Office of the
Secretary of Defense

UNMANNED AERIAL VEHICLES ROADMAP

December 2002

2002 - 2027

This document was developed by the Office of the Secretary of Defense (Acquisition, Technology, & Logistics), Air Warfare.
Suggested changes, corrections, or updates should be forwarded to:

Dyke.Weatherington@osd.mil

OFFICE OF THE SECRETARY OF DEFENSE

WASHINGTON, DC 20301

11 MAR 2003

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
CHIEF OF STAFF OF THE AIR FORCE
CHIEF OF STAFF OF THE ARMY
COMMANDANT OF THE MARINE CORPS
CHIEF OF NAVAL OPERATIONS
DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

SUBJECT: Unmanned Aerial Vehicles (UAV) Roadmap

The Department's new UAV Roadmap provides a Defense-wide vision for UAVs and related technologies, ushering in a new era of capabilities and options for our military and civilian leaders.

Unlike the previous UAV Roadmap, this document is directive in nature, describing 49 goals for a range of topics that includes platforms, sensors, communications, technology, small UAVs, interoperability standards, airspace, the intelligence collection process, weapons, and reliability. From these goals, we derived a "Top-10" list that represents the key items for rapid unmanned capability advancement. The executive summary of the Roadmap lays out these "Top-10" goals and identifies Service and Agency leads along with target dates for completion.

The Department will promote a common vision for future UAV-related efforts by making this Roadmap widely available to industry and our Allies, and by updating it as emerging transformational concepts, such as network-centricity, are better understood. The Department is committed to transform our military into more agile, lethal, and efficient forces, capable of meeting the diverse security needs of our nation and our partners. UAVs have a central role in this transformation.

E.C. Aldridge, Jr.
Under Secretary of Defense (AT&L)

John P. Stenbit
Assistant Secretary of Defense (C3I)

Executive Summary

This document presents the Department of Defense's (DoD) Roadmap for developing and employing Unmanned Aerial Vehicles (UAVs) and Unmanned Combat Air Vehicles (UCAVs) over the next 25 years (2002 to 2027). DoD's operational UAV systems include Predator, Hunter, Shadow, and Pioneer which have demonstrated tremendous capability in recent military operations. Developmental systems such as Global Hawk and many small UAV systems have also been put to the test in recent combat and combat support operations. Taken as a whole, this technology area offers profound opportunities to transform the manner in which this country conducts a wide array of military and military support operations. As with any new technology, there is naturally some reluctance to transition to a radically new capability. The need to fully demonstrate UAVs in combat and realistic training environments is critical to the migration of this technology.

The overarching goal of this roadmap, in concert with the Defense Planning Guidance (DPG), is to define clear direction to the Services and Departments for a logical, systematic migration of mission capabilities to a new class of military tools. The goal is to address the most urgent mission needs that are supported both technologically and operationally by various UAV systems. Some missions can be supported by the current state of the art in unmanned technology where the capabilities of current or near-term DoD assets are sufficient and the risk to DoD members is relative low. Other mission areas, however, are in desperate need of additional capability and present high risk to aircraft crews. These mission areas, highlighted in this roadmap, will receive significant near-term effort by the Department.

This Roadmap describes the Services' ongoing UAV efforts (Section 2) and identifies the capabilities needed by theater commanders to which UAVs could be applied (Section 3), then couples them to emerging technologies (Section 4) and operational concepts (Section 5) that could enable these capabilities within the Services' programs. The resulting Roadmap (Section 6) links capability-enhancing technologies to the life cycles of current and projected UAV programs. It is a map of opportunities, not point designs - a description of the future potential of UAVs.

This Roadmap also provides a current snapshot of the status of the Department's numerous unmanned aviation efforts. Having accurate "ground truth" on DoD's various UAV programs and research efforts does not solve problems, but it does allow the Department to place emphasis in appropriate areas. One such area is standards, the framework of common requirements necessary to ensure forward/backward compatibility within systems and interoperability among them. The Office of the Secretary of Defense (OSD), as part of its oversight responsibilities for Defense-wide acquisition and technology, intends this Roadmap to be directive in such cross-program areas as standards development and other interoperability solutions.

The U.S. military has a long and continuous history of involvement with UAVs, stretching back to 1917. UAVs had active roles in the Vietnam, Persian Gulf, and Balkans conflicts, as well as Afghan operations, providing critical reconnaissance in each. With recent technology improvements allowing more capability per pound, today's UAVs are more sophisticated and capable than ever. As the military's operational tempo has increased, so too has the employment of UAVs, to include performing a wider variety

of missions than just reconnaissance. During the 1990s, DoD invested over $3 billion in UAV development, procurement, and operations; since 2000, it has invested another $1 billion and will likely invest over $10 billion by 2010. Today, the DoD has in excess of 90 UAVs in the field; by 2010, this inventory is programmed to quadruple.

Ten years hence (2012), DoD will probably be operating F-16-size UAVs capable of supporting a variety of combat and combat support missions, including Suppression of Enemy Air Defenses (SEAD), Electronic Attack (EA), and possibly deep strike interdiction. It is also likely that vertical takeoff UAVs (rotary wing) capable of extremely long endurance (18-24 hours) will be in demonstration and limited production. Twenty-five years from now (2027), UAVs may exist with morphing airframes, able to optimize their shape for various missions and flight conditions with stretching skins and shape memory alloys permitting aerodynamic maneuvers impossible for manned aircraft. Control stations could evolve from a crew inside a multi-ton van to an individual wearing a suit tied into his own neuro-muscular system, seeing what the UAV's sensors see through a head-mounted visor.

The advantages offered by UAVs to the military commander are numerous, most notably in mission areas commonly categorized as "**the dull, the dirty, and the dangerous.**" In an era of decreasing force structure, UAVs are force multipliers that can increase unit effectiveness. For example, due to its vantage point, one unmanned sentry equipped with automated cuing algorithms and multiple sensors could survey the same area as ten (or more) human sentries ("the dull"). UAVs could reconnoiter areas contaminated with radiological, chemical or biological agents without risk to human life ("the dirty"). Unmanned Combat Air Vehicles (UCAVs) could perform the high-risk suppression of enemy air defenses (SEAD) missions currently flown by manned EA-6s or F-16s ("the dangerous") with less need for supporting aircraft. In such a role, UAVs would be potent force multipliers, releasing manned aircraft for other roles.

The Office of the Secretary of Defense has identified 49 goals for unmanned aviation in this Roadmap that support the Department's larger goals of fielding transformational capabilities, establishing joint standards, and controlling costs. Ten of these 49 goals (shown below) have priority and have been assigned an Office of Primary Responsibility (OPR) to oversee their accomplishment and a due date. These goals are consistent with the current DPG and will be further refined in the upcoming cycle. In some cases, goals addressed in this document have been directly cited in the DPG, such as the direction for development and demonstration of Unmanned Combat Air Vehicles. In many other cases, the goals to follow are at a detail level below that appropriate to the DPG. The DPG will always take precedence, however this document will be used to provide additional definition and direction for UAV and UCAV technology areas. These goals should be considered directive, and OSD, in conjunction with the Services and Defense Agencies will strive to develop, demonstrate, and operationally assess these capabilities in the timeframes indicated. Progress reports on each goal will be submitted by the respective OPRs during the first quarter of each fiscal year.

1. Develop and operationally assess for potential fielding a UCAV capable of performing several missions including SEAD/Strike/Electronic Attack; emphasize early fielding of an EA capability with growth to other missions. OPR: UCAV Joint Program Office (DARPA, USN, USAF). Due: FY10.

2. Develop and demonstrate a tactical UAV-class aviation heavy fuel engine suitable for use in UAVs such as Shadow, Pioneer and A-160. Growth potential to larger UAVs in the Predator class including Extended Range Multi-Purpose and LEWK, and options for the small UAV class are also required. OPR: DARPA, USA, USN/USMC. Due: FY05/07.

3. OSD, Joint Staff, and the Services develop capability and/or capability-performance metrics (such as those in Section 4.1) to evaluate UAV program costs. Program managers should provide Joint Staff and OSD written justification at Milestone B and C reviews when these metrics are exceeded, and provide appropriate management organizations with options for reducing costs to align them with these metrics when this occurs. OPR: OSD. Due: FY03.

4. Demonstrate High Definition Television (HDTV) capability with real-time precision targeting capability on a UAV. OPR: NIMA, USN, USAF. Due: FY05.

5. Migrate all tactical (Shadow 200) and above UAVs to Common Data Link (CDL)-compatible formats for line-of-sight (LOS) and beyond-line-of-sight (BLOS) communication. OPR: USAF, USN, USA. Due: FY06.

6. Investigate low Reynolds Number aerodynamics with a focus on improving digital flight control systems optimized for small UAVs (i.e., those having Reynolds numbers less than 1 million). OPR: OSD; USA, USN, USAF. Due: FY06.

7. Define a standard UAV interface providing critical situational awareness data and precise location data supporting airspace integration. OPR: OSD, USJFCOM. Due: FY04.

8. Coordinate revising FAA Order 7610.4 to replace the requirement for using the Certificate Of Authorization (COA) process for all UAVs with one for using the DD175 form for qualifying UAVs. OPR: USAF. Due: FY04.

9. Define security measures required for positive control of weapons employment on weaponized UAVs. OPR: USAF. Due: FY08.

10. Decrease the annual mishap rate of larger model UAVs to less than 20 per 100,000 flight hours by FY09 and less than 15 per 100,000 flight hours by FY15. OPR: USAF, USN, USA. Due: FY09/15.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

1.1 Purpose

The purpose of this roadmap is to stimulate the planning process for US military unmanned aerial vehicle (UAV) development over the period from 2002 to 2027. It is intended to assist Department of Defense (DoD) decision makers in developing a long-range strategy for UAV development and acquisition in future Quadrennial Defense Reviews (QDRs) and other planning efforts, as well as to guide industry in developing UAV-related technology. Additionally this document may help other US Government organizations leverage DoD investments in UAV technology to fulfill their needs and capabilities. It addresses the following key questions:

- What requirements for military capabilities could potentially be filled by UAVs?
- What platform, sensor, communication, and information processing technologies are necessary to provide these capabilities?
- When will these technologies become available to enable the above capabilities?

This roadmap is meant to complement ongoing Service efforts to redefine their roles and missions for handling 21st century contingencies. The Services see UAVs as becoming integral components of their future tactical formations. As an example, the Army's current Transformation initiative envisions each Brigade Combat Team having a reconnaissance, surveillance, and target acquisition (RSTA) squadron equipped with a UAV system, reflecting the initiative's emphasis on reducing weight, increasing agility, and integrating robotics.

1.2 Approach

The approach used in this document is to:

1. Identify requirements relevant to defining UAV system capabilities from authoritative sources of warfighter needs and link them to capabilities needed in future UAV platforms, sensors, communications, and information processing.
2. Develop a series of forecasting trends ("Moore's Laws"[1]) for the next 25 years for those technologies driving UAV platform, sensor, communication, and information processing performance. Define the timeframe during which the technology to address these requirements should become available for fielding.
3. Synthesize an integrated plan ("Roadmap") for UAV development opportunities by combining the above requirements and technology trends.

Such a roadmap could potentially be used in a number of ways, to include:

[1] Moore's Law (Gordon Moore of Intel Corp.) originated in 1965 as a forecast that the capability of microchip processors would double every 12 to 18 months. The semiconductor industry has used it to define its technology roadmap for sustained growth over the past 35 years.

- Evaluating the technologies planned for incorporation in current UAV programs for underachieving or overreaching in capabilities.
- Defining windows of feasibility for introducing new capabilities in the near term on existing systems or for starting new programs.
- Identifying key enabling technology development efforts to support today for use in the far term for inclusion in the Defense Technology Objectives, Joint Warfighting Science and Technology Plan, and Defense Technology Area Plan.

1.3 Scope

This roadmap describes the options of routes (current and future technologies) available to reach a number of destinations (warfighter needs). It neither authorizes specific UAV programs nor prioritizes the requirements, as this is the responsibility of the Services and the Joint Requirements Oversight Council (JROC). It does, however, identify future windows when technology should become available to enable new capabilities, linked to warfighters' needs, to be incorporated into current or planned UAV programs. Many of the technologies discussed in this study are currently maturing in Defense research laboratories and contractor facilities. The roadmap's span of 25 years was chosen to accommodate what typically constitutes the coming generation of aircraft and payload technology.

The information presented in this study is current as of 31 December 2002.

1.4 Definitions

Because they are both unmanned aircraft, the distinction between cruise missile *weapons* and UAV *weapon systems* is occasionally confused. The key discriminants are (1) UAVs are equipped and employed for recovery at the end of their flight, and cruise missiles are not, and (2) munitions carried by UAVs are not tailored and integrated into their airframe whereas the cruise missile's warhead is. This distinction is clearly made in the Joint Publication 1-02 DoD Dictionary's definition of a UAV:

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

1.5 Progress Since Previous Roadmap

Since the 2000 edition of this Roadmap, the Army, the Marine Corps, and the Navy have each developed their versions of a UAV roadmap to direct their long-term UAV efforts. Fuel cell propulsion (Conclusion 6.5.1-1) has reached the flight test stage in both manned aircraft and non-DoD UAVs (NASA Helios), and the Army has expressed plans to explore their use in a future Shadow spiral. The FY03 Foliage Penetration (FOPEN) Synthetic Aperture Radar (SAR) Integration for Terrain Characterization Advanced Concept Technology Demonstration (ACTD) is pursuing near-real-time digital terrain mapping for eventual use on Global Hawk (Conclusion 6.5.1-6). The BENVINT ACTD is exploring the utility of standardized weather sensors on UAVs (Conclusion 6.5.2-2). In the area of regulatory reform, revised Federal Aviation Authority (FAA) regulations governing UAV flight in civil airspace are being coordinated (Conclusion 6.5.2-6), and the Missile Technology Control Regime has been amended to ease the export of UAV technology in certain cases. Finally, OSD and the Services have significantly increased their investment in UCAV technology development and have begun planning for a Joint UCAV Program Office to develop, demonstrate and field UCAV systems for a variety of combat and combat support missions.

2.0 Current UAV Programs

This Section provides condensed descriptions of current Defense Department UAV efforts as background for the users of this roadmap. It categorizes the Department's UAVs as *Operational* (those currently in the hands of field units), *Developmental* (those undergoing evaluation for eventual fielding with such units), and *Other*, which includes *residual* assets withdrawn from service with fielded units, *concept exploration* platforms, and *conceptual* UAVs undergoing definition. Detailed descriptions are available in the Defense Airborne Intelligence, Surveillance, and Reconnaissance Plan (DAISRP) and at the websites listed with specific systems below.

