1985 Behavioral Engineering Conference, Warrendale, PA.

Wiener, E. L. (1988). Cockpit automation. In E. L. Wiener & D. C. Nagel (Eds.), *Human Factors in Aviation* (pp. 433-461). San Diego: Academic Press.

Wiener, E. L., & Curry, R. E. (1980). Flight deck automation: Promises and problems. *Ergonomics*, *23*(10), 995-1011.

Young, L. R. A. (1969). On adaptive manual control. *Ergonomics*, *12*(4), 635-657.

Appendix A
Terms of Reference

Unmanned Aerial Vehicles in Perspective: Effects, Capabilities, and Technologies
Terms of Reference

BACKGROUND

Unmanned aerial vehicles (UAVs) were used successfully to conduct critical missions in the recent Kosovo and Afghanistan conflicts, and as a result, renewed interest and activity is being directed toward increasing both the number and capabilities of UAVs. Planning for the introduction of unmanned aircraft into the force structure raises a number of questions, such as

1. What effects are best accomplished by unmanned aircraft?
2. What are the features that make unmanned aircraft superior to manned aircraft for specific missions and what are those missions?
3. What are the appropriate roles of manned and unmanned aircraft to accomplish the desired effects?
4. What flight management technologies and processes are needed when unmanned aircraft are used in close proximity to manned aircraft?
5. What are the correct metrics to test the contribution of unmanned aircraft to warfighting capabilities?
6. What is the right path for the development and integration of unmanned aircraft into the force structure?

The Air Force needs to understand and develop the concepts of operation, technology alternatives, and development and demonstration plans to effectively integrate and use these emerging new capabilities in the operational air forces.

Study Products

Briefing to SAF/OS & AF/CC by August 2003. Publish report by December 2003.

Charter

The goal of the 2003 SAB Summer Study is to take a considered look at the appropriate evolution of Air Force capabilities using unmanned aircraft. The study will have two main focus areas. The first focus area is the development of concepts of operation for UAV employment in combat and non-combat roles. The second focus area is technology development and demonstration – the readiness and suitability of hardware and software systems for a range of possible aircraft configurations. The related issues of weapons, sensors, communication, logistical support, and basing will be addressed but not studied in depth.

Building on previous SAB studies, the study will

- Provide notional concepts of operation that support the operational capabilities addressed in the study and address issues that may affect management processes or technology design and development.

- Consider innovative missions for unmanned aerial vehicles that are not just a replication of manned missions and the features that make unmanned aircraft superior to manned aircraft for specific missions.

- Consider the evolution of roles and the appropriate division of tasks for manned and unmanned aircraft over a spectrum of possible applications – from fighters and bombers to transports and reconnaissance aircraft in the near-, mid-, and far-term.

- Survey and recommend air vehicle platform and software technology needs and availability – such as avionics, propulsion, flight control, and stealth. Consider the flight management technologies and processes that are needed when unmanned aircraft are used in close proximity to manned aircraft.

- Consider how the Air Force tests the contribution of unmanned aircraft to warfighting capabilities including the development of the test and demonstration metrics.

- Recommend technology and system capabilities development and demonstration plans.

Appendix B
Study Organization

Study Chairman
Dr. Ray O. Johnson

Vice Study Chairman
Dr. Malcolm R. O'Neill, (Lt Gen, USA Retired)

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Appendix C
Acronyms and Abbreviations

AAIB	Air Accident Investigation Board
AAR	Automated Aerial Refueling
A/C	Aircraft
ACC	Air Combat Command
ACM	Advanced Cruise Missile
ACTD	Advanced Concept Test Design
AEA	Airborne Electronic Attack
AEHF	Advanced Extremely High Frequency
AEW	Airborne Early Warning
AF	Air Force
AFB	Air Force Base
AFC2ISRC	Air Force Command, Control, Intelligence, Surveillance, and Reconnaissance Center
AFRL	Air Force Research Laboratory
AFRL/DE	Air Force Research Laboratory Directed Energy Directorate
AFRL/MN	Air Force Research Laboratory Munitions Directorate
AFRL/PR	Air Force Research Laboratory Propulsion Directorate
AFRL/VA	Air Force Research Laboratory Air Vehicles Directorate
AFSAB	Air Force Scientific Advisory Board
AFSOC	Air Force Special Operations Command
AMRAAM	Advanced Medium-Range Air to Air Missile (AIM-120)
AO	Area of Operations
AoA	Analysis of Alternatives
AOC	Air Operations Center
APU	Auxiliary Power Unit
ASC	Aeronautical Systems Center
ASRS	Aviation Safety Reporting System
ASW	Antisubmarine warfare
ASuW	Anti-surface warfare
ATC	Air Traffic Control
ATD	Advanced Technology Demonstration
AT&L	Acquisitions, Technology, and Logistics
AT3	Advanced Tactical Targeting Technology
ATR	Automatic Target Recognition