Since the previous edition of this Roadmap, the number of UAV programs under development by the DoD has increased substantially. In addition, the Army, Navy, and Marines have each developed Service-specific roadmaps for their UAV efforts. Finally, the Air Force began its "Pathfinder" initiative, which uses a spiral development process to reduce the time to field systems. Of the ten programs selected for this initiative, two are major UAV programs (Global Hawk and Unmanned Combat Air Vehicle (UCAV)). Figure 2.0-1 presents a consolidated timeline of the Services' ongoing and planned programs, reflecting these Service UAV roadmaps. Those UAVs that started as ACTDs or ATDs are so indicated on the left end of their identification bar, with the leftmost vertical bar representing the conclusion of that program's ACTD or ATD. The rightmost vertical line on each program's bar represents actual or projected initial operational capability (IOC). This figure is a key component of the overall UAV Roadmap for the next 25 years, shown in Figure 6.2-1.

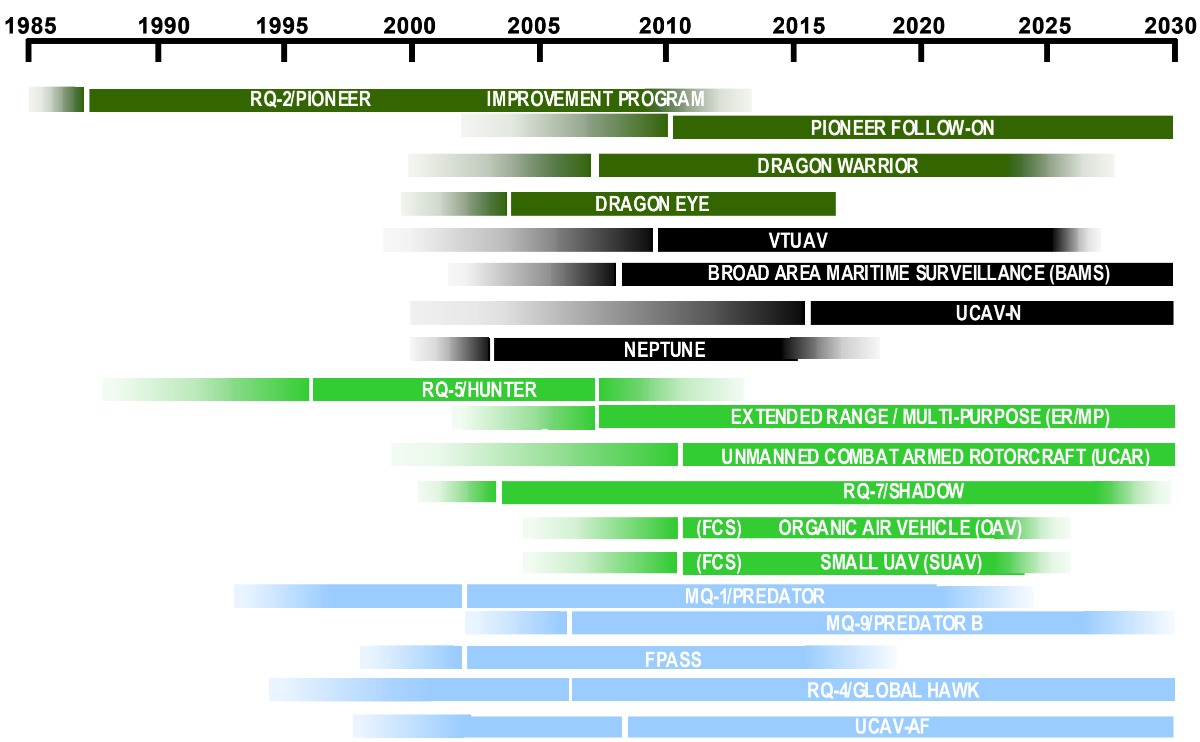


FIGURE 2.0-1: TIMELINE OF CURRENT AND PLANNED DOD UAV SYSTEMS.

2.1 Operational UAV Systems

2.1.1 MQ-1 Predator

The Air Force MQ-1 Predator was one of the initial ACTDs in 1994 and transitioned to an Air Force program in 1997. It takes off and lands conventionally on a runway and can carry a maximum 450 lb payload for 24+ hours. Operationally, it is flown with a gimbaled electro-optical/infrared (EO/IR) sensor and a SAR, giving it a day/night, all-weather (within aircraft limits) reconnaissance capability. It uses either a line-of-sight (C-band) or a beyond-line-of-sight (Ku-band Satellite Communications (SATCOM)) data link to relay color video in real time to commanders. Since 1995, Predator has flown surveillance missions over Iraq, Bosnia, Kosovo, and Afghanistan. In 2001, the Air Force demonstrated the ability to employ Hellfire missiles from the Predator, leading to its designation being changed from RQ-1 to MQ-1 to reflect its multi-mission capability. The Air Force operates 12 systems in three Predator squadrons and is building toward a force of 25 systems consisting of a mix of 100 MQ-1 and MQ-9 aircraft. IOC is anticipated in 2003. *www2.acc.af.mil/library/factsheets/predator*

MQ-1 Predator/General Atomics/Air Force

Weight:	2250 lb
Length:	28.7 ft
Wingspan:	48.7 ft
Payload:	450 lb
Ceiling:	25,000 ft
Radius:	400 nm
Endurance:	24+ hr

2.1.2 RQ-2 Pioneer

The Navy/Marine RQ-2 Pioneer has served with Navy, Marine, and Army units, deploying aboard ship and ashore since 1986. Initially deployed aboard battleships to provide gunnery spotting, its mission evolved into reconnaissance and surveillance, primarily for amphibious forces. Launched by rocket assist (shipboard), by catapult, or from a runway, it recovers into a net (shipboard) or with arresting gear after flying up to 5 hours with a 75 lb payload. It currently flies with a gimbaled EO/IR sensor, relaying analog video in real time via a C-band line-of-sight (LOS) data link. Since 1991, Pioneer has flown reconnaissance missions during the Persian Gulf, Bosnia, and Kosovo conflicts. The Navy ceased Pioneer operations at the end of FY02 and transferred their assets to the Marine Corps. The Marine Corps is embarking on improvements to the Pioneer to extend their operations with it until FY09 or a replacement is fielded. Such an improved Pioneer would fulfill the third tier of the Marines' UAV roadmap, which calls for a system to support the Marine Expeditionary Force (MEF)/division out to a radius of 200 km (108 nm). *http://uav.navair.navy.mil/pioneer*

RQ-2 Pioneer/Pioneer UAVs, Inc./USMC

Weight:	452 lb
Length:	14 ft
Wingspan:	17 ft
Payload:	75 lb
Ceiling:	15,000 ft
Radius:	100 nm
Endurance:	5 hr

2.1.3 RQ-5 Hunter

The RQ-5 Hunter was originally a joint Army/Navy/Marine Corps Short Range UAV program that the Army intended to meet division and corps level requirements. It takes off and lands (using arresting gear) on runways and can carry up to 200 lb for over 11 hours. It uses a gimbaled EO/IR sensor, relaying its video in real time via a second airborne Hunter over a C-band line-of-sight data link. Hunter deployed to Macedonia to support NATO Balkan operations in 1999, 2000, 2001, and 2002. Although full rate production (FRP) was canceled in 1996, seven low rate initial production (LRIP) systems of eight aircraft each were acquired, four of which remain in service: two for training, doctrine development, and exercise support, and two for contingency support. A competitively selected Extended Range/Multi-Purpose (ER/MP) UAV system will begin to replace it as early as FY05-06. *www.redstone.army.mil/jtuav*

RQ-5 Hunter/TRW;IAI/Army

Weight:	1600 lb
Length:	23 ft
Wingspan:	29.2 ft
Payload:	200 lb
Ceiling:	15,000 ft
Radius:	144 nm
Endurance:	11.6 hr

2.1.4 RQ-7 Shadow 200

The Army selected the RQ-7 Shadow 200 (formerly Tactical UAV (TUAV)) in December 1999 to meet its Brigade level UAV requirement for support to ground maneuver commanders. Catapulted from a rail, it is recovered with the aid of arresting gear. It will be capable of remaining on station for 4 hours at 50 km (27 nm) with a payload of 60 lbs. Its gimbaled EO/IR sensor will relay video in real time via a C-band LOS data link. Current funding allows the Army to procure 39 systems of four aircraft each for the active duty forces and 2 systems of four aircraft each for the reserve forces. Approval for full rate production (acquisition Milestone C) and IOC occurred in September 2002. The Army's acquisition objective, with the inclusion of the Army Reserve component, is 83 total systems. *www.tuav.redstone.army.mil*

RQ-7 Shadow 200/AAI/Army

Weight:	327 lb
Length:	11.2 ft
Wingspan:	12.8 ft
Payload:	60 lb
Ceiling:	15,000 ft
Radius:	68 nm
Endurance:	4 hr

2.2 Developmental UAV Systems

2.2.1 RQ-4 Global Hawk

The Air Force RQ-4 Global Hawk is a high altitude, long endurance UAV designed to provide wide area coverage of up to 40,000 nm^2 per day. It successfully completed its Military Utility Assessment, the final phase of its ACTD, in June 2000, and transitioned into Engineering and Manufacturing Development (EMD) in March 2001. It takes off and lands conventionally on a runway and currently carries a 1950 lb payload for up to 32 hours. Global Hawk carries both an EO/IR sensor and a SAR with moving target indicator (MTI) capability, allowing day/night, all-weather reconnaissance. Sensor data is relayed over Common Data Link (CDL) line-of-sight (LOS) (X-band) and/or beyond-line-of-sight (BLOS) (Ku-band SATCOM) data links to its Mission Control Element (MCE), which distributes imagery to up to seven theater exploitation systems. Residuals from the ACTD consisted of four aircraft and two ground control stations. Two more ACTD advanced aircraft will be delivered in early FY03 to support EMD and contingency operations. The Air Force has budgeted for 27 production aircraft in FY02-07, and plans a total fleet of 51. The Air Force plans to add other sensor capabilities in a spiral development process as this fleet is procured. Ground stations in theaters equipped with the Common Imagery Processor (CIP) will eventually be able to receive Global Hawk imagery directly. IOC for Imagery Intelligence (IMINT)-equipped aircraft is expected to occur in FY06. *www2.acc.af.mil/library/factsheets/globalhawk*

RQ-4 Global Hawk/Northrop Grumman/Air Force

Weight:	26,750 lb
Length:	44.4 ft
Wingspan:	116.2 ft
Payload:	1950 lb
Ceiling:	65,000 ft
Radius:	5400 nm
Endurance:	32 hr

2.2.2 Broad Area Maritime Surveillance

In December 2001, Secretary of the Navy directed, on an accelerated basis, the acquisition of an unmanned persistent intelligence, surveillance, and reconnaissance

(ISR) capability in support of the warfighter. In response, the Navy developed a two-phased approach to rapidly acquire a Broad Area Maritime Surveillance (BAMS) UAV system using current available platforms to speed acquisition, sensor development, concept of operations (CONOPS) development and achieve low risk. The first phase, the Global Hawk Maritime Demonstration (GHMD), will procure two off-the-shelf Air Force Global Hawk UAV platforms with sensors modified for maritime ISR missions and associated ground equipment for Navy use in CONOPS development, technology validation and to conduct experimentation in a maritime environment. The second phase, the BAMS UAV Program, is a formal DoD acquisition initiated to develop, test, field and support a maritime patrol, reconnaissance, and strike support UAV system. An Analysis of Alternatives is currently underway that will be used to help determine the platform and force structure required to support the BAMS UAV mission. An estimated 50 air vehicles are planned but the final number will be adjusted when the objective platform is selected. The BAMS UAV Initial Operating Capability (IOC) is currently planned for FY09.

2.2.3 RQ-8 Fire Scout

The Fire Scout vertical take-off and landing (VTOL) tactical UAV (VTUAV) program is currently in EMD and LRIP. Five Air Vehicles and four Ground Control Stations are now in Developmental Testing. A significant number of successful test flights have been accomplished demonstrating autonomous flight, Tactical Control Data Link (TCDL) operations, Multi-Mission Payload performance and Ground Control Station operations. Fire Scout Tactical Control System developmental testing is scheduled for mid-FY03. With continuing FY03 EMD testing successes, the Navy has recognized the VTUAV program value for the emerging Landing Craft Support series of surface vessels. The Navy is currently reviewing the VTUAV Operational Requirements Document (ORD) and funding has been added to the FY04 budget to continue development and to conduct shipboard demonstrations. Additional out year funding for VTUAV is being considered for future development and production.
http://uav.navair.navy.mil/vtuav

RQ-8 Fire Scout/Northrop Grumman/Navy

Weight:	2650 lb
Length:	22.9 ft
Rotorspan:	27.5 ft
Payload:	300 lb
Ceiling:	19,000 ft
Radius:	150 nm
Endurance:	5+ hr

2.2.4 MQ-9 Predator B

Predator B is a larger, more capable, turboprop-engined version of the Air Force MQ-1B/Predator developed jointly by NASA and General Atomics as a high altitude endurance UAV for science payloads. Its initial flight occurred in February 2001. The Office of the Secretary of Defense acquired both existing Predator B prototypes in October 2001 for evaluation by the Air Force. With the capability to carry up to ten

Hellfire missiles, the MQ-9 could serve as the killer portion of a MQ-1/MQ-9 hunter/killer UAV team. Current funding plans are to acquire nine MQ-9s, although Congress has expressed interest in increasing the procurement.

MQ-9 Predator B/General Atomics/Air Force

Weight:	10,000 lb
Length:	36.2 ft
Wingspan:	64 ft
Payload:	750 lb internal/3000 lb external
Ceiling:	45,000 ft
Radius:	400 nm
Endurance:	24+ hr

2.2.5 Dragon Eye

Dragon Eye is a mini-UAV (4-foot wingspan and 4 lb weight) developed as the Marine Corps Warfighting Laboratory's (MCWL) answer to the Navy's Over-The-Hill Reconnaissance Initiative and the Marines' Interim Small Unit Remote Scouting System (I-SURSS) requirement. The potential Navy version is referred to as *Sea ALL*. *Dragon Eye* fulfills the first tier of the Marine Corps UAV roadmap by providing the company/ platoon/squad level with an organic RSTA capability out to 10 km (5 nm). It can carry either an EO, IR, or low light TV as its sensor. The first prototype flew in May 2000, with low rate production contracts (40 aircraft) awarded to AeroVironment and BAI Aerosystems in July 2001. By March 2003 the Marine Corps will award a production contract to one of these two vendors following user operational assessment. IOC is planned for the Fall of 2003. A total of 311 systems, each with 3 aircraft and one ground station, are planned. *www.mcwl.quantico.usmc.mil/images/downloads/dragoneye*

Dragon Eye/BAI Aerosystems; AeroVironment/Marine Corps

Weight:	4.5 lb
Length:	2.4 ft
Wingspan:	3.8 ft
Payload:	1 lb
Ceiling:	1000 ft
Radius:	2.5 nm
Endurance:	45-60 min

2.2.6 Force Protection Aerial Surveillance System (FPASS)

FPASS is designed for ease of use by Air Force security personnel to improve situational awareness of the force protection battlespace by conducting area surveillance, patrolling base perimeters and runway approach/departure paths, and performing convoy over watch. The Air Force Electronic Systems Center developed *FPASS* to address a 1999 U.S. Central Command (CENTCOM) request for enhancing security at overseas bases. CENTAF refers to the *FPASS* vehicle as *Desert Hawk.* Battery-powered, it is launched with the aid of a bungee cord and equipped with either a visible or an uncooled IR video sensor. Each system consists of six aircraft and a laptop control station. Delivery of initial systems began in July 2002.

FPASS/Lockheed Martin/Air Force

Weight:	5 lb
Length:	3 ft
Wingspan:	4 ft
Payload:	1 lb
Ceiling:	1,000 ft
Radius:	5 nm
Endurance:	60-90 min

2.2.7 Neptune

Neptune is a new tactical UAV design optimized for at-sea launch and recovery. Carried in a 72x30x20 inch case that transforms into a pneumatic launcher, it can be launched from small vessels and recovered in open water. It can carry IR or color video sensors, or can be used to drop small payloads. Its digital data link is designed to minimize multipath effects over water. First flight occurred in January 2002, and an initial production contract was awarded to DRS Unmanned Technologies in March 2002.

Neptune/DRS Unmanned Technologies/Navy

Weight:	80 lb
Length:	6 ft
Wingspan:	7 ft
Payload:	20 lb
Ceiling:	8,000 ft
Radius:	40 nm
Endurance:	4 hr

2.2.8 Air Force UCAV (X-45)

The joint Defense Advanced Research Projects Agency (DARPA)/Air Force UCAV System Demonstration Program (SDP) is designed to demonstrate the technological feasibility, military utility, and operational value of a UCAV system to effectively and affordably prosecute Suppression of Enemy Air Defenses (SEAD) and strike missions in the 2010+ high threat environment. Two X-45A (Spiral 0) demonstrator air vehicles have been delivered to NASA's Dryden facility at Edwards AFB; first flight occurred in May 2002. Design has started on the next generation X-45C (Spiral 1) air vehicle, which will add stealth characteristics; first flight is expected in late 2005. The Air Force has budgeted for up to 36 UCAV systems for delivery by 2010 for early operational capability and warfighter assessment. An effects-based spiral development approach is envisioned to rapidly field initial UCAV capability and expand that capability as technology and funding permit. *www.darpa.mil/ucav*

UCAV/Boeing/DARPA Air Force

	X-45A	**X-45C**
Weight:	12,000 lb	35,000 lb
Length:	26.3 ft	36 ft
Wingspan:	33.8 ft	48 ft
Payload:	1,500 lb	4,500 lb
Ceiling:	35,000 ft	40,000 ft
Speed:	0.75 M	0.85 M
Endurance/ Combat Radius:	1.5 hr	1,000 nm + 2 hr loiter

2.2.9 UCAV-Navy (X-46/X-47)

The DARPA/Office of Naval Research's Naval Unmanned Combat Air Vehicle (UCAV-N) Advanced Technology Demonstration (ATD) Program is examining the critical technologies and systems needed to operate a large autonomous UAV from a Navy aircraft carrier. The system is envisioned to be multi-mission capable with an initial focus on tactical surveillance, evolving into a SEAD/strike system as the concept matures. The UCAV-N acquisition cost goal is 50 percent of the Navy's F-35 variant, and its operating cost goal is 50 percent of the F/A-18C/D's. The Naval Unmanned Combat Air Vehicle (UCAV-N) ATD program will be merged with the current Air Force UCAV program under a Joint Program office. Both Northrop-Grumman (X-47A Pegasus) and Boeing (X-46) will partake in a Joint Strike Fighter (JSF)-like competition to meet Air Force and Navy requirements. First flight of a shore-based catapult and arrested-landing-capable UCAV-N demonstrator is expected in late FY06. Fourteen Air Force UCAV's are scheduled for delivery by FY08 while the Naval UCAV is planned to achieve IOC before 2015. *www.darpa.mil/tto/programs/ucav-n*

UCAV-N/DARPA Navy

Weight:	29,000 lb
Length:	34 ft
Wingspan:	50 ft
Payload:	5,500 lb
Ceiling:	40,000 ft
Radius:	1,500 nm
Endurance:	12 hours

2.2.10 UCAR

UCAR/DARPA Army (Artist Depiction)

The **Unmanned Combat Armed Rotorcraft (UCAR)** is a DARPA/Army program begun in FY02 to develop an unmanned attack helicopter for the armed reconnaissance and attack missions at 20 to 40 percent the acquisition cost of a RAH-66 Comanche and 20-50 percent of the operating cost of an AH-64 Apache. This system will be a critical component of the Army Objective Force system-of-systems architecture. Phase I study contracts to conduct system trades and concept exploration were awarded to Boeing, Lockheed Martin, Northrop Grumman, and Sikorsky in May 2002. First flight is anticipated in 2006, leading to an acquisition decision in 2009. With *UCAR*, the Army, Navy, and Air Force each now have unmanned combat aircraft initiatives.

2.2.11 Dragon Warrior

Dragon Warrior is an unmanned rotorcraft designed to provide the Marine Expeditionary Unit (MEU) or regiment with an organic reconnaissance, surveillance, precision targeting, battle damage assessment, and communication relay capability. It will be capable of launching and recovering from ships during amphibious operations and transitioning to land-based operations from a single High-Mobility Multi-Purpose Wheeled Vehicle (HMMWV) and trailer. Each system would consist of two rotorcraft. It would be equipped with an EO/IR sensor and laser range finder plus an interchangeable communication relay payload. First tethered flight was conducted in 2002, and first free flight should occur in 2003. A procurement decision is expected in FY06.
www.mcwl.quantico.usmc.mil/images/downloads/dragonwarrior

Dragon Warrior/NRL/Marine Corps

Weight:	340 lb
Length:	7 ft
Rotorspan:	9 ft
Payload:	35 lb
Ceiling:	18,000 ft
Radius:	50 nm
Endurance:	3-5 hrs

2.2.12 Program Summaries

TABLE 2.2-1: SUMMARY HISTORY OF RECENT UAV PROGRAMS.

System	Manufacturer	Lead Service	First Flight	IOC	Aircraft Built	Aircraft Fielded	Status
MQ-1/Predator	General Atomics	Air Force	1994	2003	80	22	93 ordered
RQ-2/Pioneer	Pioneer UAVs, Inc	Navy	1985	1986	175	10	Extended life
BQM-145	Teledyne Ryan	Navy	1992	n/a	8	0	Cancelled '93
RQ-3/DarkStar	Lockheed Martin	Air Force	1996	n/a	3	0	Cancelled '99
RQ-4/G'Hawk	Northrop Grumman	Air Force	1998	2006	6	0	51 planned
RQ-5/Hunter	IAI/TRW	Army	1991	n/a	72	41	Sunset system
RQ-6/Outrider	Alliant Techsystems	Army	1997	n/a	19	0	Cancelled '99
RQ-7/Shadow200	AAI	Army	1991	2003	32	24	164 planned
RQ-8/Fire Scout	Northrop Grumman	Navy	1999	n/a	3	0	Cont. Develm't
MQ-9/Predator B	General Atomics	Air Force	2001	TBD	2	0	6 planned
Dragon Eye	BAI Aerosystems/ AeroVironment	USMC	2000	2003	40	0	933 planned

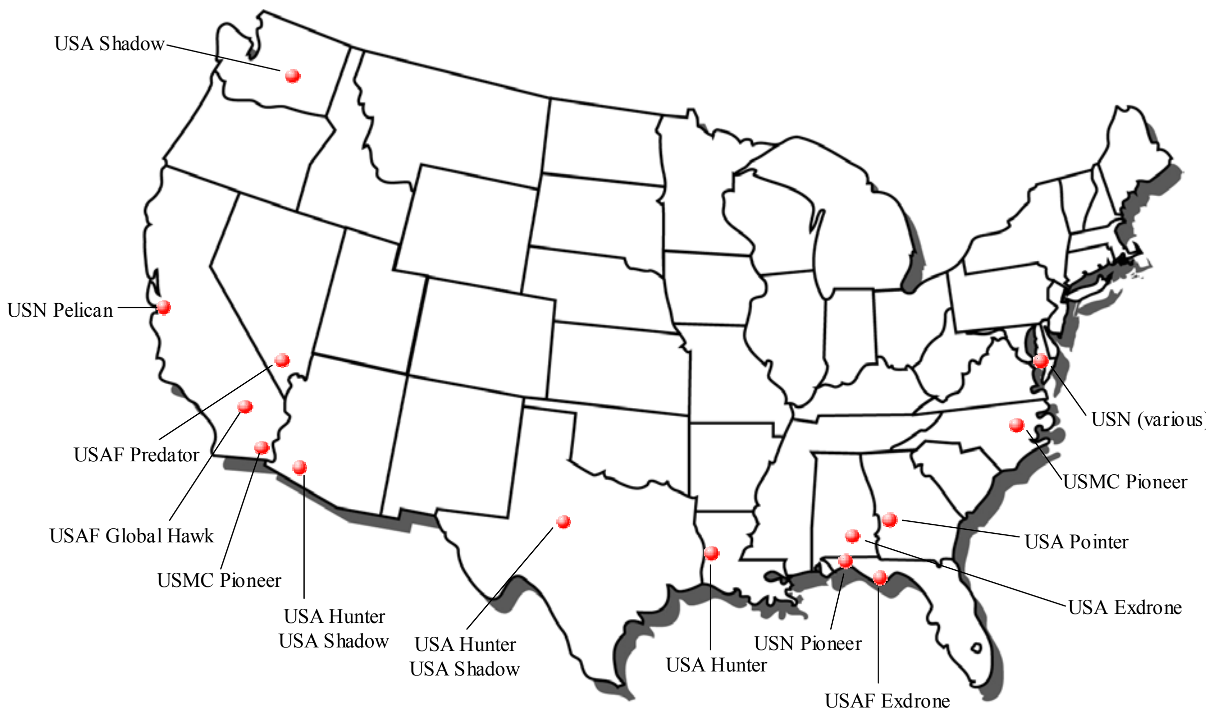


FIGURE 2.2-1: LOCATIONS OF U.S. MILITARY UAVS.

2.3 Other UAV Systems

2.3.1 Residual UAV Systems

The US military maintains the residual hardware of several UAV programs that are not current programs of record, but that have deployed with operational units using trained, uniformed operators in recent years. Eighty-two *BQM-147 Exdrones*, an 80-lb delta-wing design, remain from over 500 built. Originally built as expendable communication jammers, Exdrones were converted to the reconnaissance role with the addition of a video camera, and 45 of them were deployed during the Gulf War. In 1997-98, 38 were rebuilt to the *Dragon Drone* standard (which includes the addition of a gimbaled EO sensor) and have since deployed twice with Marine Expeditionary Units.

Air Force Special Operations Command (Hurlburt Field, FL) is using 15 Exdrones as testbeds to explore potential UAV concepts and payloads for special operations forces. The Army Air Maneuver Battle Lab (Ft Rucker, AL) is also experimenting with Exdrones, having acquired 30 in 2001.

BQM-147 Dragon Drone/BAI Aerosystems/Marines

Weight:	90 lb
Length:	5.25 ft
Wingspan:	8.2 ft
Payload:	15 lb
Ceiling:	10,000 ft
Radius:	26 nm
Endurance:	2.5 hr

Approximately 100 hand-launched, battery powered FQM-151/*Pointers* have been acquired by the Marines and the Army since 1989 and were employed in the Gulf War. Most recently, the Navy used Pointer to help clear the Vieques, Puerto Rico, range of demonstrators, and the Army acquired six systems for use at its Military Operations in Urban Terrain (MOUT) facility at Ft Benning, GA. Pointers have served as testbeds for numerous miniaturized sensors (e.g., uncooled IR cameras and chemical agent detectors) and have performed demonstrations with the Drug Enforcement Agency, National Guard, and special operations forces. *http://uav.navair.navy.mil/smuav*

FQM-151 Pointer/AeroVironment/Navy

Weight:	10 lb
Length:	6 ft
Wingspan:	9 ft
Payload:	2 lb
Ceiling:	1000 ft
Radius:	3 nm
Endurance:	1 hr

2.3.2 Concept Exploration UAV Systems

ACTDs have been responsible for successfully spawning a number of recent UAV programs, such as Predator and Global Hawk, on an accelerated development basis. Because ACTDs are focused on quickly putting a capability into a theater commander's hands for his evaluation before committing resources for the attendant training, spares, technical documentation, etc., required for a fully operational system, those efforts receiving a favorable endorsement arrive at the Defense Acquisition Board with a significant bill for "operationalization." Three ACTDs are currently exploring new concepts involving unmanned aviation.

The **Counter Proliferation II ACTD**, sponsored by the Defense Threat Reduction Agency (DTRA), envisions deploying two mini-UAVs (*Finders*) from a larger Predator UAV to conduct point detection of chemical agents. The employment concept

for *Finder* (Flight Inserted Detection Expendable for Reconnaissance) is to fly up to 50 nm from Predator and loiter in the vicinity of a suspected chemical agent cloud for up to 2 hours, passing its sensor data back to the Predator for relay to warfighters and/or collecting air samples for recovery by ground forces for analysis. Eight Finder systems (16 vehicles) are to remain as residuals when the ACTD ends in 2004.
www.jhuapl.edu/colloq/foch

Finder/NRL/ACTD

Weight:	59 lb
Length:	5.25 ft
Wingspan:	8.6 ft
Payload:	13.5 lb
Ceiling:	15,000 ft
Radius:	50 nm
Endurance:	10 hr

The **Loitering Electronic Warfare Killer (LEWK)** ACTD, initiated in FY01, is to demonstrate and assess an affordable, recoverable UAV capable of providing limited radar jamming and/or lethal/non-lethal munitions delivery for the SEAD mission. Communication relay and imagery receipt from the vehicle will also be demonstrated. LEWK, similar in size to a 1000-lb general-purpose bomb, can be released in flight as either an external or internal store of an aircraft or helicopter. Upon release, it deploys extendable wings and can loiter in the target area for up to 8 hours before recovery by parachute. First half-scale flight occurred in September 2001, with the first full-scale flight scheduled in March 2003 and operational demonstrations in 2004. Five LEWKs are envisioned as residuals at the conclusion of the ACTD. LEWK is the top contender to be the USMC replacement for its Pioneer UAVs.