AWACS	Air Warning and Control System
BAT	Brilliant Anti-Armor Submunition
BDA	Battle Damage Assessment
BIC	Business Initiative Council
BLOS	Beyond Line of Sight
BMC2	Battle Management Command and Control
BPI	Boost-Phase Intercept
BVRAAM	Beyond Visual Range Air-to-Air Missile
C2	Command and Control
C2TIG	Command and Control Training and Innovation Group
C3	Command, Control and Communications
C4	Command, Control, Communications, and Computers
C4ISR	Command, Control, Communications, Computers, and Intelligence, Surveillance and Reconnaissance
CAOC-X	Combined Air Operations Center, Experimental
CAP	Combat Air Patrol
CAPT	Captain
CAS	Close Air Support
CBR	Chemical, Biological, and Radiological
CBRNE	Chemical, Biological, Radiological, Nuclear or High-Yield Explosive
cc	Cubic Inches
CDL	Common Data Link
CFD	Computational Fluid Dynamics
Chem/Bio	Chemical/Biological
CIA	Central Intelligence Agency
CM	Conventional Munition
COMM	Communications
CONEMP	Concept of Employment
CONOPS	Concept of Operations
COTS	Commercial Off-the-Shelf
CSAR	Combat Search and Rescue
CUTLASS	Combat Uninhabited Target Locate and Strike System
CWIN	Cyber Warning and Information Network
DSB	Defense Science Board
DARPA	Defense Advanced Research Projects Agency
DCA	Defensive Counter-Air
DCGS	Distributed Common Ground System

DE	Directed Energy
DEAD	Destruction of Enemy Air Defenses
DGPS	Differential Global Positioning System
DIAL	Differential Absorption Lidar
DMT	Distributed Mission Training
DoD	Department of Defense
ECM	Electronic Counter Measures
EMCON	Emissions Control
EMD	Engineering, Manufacturing, and Development
ENSIP	Engine Structural Integrity Program
EO	Electro-Optical
EO/IR	Electro-Optical/Infrared
ERGM	Extended Range Guided Munition
ESM	Electronic Support Measures
Exfil	Exfiltration
EW	Electronic Warfare
F2T2EA	Find, Fix, Track, Target, Engage, Assess
FAA	Federal Aviation Administration
FAC	Forward Air Controller
FM	Frequency-modulated
FMS	Flight Management System
FH	Flight Hours
G	Unit of Gravitational Force (also “g”)
GA	General Atomics
GCS	Ground Control Systems
GH	Global Hawk
GM	Global Mobility
GMTI	Ground Moving Target Indicator
GN&C	Guidance, Navigation, and Control
GPS	Global Positioning System
GR	Global Response
GS	Global Strike
GTE	Gas Turbine Engines
GTOW	Gross Take-Off Weight
HAE	high altitude endurance
HALE	High Altitude Long Endurance

HARM	High Speed Anti-Radiation Missile
HBPR	high bypass ratio
HCI	Human Computer Interaction
HDHD	high demand/high density
HDLD	high demand/low density
HLS	Homeland Security
HMI	Human Machine Interface
HPM	High Powered Microwave
Hr	Hour(s)
HS	Homeland Security
H-SI	Human-System Integration
HW/SW	Hardware/Software
IC	Internal Combustion
ICAO	International Civil Aviation Organization
ID	Identification
IFF	Identification of Friend/Foe
IFFN	Identification, Friend, Foe, or Neutral
IFR	Instrument Flight Rules
IFT	Initial Flight Training
IHPTET	Integrated High-Performance Turbine Engine Technology
Infil	Infiltration
INS	Inertial Navigation System
INU	Inertial Navigation Unit
IO	Information Operations
IP	Internet Protocol
IPT	Integrated Product Team
IR	Infrared
IRCM	Infrared counter measures
IRST	Infrared Search and Track system
ISR	Intelligence, Surveillance, and Reconnaissance
J8	Joint Staff Directorate for Requirements and Integration
JCM	Joint Countermeasures
JCS	Joint Chief of Staff
JDAM	Joint Direct Attack Munition
JSF	Joint Strike Fighter
JSOW	Joint Standoff Attack Weapon