LEWK/SAIC/ACTD

Weight:	800 lb
Length:	10 ft
Wingspan:	15 ft
Payload:	200 lb
Ceiling:	15,000 ft
Radius:	400-500 nm
Endurance:	8 hr

The **Hunter Standoff Killer Team (HSKT)** ACTD draws on experience gained in the Army's Airborne Manned/Unmanned System Technology (AMUST) program conducted in 2000-2001. AMUST teamed an AH-64 Apache in the killer role with a RQ-5 Hunter UAV in the hunter role, linking the UAV's video directly into the helicopter's cockpit. The Apache crew controlled the Hunter's sensor while the Hunter ground control station controlled its route of flight. HSKT intends to expand on this concept, adding technology from the earlier Rotorcraft Pilot's Associate program.

Although not truly UAVs, two projects, one Air Force and one Army, are exploring expendable, munition-size devices for quick reaction, real time point reconnaissance. The Air Force effort originated as an Information Warfare Battlelab initiative (**Microglider)** and has evolved into **Silent Eyes**. Dropped from a Predator wing pylon, it deploys stowed wings, glides unpowered over a preprogrammed route, and circles its target, returning color still images for battle damage assessment prior to impact. The Army **QuickLook** effort is a GPS-guided, powered (10 hp engine) device that is fired from a 155-mm howitzer. Once launched, a drag chute deploys to slow the device so inflatable wings can deploy which then enables it to reconnoiter a 7.3 nm^2 (25 km^2) area during its 45-minute flight. First all-up flight is scheduled for late 2002, followed by a Future Combat System demonstration at Communications Electronic Command (CECOM) in January 2003.

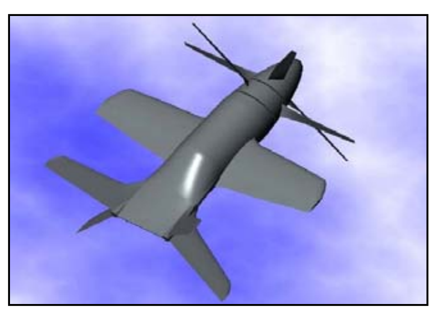
SilentEyes/Raytheon/Air Force

Weight:	10 lb
Length:	1.6 ft
Wingspan:	2.3 ft
Payload:	5 lb
Ceiling:	25,000 ft (release in glide)
Radius:	33 nm (glide)
Endurance:	20 min

Sensorcraft is an Air Force Research Laboratory (AFRL) concept for a sensor-driven UAV design; multiple definition contracts were awarded at the start of FY01. Its intent is to optimize a configuration for future airborne radar imaging and signals collection, then design the airframe, flight controls, and propulsion to conform to this configuration. The initiative integrates UAV-related efforts across a number of AFRL directorates and technology areas.

Under the Small Business Initiative Research (SBIR) program, AFRL is developing **Skytote**, a vertical takeoff and landing (VTOL) UAV that transitions to horizontal flight. Skytote may be used for a variety of missions, including precision delivery and resupply of special operations teams, port and base security surveillance, and delivery of non-lethal weapons. The project is based on Air Force Special Operations Command (AFSOC) and U.S. Special Operations Command (SOCOM) mission need requirements.

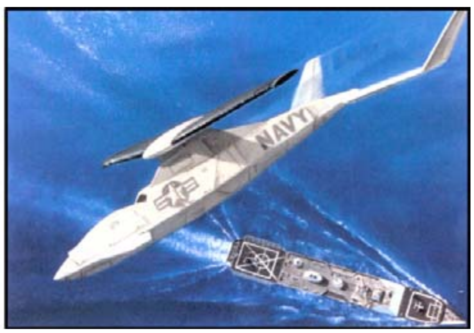
Sensorcraft/Air Force (artist concept)



Skytote/Air Force (artist concept)

2.3.3 DARPA UAV Programs

In addition to its involvement in three UCAV/UCAR demonstration programs (see Sections 2.2.9, 2.2.10, and 2.2.11), the Defense Advanced Research Projects Agency (DARPA) is currently sponsoring five other innovative UAV designs. The Advanced Air Vehicle (AAV) program is developing two unmanned rotorcraft projects, the Boeing **X-50 Dragonfly** Canard Rotor Wing (CRW) and the Frontier **A160 Hummingbird**. The attributes being explored under the AAV program are speed, altitude, and endurance. The goal is to substantially improve the performance of rotorcraft to levels nearing that of fixed wing aircraft. The *Dragonfly* will demonstrate the ability to takeoff and land from a hover, then transition to fixed wing flight for cruise, using its stopped rotor as its wing. The result will be a high speed (400+ kts) rotorcraft. CRW is expected to fly in 2003. The other AAV project is the *Hummingbird*, which uses a hingeless, rigid rotor to achieve a high endurance (24+ hrs), high altitude (30,000 ft) rotorcraft. Its first flight occurred in January 2002. *www.darpa.mil/tto/programs/aav*



X-50 Dragonfly/Boeing/DARPA

Weight:	1785 lb
Length:	17.7 ft
Wingspan:	12.0 ft
Payload:	200 lb
Ceiling:	10,000 ft
Radius:	108 nm
Endurance:	4 hr

A160 Hummingbird/Frontier/DARPA

Weight:	4000 lb
Length:	35 ft
Rotorspan:	36 ft
Payload:	300+ lb
Ceiling:	30,000 ft
Radius:	1500 nm
Endurance:	24+ hr

DARPA and the Army are exploring designs for both **Micro Air Vehicles (MAVs)**—aircraft no more than 6 to 12 inches in any dimension—and a slightly larger **Organic Air Vehicle (OAV)** to accompany the Army's Future Combat System's (FCS) robotic ground vehicles. The primary difference between the two systems is the MAV is focused on a small system suitable for backpack deployment and single-man operation, whereas the OAV is aimed at a larger system transported aboard one of the FCS ground vehicles. Honeywell was awarded an agreement to develop and demonstrate the OAV concept, and Robotic Technology, Inc., was subcontracted to develop the OAV under the FCS contract. The OAV is envisioned as a scalable-in-size UAV that can be launched and controlled from a HMMWV or robotic vehicle to provide over-the-hill RSTA. It is to be demonstrated with other FCS components at CECOM in 2003. Allied Aerospace has been awarded an agreement as part of the MAV ACTD, which pushes the envelope in small, lightweight propulsion, sensing, and communication technologies. Following its Military Utility Assessment (MUA) in FY04, 25 MAV systems are to transfer to the Army in FY05. A third effort, by DARPA's Synthetic Multifunctional Materials program, has developed a 6-ounce MAV, the AeroVironment *Wasp,* having an integrated wing-and-battery which has flown for 1.8 hours. *www.darpa.mil/tto/programs/mav*



	Wasp AeroVironment	**iStar Allied Aerospace**	**Kestrel Honeywell**
Weight:	.04 lb	5 lb	25 lb
Length:	8 in	12 in	42 in
Diameter:	13 in wingspan	9 in	17 in
Payload:	.01 lb	1 lb	10 lb
Ceiling:	1200 ft	16,000 ft	TBD
Radius:	0.5 nm	5.5 nm	11 nm
Endurance:	100 min	40 min	120 min

2.4 UAV Financial Data

Between 1990 and 1999, the Department of Defense invested over $3 billion in UAV development, procurement, and operations. The current FY03-09 Presidential Budget for UAV programs of $16.2 billion will help multiply that amount by nearly six times in the current decade (see Figure 2.5-1). Plus-ups in the wake of September 11 increased the FY02 UAV budget figure by $250M, and make FY03 the first billion-dollar year in UAV history (see Table 2.5-1). In numbers of UAVs, by 2010, the U.S. UAV inventory is expected to quadruple from 80 today to over 300 (not counting micro and mini UAVs) and to support a wider range of missions—Signal Intelligence (SIGINT) reconnaissance, communication relay, and SEAD—compared to today's imagery reconnaissance and strike capability.

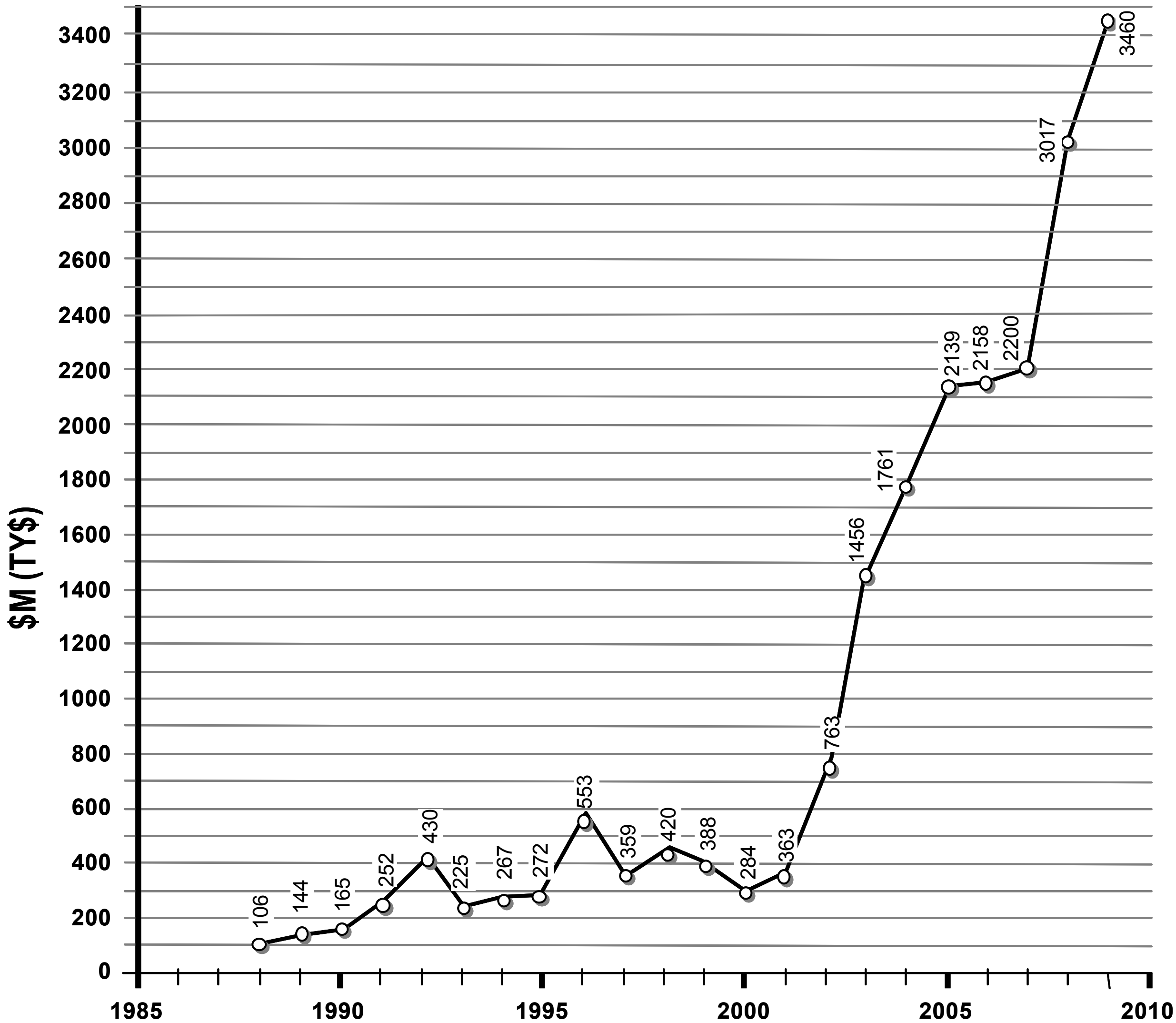


FIGURE 2.4-1: DOD ANNUAL FUNDING PROFILE FOR UAVS.

TABLE 2.4-1: FY04 PRESIDENTIAL BUDGET FOR UAV PROGRAMS.

Program	FY03*	FY04*	FY05*	FY06*	FY07*	FY08*	FY09*	Total*
Predator	227.9	358.0	329.4	355.0	241.4	266.5	374.2	2152.4
Pioneer	29.1	36.3	17.7	9.9	10.7	11.2	11.4	126.3
Hunter	33.9	29.2	28.2	28.1	26.0	24.6	25.2	195.2
Global Hawk	510.5	624.2	625.7	688.8	869.6	800.5	730.6	4849.9
Shadow 200	179.0	132.0	124.8	89.0	90.5	93.6	90.2	799.1
ER/MP	0.0	23.1	33.6	71.0	85.7	140.0	168.7	522.1
Fire Scout/VTUAV	38.6	4.0	0.0	0.0	0.0	180.0	270.0	492.6
UCAV (AF & Navy)	171.3	347.8	573.3	530.3	361.7	914.7	1226.1	4125.2
BAMS	0.0	25.1	224.4	187.1	322.1	415.2	440.3	1614.2
GH Maritime Demo	189.4	76.4	57.3	59.2	61.9	56.5	56.9	557.6
UCAR	33.0	49.4	75.9	107.7	84.2	86.2	47.0	483.4
Various Small UAV	51.6	52.4	55.0	55.0	55.0	55.0	55.0	379.0 estimated
Grand Total	**1455.7**	**1761.6**	**2139.1**	**2158.0**	**2199.6**	**3016.9**	**3459.5**	**16190.4**

* All budget figures are given in millions of dollars and roll up RDT&E, procurement, and O&S together.

2.5 UAV Proliferation

2.5.1 Foreign UAV Development

Currently, some 32 nations are developing or manufacturing more than 250 models of UAVs (see Figure 2.6-1); 41 countries operate some 80 types of UAVs, primarily for reconnaissance. Table 2.4-2 categorizes selected foreign UAVs and can be used to identify mission niches either complementing or not being performed by current U.S. UAVs. Systems not yet fielded are italicized in the table. Knowledge of such niches allows U.S. planners to rely on and better integrate the unique capabilities of coalition UAV assets in certain contingencies. The one niche common to a number of other countries but missing in the U.S. UAV force structure is a survivable penetrator for use in high threat environments. France and Germany have employed CL-289s with success in Bosnia and Kosovo, Russia's VR-3 *Reys* may be succeeded soon by the Tu-300, and Italy's new Mirach 150 supports its corps-level intelligence system. All are essentially jet engines with cameras attached which fly at low altitude at high subsonic speed to increase their survivability. Previous U.S. counterparts, the D-21, 1963-1971, (a Mach 3 reconnaissance drone dropped from a B-52) and the RQ-3 *DarkStar*, relied on supersonic speed or stealth as well as high altitude for their survivability.

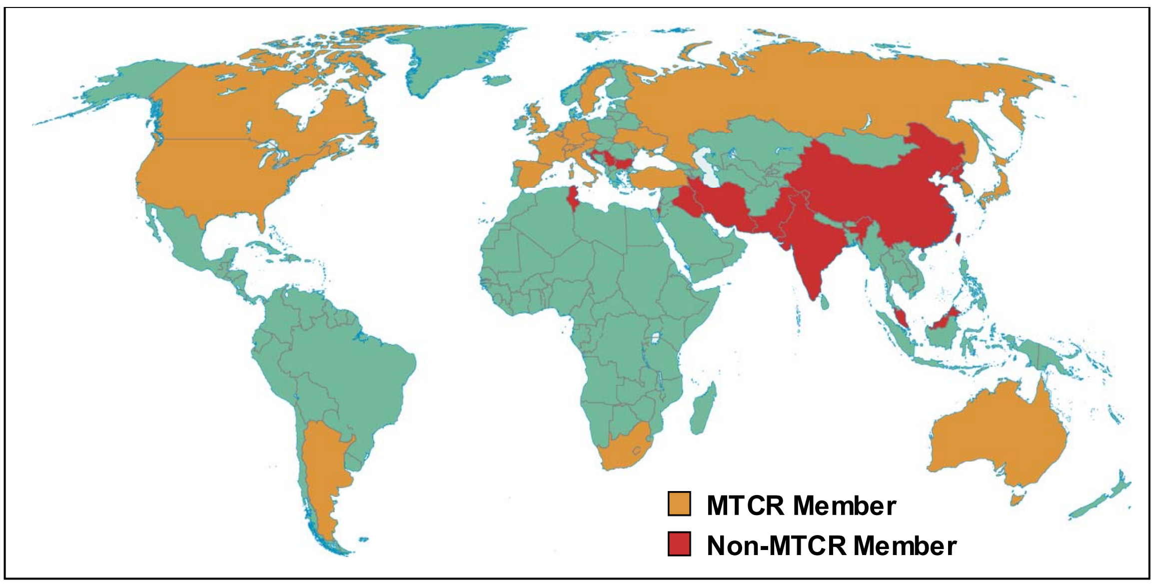


FIGURE 2.6-1: UAV MANUFACTURING COUNTRIES.

TABLE 2.5-1: CLASSES OF WORLDWIDE MILITARY RECONNAISSANCE UAVS.

	Tactical	Specialized			Endurance	
Country	**Over-the-Hill**	**Close Range**	**Maritime**	**Penetrating**	**Medium Rng**	**Long Rng**
United States	*Dragon Eye* *FPASS*	Hunter Shadow	Pioneer			
France		Crecerelle *MCMM*		CL-289 *MCMM*	*Eagle 1* *MALE*	
Germany	Luna	Brevel	*Seamos*	CL-289		*Eurohawk*
United Kingdom		Phoenix *Watchkeeper*			*Watchkeeper*	
Italy		Mirach 26 *Falco*		Mirach 150	*Predator*	
Israel		Scout/Searcher			*Heron*	
Russia		Shmel/Yak-61		VR-3 Reys VR-2 Strizh		

2.5.2 Export Policy

The sale of U.S.-manufactured UAVs to foreign militaries offers the triple advantages of 1) supporting the U.S. industrial base for UAVs, 2) potentially lowering the unit costs of UAVs to the Services, and 3) ensuring interoperability by equipping allied forces with mutually compatible systems. Balanced against these advantages, however, is the concern that the UAV capable of carrying a given weight of reconnaissance sensors and data links on a round trip could be modified to carry an equal weight of explosives twice that distance on a one-way mission. As the range, accuracy, and payload capacity of UAVs have overtaken those of cruise missiles and some ballistic missiles, controlling their proliferation has become a concern. UAVs fall under the terms of the Missile Technology Control Regime (MTCR), an informal and voluntary political agreement among 33 countries to control the proliferation of unmanned rocket and aerodynamic systems capable of delivering weapons of mass destruction (see Table 2.6-2). Predator and Global Hawk both fall under Category I definitions (vehicles capable of carrying 500 kg of payload to a range of 300 km) of the MTCR and were therefore subject to a strong presumption of denial for export under the existing agreement. The U.S. Defense and State Departments drafted an updated interim policy to the MTCR in late 2001 to allow UAV (including UCAV) exports to selected countries on a case-by-case basis.

U.S.-manufactured UAVs have been exported to numerous foreign countries over the past 40 years, from *Falconers* to the United Kingdom in the 1960s and *Firebees* to Israel in the 1970s to *Gnat 750s* to Turkey in the 1990s. The recently revised MTCR agreement allowed approval of the sale of six *Predators* to Italy in 2002. Overseas interest in *Global Hawk* has led to one demonstration in Australia, followed by a request to acquire the first two of as many as ten by that government. A demonstration of a SIGINT-variant (*Eurohawk*) is planned to be held in Germany in the future.

TABLE 2.5-2: MTCR MEMBER INTEREST IN UAVS.

MTCR Member*	UAV Exporter	UAV Operator	UAV Manufacturer	UAV Developer
Argentina	no	yes	yes	yes
Australia	yes	yes	yes	yes
Austria	yes	no	yes	yes
Belgium	no	yes	yes	yes
Brazil	no	no	no	no
Canada	yes	no	yes	yes
Czech Republic	no	yes	yes	yes
Denmark	no	yes	no	no
Finland	no	yes	no	no
France	yes	yes	yes	yes
Germany	yes	yes	yes	yes
Greece	no	no	no	yes
Hungary	no	no	no	yes
Iceland	no	no	no	no
Ireland	no	no	no	no
Italy	yes	yes	yes	yes
Japan	yes	yes	yes	yes
Luxembourg	no	no	no	no
The Netherlands	no	yes	no	no
New Zealand	no	no	no	no
Norway	no	no	no	yes
Poland	no	no	no	no
Portugal	no	no	no	yes
Russia	yes	yes	yes	yes
South Africa	yes	yes	yes	yes
South Korea	no	yes	yes	yes
Spain	no	no	yes	yes
Sweden	no	yes	yes	yes
Switzerland	yes	yes	yes	yes
Turkey	yes	yes	yes	yes
Ukraine	yes	yes	yes	yes
United Kingdom	yes	yes	yes	yes
United States	yes	yes	yes	yes
***Although not a member of the MTCR, Israel has pledged to abide by its guidelines.**				

3.0 Requirements

Requirements, along with the available systems (Section 2) and the emerging technologies to enable them (Section 4), are the three foundation stones of this Roadmap. The purpose of this section is to identify current and emerging requirements for military capabilities that could possibly be addressed by UAVs, regardless of whether a formal Mission Needs Statement is written against them. Three sources of these requirements are examined here: 40 years of historical UAV use by the Services, the annual Combatant Commanders' Integrated Priority Lists, and the most recent (January 2003) poll by the Joint Chief of Staff (JCS) of the theaters and the Services of their UAV needs.

3.1 Historically Validated UAV Roles

Although how the Services have employed UAVs over the past 40 years is no sure indicator of how they will use them in the next 25, most of the current UAV programs show a strong correlation with a line of past UAV programs built to fulfill similar requirements. The Services have repeatedly sought to fill five legacy roles with UAVs, implying the underlying requirements are of a long-term, enduring validity and therefore can be expected to continue through the period of this roadmap. These five roles, and the succession of UAVs, procured or attempted, to fill them, are shown in Table 3.1-1.

TABLE 3.1-1. HISTORICALLY VALIDATED UAV ROLES.

UAV Role:	Brigade/Division asset for reconnaissance, surveillance, and target acquisition (RSTA)
Proponent:	Army
Heritage:	Falconer (1950-60s) – Aquila (1970-80s) – Pioneer (1980-90s) – Outrider (1990s) – Shadow 200 (2000s)
UAV Role:	Shipborne asset for reconnaissance and naval gunfire support
Proponent:	Navy
Heritage:	Project Blackfly (1970s) – Pioneer (1980-2000s) – Fire Scout (2000s)
UAV Role:	Small unit asset for over-the-hill reconnaissance
Proponent:	Marine Corps
Heritage:	Bikini (1960-70s) – Pointer (1980-90s) – Dragon Eye (2000s)
UAV Role:	Survivable asset for strategic penetrating reconnaissance
Proponent:	Army/Air Force
Heritage:	Osprey (1960s) – D-21 (1960-70s) – Classified Program (1980s) – DarkStar (1990s)
UAV Role:	High Altitude endurance asset for standoff reconnaissance
Proponent:	Air Force
Heritage:	Compass Arrow (1960s) – Compass Dwell (1970s) – Compass Cope (1970s) – Condor (1980s) – Global Hawk (1990-2000s)

3.2 Combatant Commander Requirements for UAVs

A Combatant Commander's Integrated Priority List (IPL) is submitted annually by each of the nine Unified Commands to identify and prioritize the shortfalls in each theater's warfighting capabilities. They are the seminal source of joint requirements from our nation's warfighters. IPLs offer the advantages of being "direct from the field" in pedigree, joint in perspective, and reexamined annually, so their requirements remain both current and auditable over the years. Taken as a whole, they are the only source to enumerate worldwide (vice Service- or theater-centric) requirements.

Of the 117 requirements submitted in the latest (2002) combined IPLs for funding in the FY03-08 FYDP, 42 (36 percent) identified needed capabilities that could potentially be filled by using UAVs. Four of the 42 specifically identified "UAVs" as a desired solution to the stated requirement. All but one of these capabilities have previously been associated in some form (a flight demonstration, a technical study, etc.) with UAVs, as shown in Table 3.2-1. These 42 requirements can be organized into 17 mission areas, as shown in Figure 3.2-1.

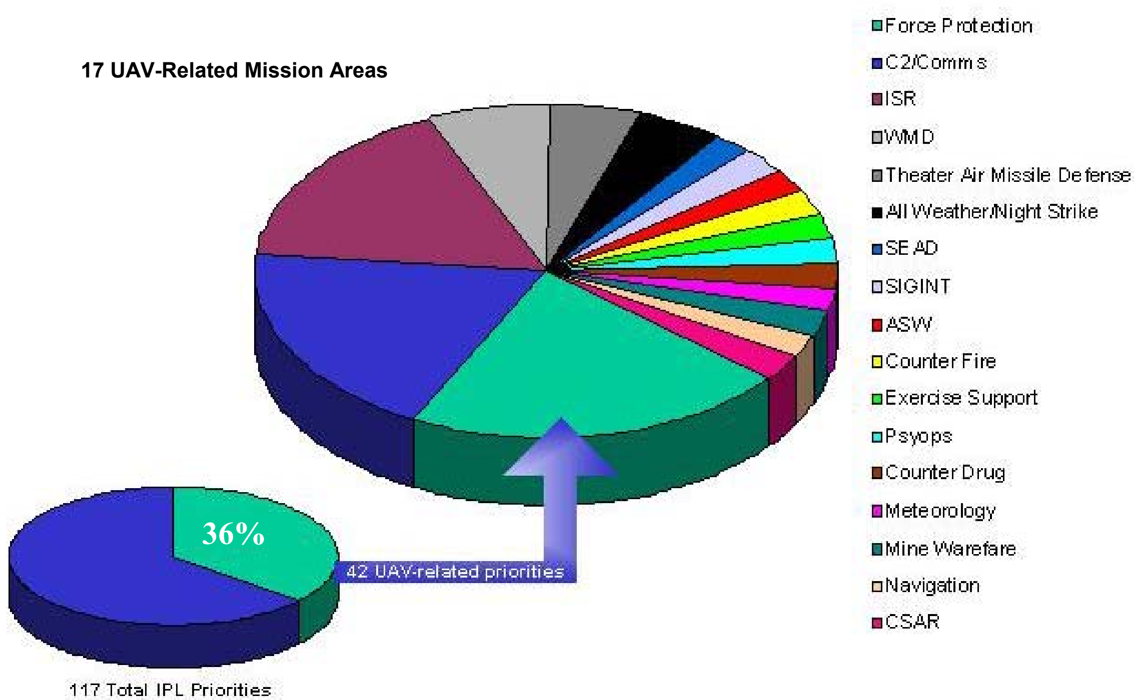


FIGURE 3.2-1: IPL PRIORITIES LINKED TO UAV MISSIONS.

Although EO/IR/SAR sensors have been the predominant payload fielded on DoD UAVs to date, Table 3.2-1 shows a number of other payloads have been previously flown on UAVs in proof-of-concept demonstrations. These demonstrations have shown UAVs can perform the tasks inherent in most of these 17 mission areas. They show that UAVs can be *a candidate solution* for certain requirements. UAVs should be *the preferred solution* over their manned counterparts when those requirements involve the familiar three jobs best left to UAVs: the dull (long dwell), the dirty (sampling for hazardous materials), and the dangerous (extreme exposure to hostile action).

TABLE 3.2-1: UAV MISSION AREAS.