JSSG	Joint Service Specification Guide
JSTARS	Joint Surveillance Target and Attack Radar System
JTRS	Joint Tactical Radio System
K	Kilo
Kg	Kilogram
Kft	1000 feet
Klbs	1000 pounds
Kts	Nautical miles per hours (also “knots”)
LADAR	Laser Radar (also LIDAR)
LAM	Loiter Attack Missile
Lbs	Pounds
LCDR	Lieutenant Commander
LCF	low cycle fatigue
LD/HD	Low Density/High Demand
LEO	Low Earth Orbit
LEWK	Loitering Electronic Warfare Killer
LGB	Laser Guided Bomb
LIDAR	Light Detection and Ranging
LOCAAS	Low Cost Autonomous Attack System
LO	Low-observable
LOAL	Lock after launch
LOS	line of sight
LP	Low Pressure
LPI/LPD	Low Probability of Intercept/Low Probability of Detection
LRS	Long Range Strike
LT	Lieutenant
LWIR	Long-Wave Infrared
MAE	Medium Altitude Endurance
MALD	Miniature Air Launched Decoy
MANPADS	Man-Portable Air Defense System
Mbs	Megabytes per second
MCE	Mission Control Element
MCS	Mission Control Station
Med	Medium
Medevac	Medical Evacuation
MM	Mission Management

MOA	Memorandum of Agreement
MP-CDL	Multi-Purpose Common Datalink
MRM	Medium Range Munition
MTI	Moving Target Intelligence
MTSI	Miniature Sensor Technology Integration
MUAVs	Micro or Miniature Uninhabited Aerial Vehicles
MUOS	Mobile User Objective System
MWIR	Medium Wave Infrared
Mx	Missile
NAS	National Airspace
NAVAIR	Naval Aviation Systems Command
NBC	Nuclear, Biological, and Chemical
NCO	Network-Centric Operations
NIIRS	National Imagery Interpretability Rating Scale
Nm	Nautical Miles
Non-pene	Non-Penetrating
NR	Nuclear Response
NRAC	Naval Research Advisory Council
NSA	National Security Agency
OEF	Operation Enduring Freedom
OEM	Original Equipment Manufacturer
OIF	Operation Iraqi Freedom
O&S	Operations and Support
OTS	Off The Shelf
OSD	Office of the Secretary of Defense
OTH	Over The Horizon
OUSD	Office of the Under Secretary of Defense
PAM	Precision Attack Missile
PGMM	Precision Guided Mortar Munitions
PLI	Position Location Information
Prot	Protection
PSYOPS	Psychological Operations
RAP	Required Aircrew Proficiency
Recce	Reconnaissance
Res	Resolution
Re	Reynolds number

RF	Radio Frequency
ROE	Rules of Engagement
RTB	Return to Base
RTWG	Rights in Technical Data Working Group
SA	Situation Awareness
S&A	See and Avoid
SAB	Scientific Advisory Board
SAP	Special Access Project
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SCAR	Strike Coordinating Armed Reconnaissance
SC4ISR	Space & Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
SDB	Small Diameter Bomb
SE	Systems Engineering
SEAD	Suppression of Enemy Air Defenses
SFC	Specific Fuel Consumption
SHAE	Survivable High Altitude Endurance
SL	Survivable Large
SLOC	Software lines of code
SMAE	Survivable Medium Altitude Endurance
SMAV	Small Unmanned Aerial Vehicle
SPO	Systems Program Office
S&T	Science and Technology
TCA	Transformational Communications Architecture
TCS	Transformational Communications System
TID	Target Identification
TOGW	Takeoff Gross Weight
TOS	Time on Station
TSFC	Thrust Specific Fuel Consumption
UAV	Unmanned or Uninhabited Aerial Vehicles
UAVBL	Unmanned Aerial Vehicle Battle Lab
UCAV	Unmanned or Uninhabited Combat Aerial Vehicles
UGS	Unattended Ground Sensors
UGV	Unmanned Ground Vehicle
UHF	Ultra-High Frequency
UNITE	UAV National Industry Team

VAATE	Versatile Affordable Advanced Turbine Engine
VFR	Visual Flight Rules
VTOL	Vertical Takeoff and Landing
W	Watt
WGS	Wideband Gapfiller Satellite

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