Requirements (Mission Areas)	**Justification for UAV Use** "Dull"	"Dirty"	"Dangerous"	**Prior UAV Experience** (UAV/Payload, Place Demonstrated, Year)
Intelligence, Surveillance, & Reconnaissance (ISR)	x		x	Pioneer, Exdrone, Pointer/Gulf War, 1990-91 Predator, Pioneer/Bosnia, 1995-2000 Hunter, Predator, Pioneer/Kosovo, 1999
C2/Communications	x			Hunter/CRP, 1996; Exdrone/TRSS, 1998 Global Hawk/ACN, Predator/ACN, ongoing
Force Protection	x	x	x	Camcopter, Dragon Drone/Ft Sumner, 1999
Signals Intelligence (SIGINT)	x		x	Pioneer/SMART, 1995 Hunter/LR-100/COMINT, 1996 Hunter/ORION, 1997
Weapons of Mass Destruction (WMD)		x	x	Pioneer/RADIAC/LSCAD/SAWCAD, 1995 Telemaster/Analyte 2000, 1996 Pointer/CADDIE 1998 Hunter/SAFEGUARD, 1999
Theater Air Missile Defense (TAMD)	x		x	Israeli HA-10 development, (canceled) Global Hawk study, 1997
Suppression of Enemy Air Defenses (SEAD)			x	Hunter/SMART-V, 1996 Hunter/LR-100/IDM, 1998
Combat Search and Rescue (CSAR)			x	Exdrone/Woodland Cougar Exercise, 1997 Exdrone/SPUDS, 2000
Mine Counter Measures (MCM)			x	Pioneer/COBRA, 1996 Camcopter/AAMIS, 1999 (Germany)
Meteorology and Oceanography (METOC)	x		x	Aerosonde/Visala, 1995 Predator/T-Drop, 1997 Predator/BENVINT ACTD, 2002
Counter Narcotics (CN)	x		x	Predator/Ft Huachuca, 1995 Pioneer/So. California, 1999
Psychological Ops			x	Non-DoD UAV/leaflet dispensing, 1990's
All Weather/Night Strike			x	DASH/Vietnam, 1960s Predator/Afghanistan, 2001
Exercise Support	x			Predator/JOTBS, 2002
Counter Fire			x	none
Anti Submarine Warfare	x			DASH, 1960s
Navigation	x			Hunter/GPS Pseudolite, 2000

3.3 JROC-Validated Requirements for UAVs

In response to an August 2000 Joint Staff-led, Joint Requirements Oversight Council-validated survey, Unified Command and Service staffs were given eighteen mission areas to prioritize in terms of their desirability for being performed by four UAVs (Predator, Global Hawk, Shadow 200, and/or VTUAV); the results are shown in Table 3.3-1. Where different, rankings from the previous survey are shown in parentheses. Although one-to-one alignments of these 17 missions with the previously described 17 priorities from the IPLs for UAVs is inexact, the priorities of the two for congruent mission areas are in general agreement, as is shown in the last column.

TABLE 3.3-1: COMBATANT COMMANDER/SERVICE UAV MISSION PRIORITIZATION MATRIX—2003.

Mission	Predator	Global Hawk	TUAV		
Reconnaissance	1	1	1	1	3
Signals Intel	3	2	5 (7)	4	8
Mine Detection/CM	11 (7)	13 (12)	6 (4)	5	11
Precision Target Location and Designation	2	12 (11)	2 (3)	2	-
Battle Management	10 (8)	6 (7)	7 (5)	9 (7)	-
Chem/Bio Reconnaissance	7 (10)	9 (10)	4 (6)	7 (9)	4
Counter Cam/Con/Deception	5 (4)	5	8	11	-
Electronic Warfare	8 (6)	4	9	10	10
Combat SAR	6 (5)	7 (8)	10	6 (8)	12
Communications/Data Relay	9	3	3 (2)	3	2
Information Warfare	14 (11)	8 (6)	11	8 (6)	-
Digital Mapping	13 (12)	10 (9)	12	13 (12)	-
Littoral Undersea Warfare	-	-	-	12 (13)	-
SOF Team Resupply	12	-	15	15	-
Weaponization/Strike	4	11	13		6
GPS Psuedolite	-	14	-		9
Covert Sensor Insertion	-	-	14	14	-
Decoy/Pathfinder	-	-	16	16	-

4.0 Technologies

The third foundation stone of this Roadmap, emerging technologies, provides the means by which today's UAV systems (Section 2) will evolve the capabilities necessary to provide the warfighters' requirements (Section 3). These three elements are brought together to form the Roadmap proper in Section 6. In this section, technologists have provided their best estimates of what UAV-related developments will occur and when we should see them in the field over the next 25 years. Four technology areas are addressed: Platforms (propulsion and survivability), Payloads (sensors, relays, and weapons), Communication, and Processors.

4.1 Platforms

The requirements for UAVs identified in Section 3 reveal the overwhelming majority of UAV uses involve dull (long duration) or dangerous (high potential for loss) aspects. These mission requirements translate to technology requirements for increased platform endurance, increased platform survivability, and/or lower platform cost. The dirty mission set implies low cost, disposable (generally small) UAV systems, focusing on simple, COTS based solutions.

4.1.1 Propulsion

Endurance is driven by propulsion. Two key propulsion metrics are specific fuel consumption (SFC) for efficiency and mass specific power (MSP) for performance. Figures 4.1-1 and 4.1-2 show trends in SFC and MSP, respectively, expected over the next 25 years. Projected propulsion advances over the next 25 years are depicted in 4.1-3 and discussed in Appendices A and D.

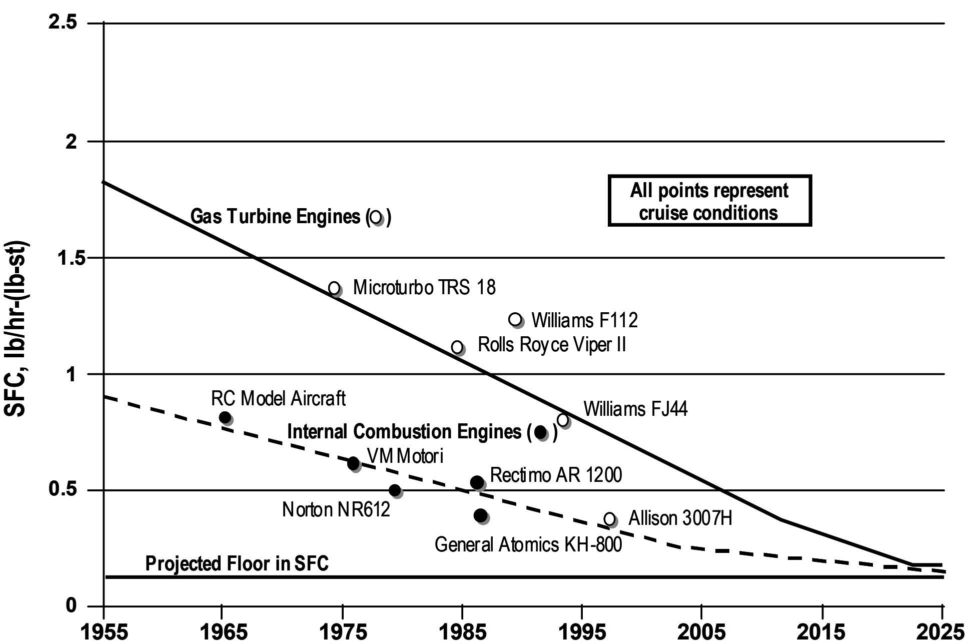


FIGURE 4.1-1: SPECIFIC FUEL CONSUMPTION TRENDS.

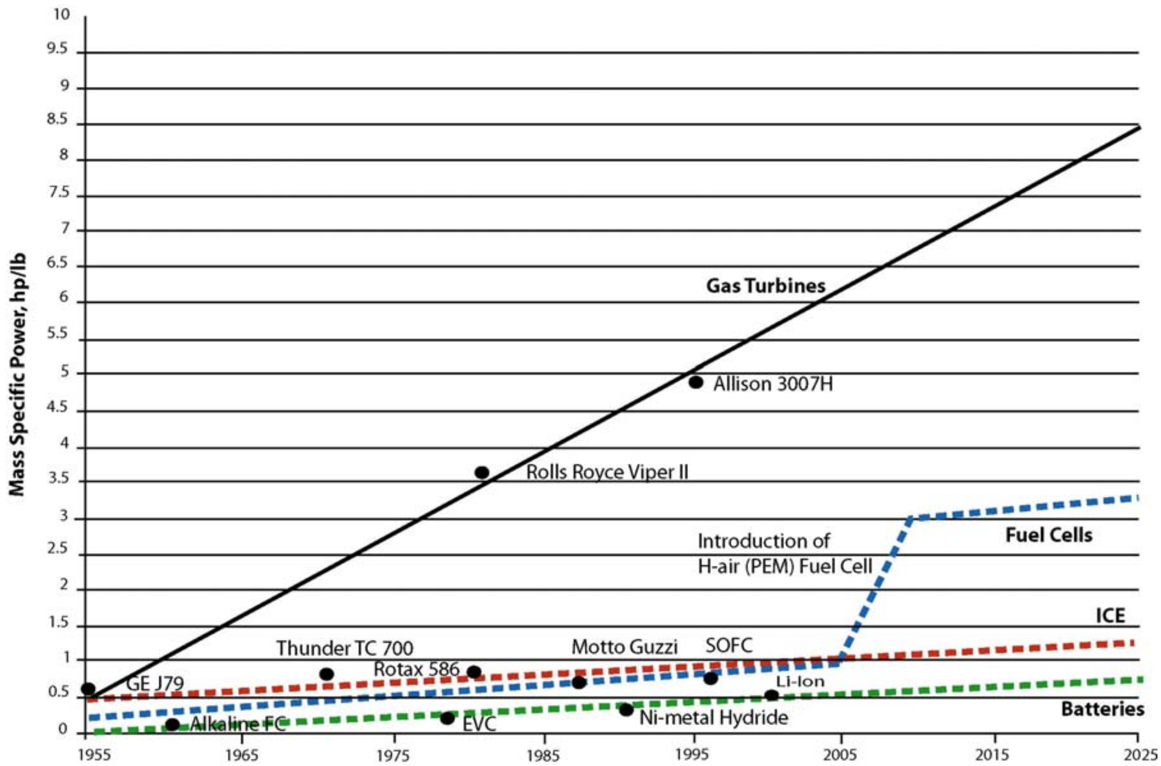


FIGURE 4.1-2: MASS SPECIFIC POWER TRENDS.

	Now	2010	2015
Turbine Engine	Turbofan, turboprop, Integrated High Performance Turbine Engine Technology (IHPTET)	Versatile Affordable Advanced Turbine Engines (VAATE-1)	VAATE-II Note: VAATE ends in 2017
Hypersonics Scramjets	AF Single Engine Scramjet Demo, Mach 4-7 X-43C Multi-engine, Mach 5-7	Robust Scramjet: broader operating envelope and reusable applications (e.g. turbine-based combined cycles)	Hypersonic cruise missiles could be in use w/in operational commands. Prototype high Mach (8-10) air vehicles possible
Turboelectric Machinery	Integrated Drive Generator on Accessory Drive, Integrated Power Unit – F-22	No AMAD, Electric Propulsive Engine Controls, Vehicle Drag Reduction/Range Extension	Enabling electrical power for airborne directed energy weaponry
Rechargeable Batteries	Lead Acid, NiCd, in wide use Lithium Ion under development – (B-2 battery – 1st example)	Lithium Ion batteries in wide use (100-150 WH/kg)	Lithium polymer batteries in wide use (300-400 WH/kg)
Photovoltaics	Silicon based single crystal cells in rigid arrays	Flexible thin films Multi-junction devices – Germanium, Gallium based	Concentrator cells and modules technologies (lens, reflectors)
Fuel Cells	Prototypes in large UAVs – NASA ERAST (Helios)	Production PEM fuel cells (automobile industry driven) available for UAVs	Fuel cells size, weight reductions Improvements in reformers resulting in multi fuels use

FIGURE 4.1-3: PROPULSION/POWER TECHNOLOGY FORECAST.

4.1.2 Survivability

Aircraft survivability is a balance of tactics, technology (for both active and passive measures), and cost for a given threat environment. For manned aircraft, aircraft survivability equates to crew survivability, on which a high premium is placed. For UAVs, this equation shifts, and the merits of making them highly survivable, vice somewhat survivable, for the same mission come into question. Insight into this tradeoff is provided by examining the Global Hawk and DarkStar programs. Both were built to the same mission (high altitude endurance reconnaissance) and cost objective ($10 million flyaway price); one (DarkStar) was to be more highly survivable by stealth, the other only moderately survivable. Performance could be traded to meet the cost objective. The resulting designs therefore traded only performance for survivability. The low observable DarkStar emerged as one-third the size (8,600 versus 25,600 lbs) and had one-third the performance (9 hrs at 500 nm versus 24 hrs at 1200 nm) of its conventional stablemate, Global Hawk. It was canceled for reasons that included its performance shortfall outweighing the perceived value of its enhanced survivability. Further, the active countermeasures planned for Global Hawk's survivability suite were severely pared back as an early cost savings measure during its design phase.

The value of survivability in the UAV design equation will vary with the mission, but the DarkStar lesson will need to be reexamined for relevance to future UCAV designs. To the extent UAVs inherently possess low or reduced observable attributes, such as having seamless composite skins, fewer windows and hatches, and/or smaller sizes, they will be optimized for some level of survivability. Trading performance and/or cost for survivability beyond that level, however, runs counter to the prevailing perception that UAVs must be cheaper, more attritable versions of manned aircraft to justify their acquisition. As an illustration, both the Air Force and the Navy UCAVs were originally targeted at one third the acquisition cost of their closest manned counterpart, the JSF, and are still priced at a fraction of what it costs to buy their manned counterparts.

One low/reduced observable characteristic implicit in the Combatant Commander's IPLs, specifically for the force protection and SEAD missions, is aircraft acoustic signature. These two missions can be better supported by using quieter vehicles that are less susceptible to detection, whether by base intruders (acoustic) in the force protection role or by a hostile integrated air defense system employing active and passive (radar and acoustic) detection systems for the SEAD mission. Electric power systems, such as fuel cells, offer lower noise and infrared signatures for smaller UAVs while providing comparable mass specific power to that of Internal Combustion Engines (ICE).

If active and passive measures fail to protect the aircraft, the focus of survivability shifts from completing the mission to saving the aircraft. Two emerging technologies hold significant promise in this area for UAVs, self-repairing structures and fault tolerant flight control systems (FCSs). AFRL-sponsored research into self-repairing materials shows composites may be capable of sealing small holes or gaps in-flight, such as those inflicted by small arms fire. Several on-going efforts are intent on developing FCS software that can "reconfigure" itself to use alternative combinations of remaining control surfaces when a primary control surface is damaged or lost. Fault tolerant FCSs will be key to improving UAV reliability and enabling successful demonstration of the Services' autonomous operation initiatives.

4.1.3 Cost Control

Empty weight cost is a commonly used metric in the aviation industry because it tends to remain constant across a variety of aircraft types. That number today is roughly $1500 per pound. Table 4.1-1 provides the empty weight and cost data for DoD UAVs depicted in Figure 4.1-4. It shows current DoD UAV platforms cost approximately $1500 per pound of empty weight and $8000 per pound of payload capacity as one "cost per capability" metric. Figure 4.1-5 takes this metric further by factoring in UAV endurance (from Section 2) to also provide a link between performance and cost in terms of dollars per pound-hour. **OSD, Joint Staff, and the Services should develop capability and/or capability-performance metrics (such as those in Section 4.1) against which to evaluate UAV program costs. Program managers should provide Joint Staff and OSD written justification at Milestone B and C reviews when these metrics are exceeded, and provide appropriate management organizations with options for reducing costs to align costs with these metrics when this occurs.**[2] **OPR: OSD. Due: FY03.**

TABLE 4.1-1. UAV SYSTEM AND AIRCRAFT COSTS AND WEIGHTS.

System	Aircraft Cost FY02 $*	Aircraft Weight, lb*	Payload Weight, lb	System Cost FY02 $	Number of Acft/System
Predator	$ 1,700,000	1135	450	$ 30,000,000	4
Pioneer	$ 650,000	307	75	$ 7,000,000	4
Hunter	$ 1,200,000	1170	200	$ 20,000,000	8
Global Hawk	$ 20,000,000	9200	1950	$ 57,000,000	1
Shadow 200	$ 325,000	216	60	$ 6,200,000	4
Fire Scout	$ 1,800,000	1502	200	$ 14,200,000	3
Dragon Eye	$ 35,000	3.5	1	$ 120,000	3

* Aircraft costs are minus sensor costs, and aircraft weights are minus fuel and payload capacities. Hardware costs, including GFE, are used.

[2] Bolded text refers to OSD's priority goals for unmanned aviation discussed in section 6.4.

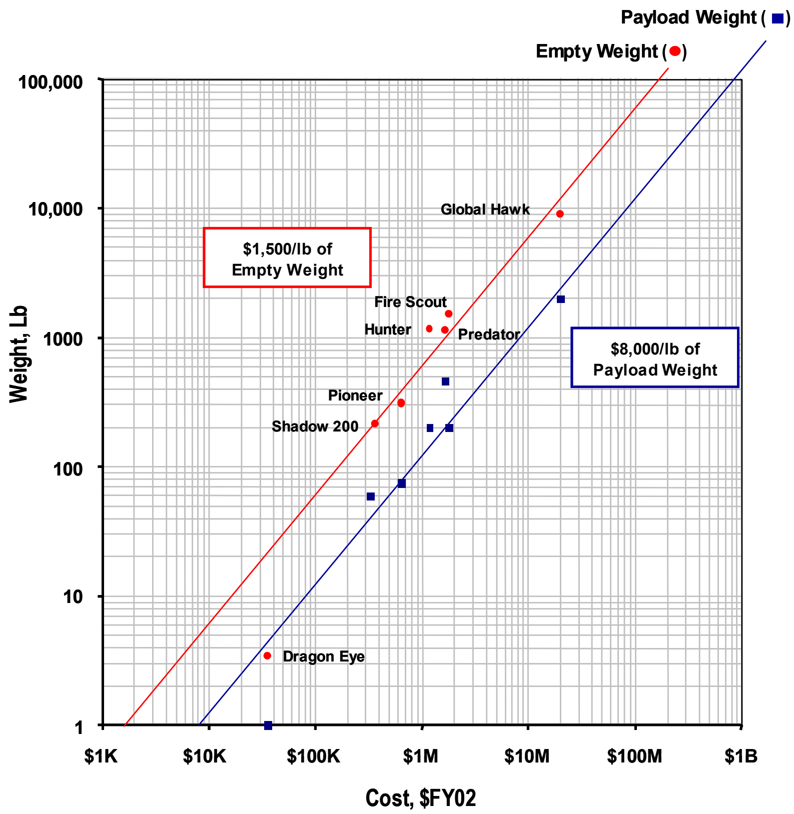


FIGURE 4.1-4: UAV CAPABILITY METRIC: WEIGHT V. COST.

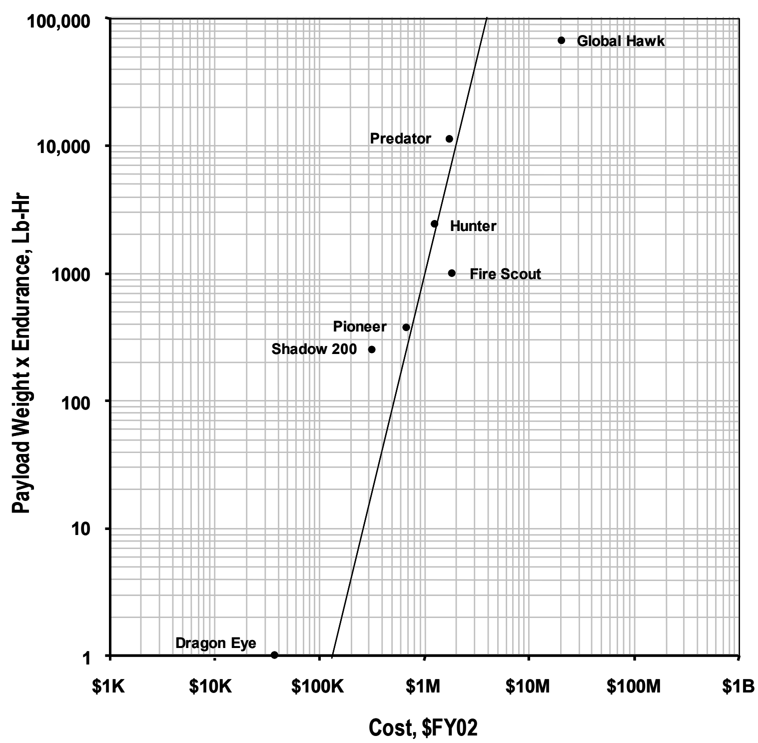


FIGURE 4.1-5: UAV PERFORMANCE METRIC: ENDURANCE V. COST.

4.2 Payloads

Of the 17 mission areas identified by the Combatant Commanders that could potentially be addressed with UAVs (see Section 3.2), ten involve sensing, three relaying (Command and Control (C2)/Communications, Psychological Operations, and Navigation), and four weapons delivery (Theater Air and Missile Defense (TAMD), SEAD, Strike, and Anti Submarine Warfare (ASW)) functions for the mission payload. The payload capacities available in current and planned U.S. military UAVs are shown in relation to platform endurance in Figure 4.2-1.

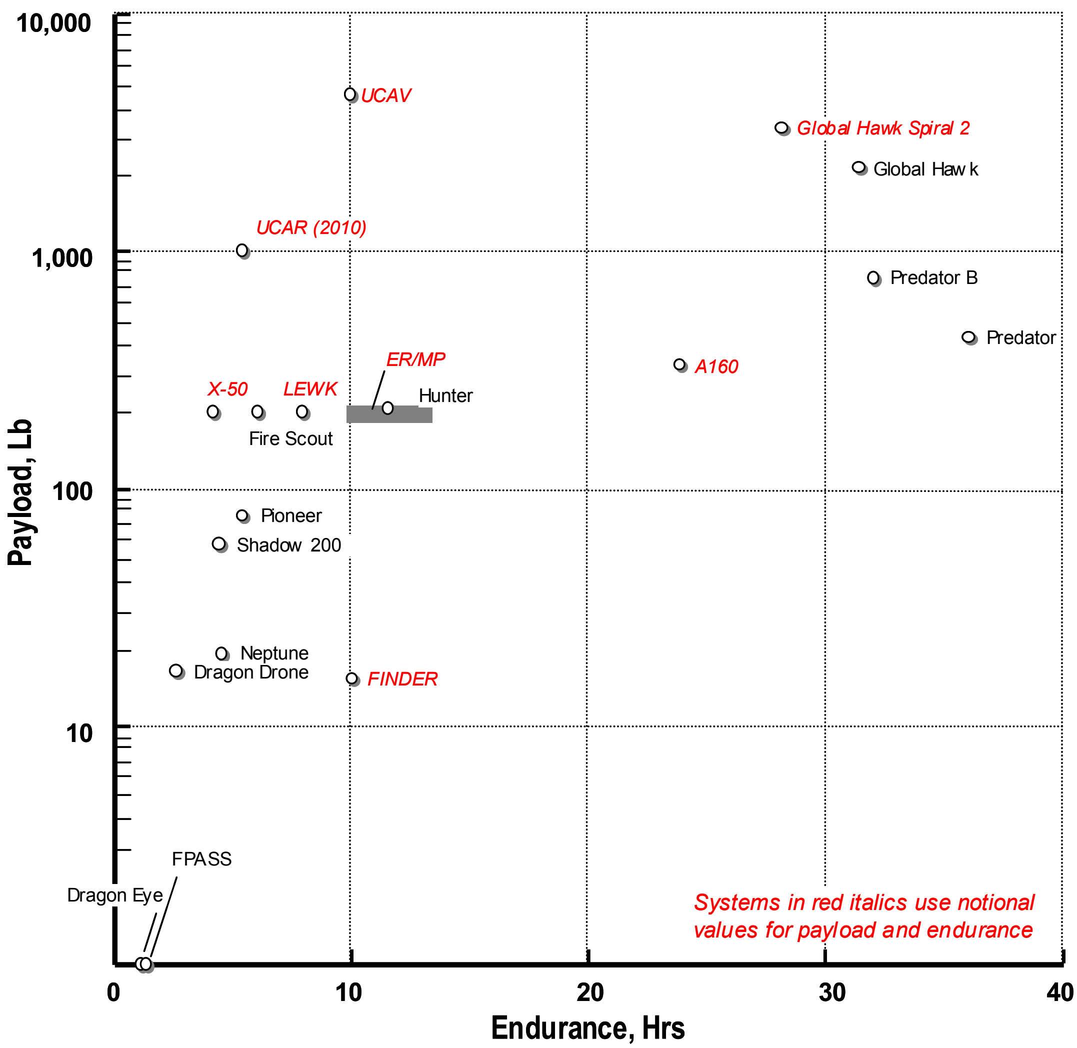
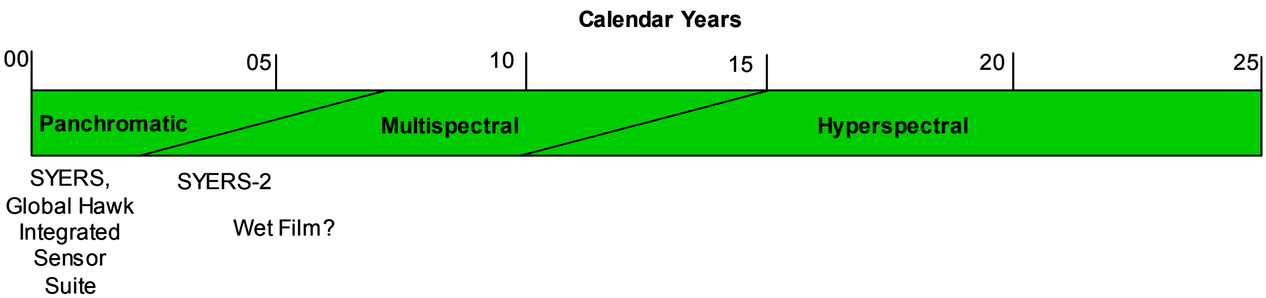


FIGURE 4.2-1: UAV PAYLOAD WEIGHT VS. ENDURANCE.

4.2.1 Sensors

Requirements for sensing payloads on UAVs extend not just to the ten mission areas mentioned above, but also to the four weapons delivery missions, due to their reliance on detecting and identifying the target to meet rules of engagement (ROE) constraints and to improve aim point accuracy. The dominant requirement for sensing is for imaging (visible, infrared, and radar), followed by signals (for the SIGINT and SEAD missions), chemical (weapons of mass destruction (WMD)), biological (WMD), radiological (WMD), meteorological (METOC), and magnetic (ASW and Mines Counter Measure (MCM)). Figures 4.2-1 through 4.2-5 depict expected developments in imaging, signals, and measurements and signatures intelligence (MASINT) sensors over the next 25 years by technology and by system, as well as describing the regimes in which such sensors must perform, the enablers necessary to improve present capabilities, and the missions for which each is applicable. Figure 4.2-6 then combines and maps these forecast developments by sensor type between now and 2010, then out to 2015.

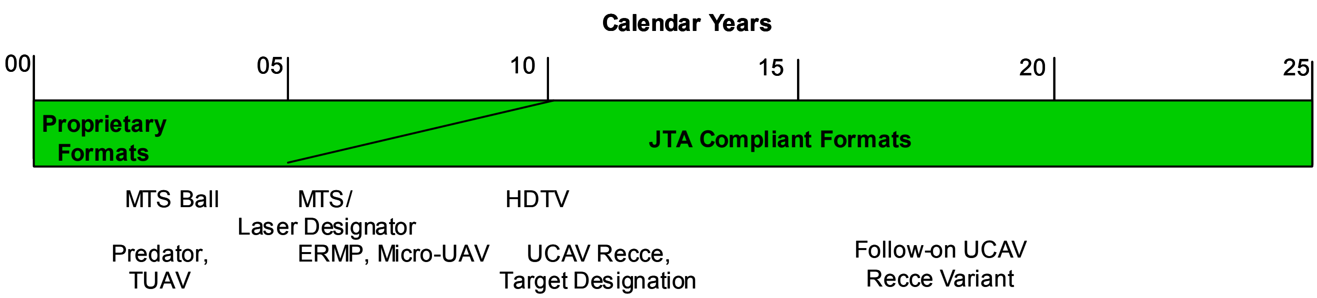


REGIME: **Medium to high altitude, relatively sophisticated sensors beyond video capabilities**

ENABLERS: **Wideband data links/architecture, focal plane arrays, lightweight optics, lightweight rigid structures, lightweight mass storage arrays (digital storage equivalent to wet film pixels/pound), onboard processing, ATC/ATR algorithm development,**

MISSIONS: **Broad area reconnaissance, high resolution spot imagery, standoff recce, intel preparation of the battlefield, positive target identification, battle damage assessment**

FIGURE 4.2-2: STILL IMAGERY SENSOR TECHNOLOGY FORECAST.

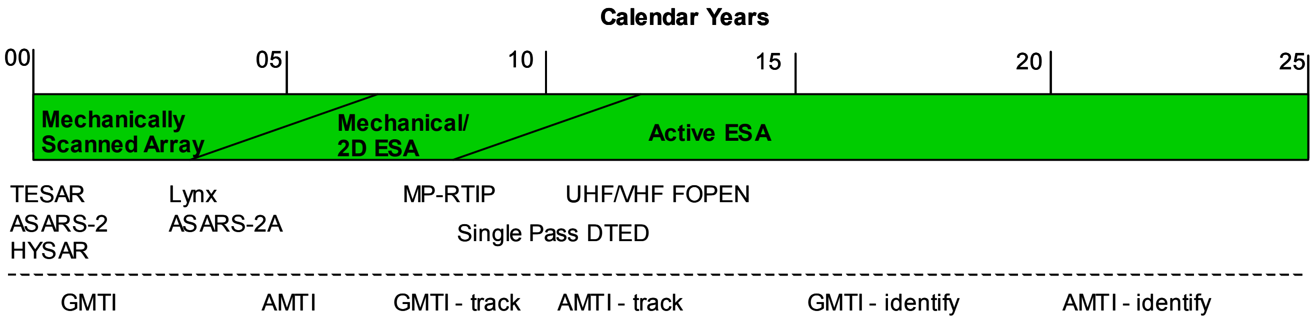


REGIME: **All altitudes, all vehicle classes except micro-UAVs**

ENABLERS: **Miniaturized focal plane arrays, tactical line-of-sight datalinks, NRT sensor-to-shooter architecture, autonomous vehicle/sensor ops, interneton the battlefield**

MISSIONS: **Low threat surveillance, over-the-hill/behind-the-building imagery, treatyverification, “stakeouts”, force protection/picket duty, precision strike/BDA, target designation**

FIGURE 4.2-3: MOTION/VIDEO IMAGERY SENSOR TECHNOLOGY FORECAST.

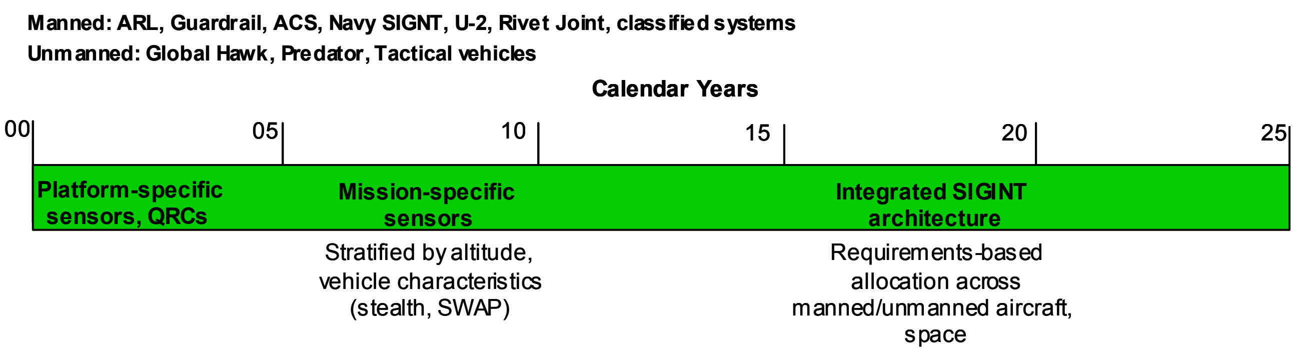


REGIME: **All altitudes, all vehicle classes except micro-UAVs**

ENABLERS: **Scalable AESA systems, operationalized FOPEN sensors/algorithms,onboard/offboard image enhancement (improved resolution, coherentchange detection), aircraft electrical generator improvements (watts/pound,power extraction efficiency)**

MISSIONS: **Broad area reconaissance, ground/air moving target imagery, intel prep of the battlefield, precision guided munition targeting data, NRT sensor-to-shooter/sensor-to-bullet data transfer, mapping, cueing**

FIGURE 4.2-4: RADAR IMAGER SENSOR TECHNOLOGY FORECAST.



REGIME: **All altitudes, all vehicle classes**

ENABLERS: **Scalable SIGINT systems, decryption software development, dense environment algorithms, conformal/multipurpose antennas**

MISSIONS: **Threat warning, cueing for imagery/electronic warfare, situational awareness, threat database, strat ELINT/COMINT**

FIGURE 4.2-5: SIGINT SENSOR TECHNOLOGY FORECAST.

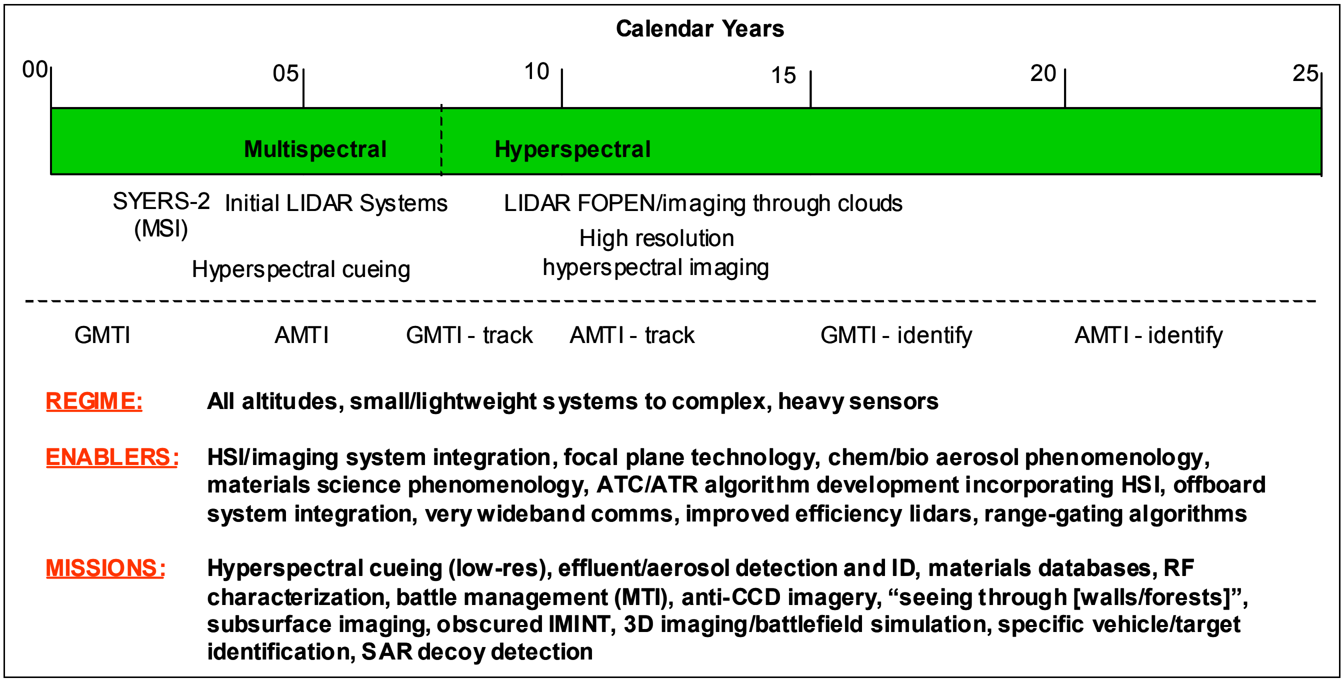


FIGURE 4.2-6: MASINT SENSOR TECHNOLOGY FORECAST.

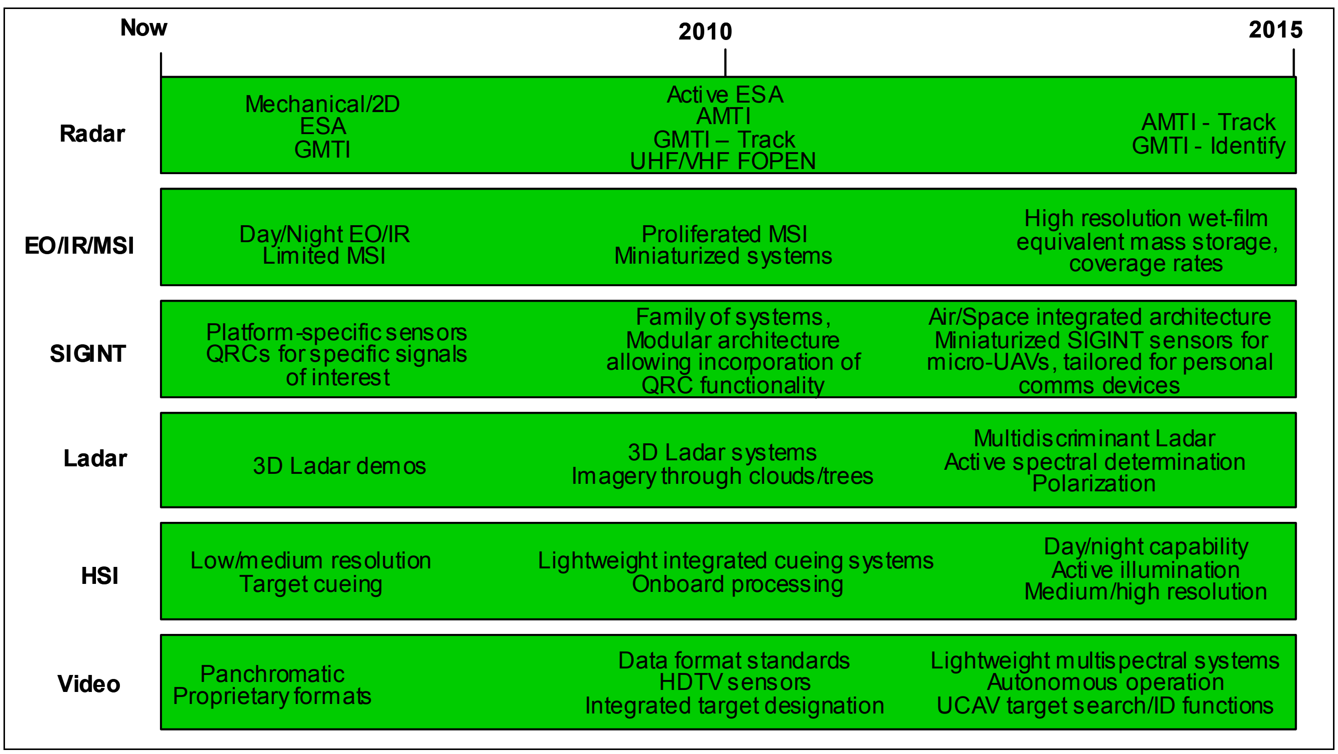


FIGURE 4.2-7: FORECAST SENSOR CAPABILITIES.

4.2.2 Communication Relay

Every Combatant Commander expressed concern over communication shortfalls in his theater (see Figure 4.3-1). By 2010, existing and planned capacities are forecast to meet only 44 percent of the need projected by Joint Vision 2010 to ensure information superiority. A separate, detailed study, Unmanned Aerial Vehicles (UAVs) as Communications Platforms, dated 4 November 1997, was conducted by OSD/C3I. Its major conclusions regarding the use of a UAV as an Airborne Communication Node (ACN) were:

- Tactical communication needs can be met much more responsively and effectively with ACNs than with satellites.
- ACNs can effectively augment theater satellite capabilities by addressing deficiencies in capacity and connectivity.
- Satellites are better suited than UAVs for meeting high capacity, worldwide communications needs.

ACNs can enhance intra-theater and tactical communications capacity and connectivity by providing 1) more efficient use of bandwidth, 2) extending the range of existing terrestrial LOS communications systems, 3) extending communication to areas denied or masked to satellite service, and 4) providing significant improvement in received power density compared to that of satellites, improving reception and decreasing vulnerability to jamming. The potential savings in logistics is also significant. In Desert Storm, the deployment of Army signal units required 40 C-5 sorties and 24 ships. By being largely self-deployable, an endurance UAV-based ACN could reduce the number of airlift sorties required for communication support by half to two thirds.

DARPA’s Adaptive Joint C4ISR Node (AJCN) is developing a modular, scalable communication relay payload that can be tailored to fly on a RQ-4/Global Hawk and provide theater-wide support (300 nm diameter area of coverage) or on a RQ-7/Shadow for tactical use (60 nm diameter area). The current program schedule calls for flight demonstrations beginning in 2004 and the addition of a simultaneous SIGINT capability by 2010.

4.2.3 Weapons

If combat UAVs are to achieve most of their initial cost and stealth advantages by being smaller than their manned counterparts, they will logically have smaller weapons bays and therefore need smaller weapons. Smaller and/or fewer weapons carried per mission means lethality must be increased to achieve equal or greater mission effectiveness. Achieving lethality with small weapons requires precision guidance (in most cases) and/or more lethal warheads. Ongoing technology programs are providing a variety of precision guidance options; some are in the inventory now. With the advent of some innovative wide kill-area warheads, hardening guidance systems, i.e., resistance to GPS jamming, appears to be the greatest technology requirement. A potentially significant advantage to smaller more precise weapons and penetrating launch platforms such as UCAVs is the reduction in collateral damage. In some cases these platform and weapons combinations could reduce an adversary’s ability to seek sanctuary within non-combatant areas.

As for increased lethality, a number of innovative weapons have shown capabilities that suggest UAV size-compatible weapons could achieve high lethality against difficult targets. The Naval Surface Weapons Center (NSWC) at Indian Head Arsenal, MD, has demonstrated a *flying plate weapon* that can reduce concrete structures to rubble or perforate steel, giving it the potential to destroy bridge piers, drop structural elements, and penetrate bunkers. New, more high-energy explosives are emerging that can be used to provide the explosive power of much larger weapons in very small configurations. NSWC's *intermetallic incendiary* technology generates a 6700^{o}F firestorm that cannot be quenched by water, offering the promise of neutralizing biological and chemical agents. The *flechette weapon* can disable vehicles, air defense sites, and similar soft targets with numerous, small, high velocity flechettes. *High power microwave* (HPM) technology uses single or repetitive pulses to disrupt or destroy transistors in command, control, and communication centers and electronics facilities. The Air Force Air Armament Center's *small diameter bomb* (SDB) is half the weight of the smallest bomb the Air Force uses today, the 500-pound Mark 82. Its 250-pound class warhead has demonstrated penetration of more than 6 feet of reinforced concrete. The Air Force hopes to deploy it by 2006 on the F-15E, followed by deployment on several other aircraft, including the UCAV.

4.2.4 Cost Control

Table 4.1-1 provides the payload capacities used in Figure 4.1-4, which shows current DoD UAVs cost approximately $8000 per pound of payload capacity (sensors), a comparable number to the payload capacity of the JSF, which is $7300 per pound (weapons). JSF has served as an early standard for setting both Air Force and Navy UCAV price goals. This same capability metric applied to the planned Air Force UCAV is $5500 per pound payload (weapons). As UAVs become smaller, or stealthier, the standoff range of sensor systems may be reduced. Reduced sensor standoff capability coupled with more use of COTS systems can have a significant impact on some sensor packages for some classes of UAVs.

4.3 Communication

Airborne data link rates and processor speeds are in a race with respect to enabling future UAV capabilities. Today, and for the near term, the paradigm is to relay virtually all airborne data to the ground and process it there for interpretation and decisions. Eventually, however, onboard processing power will outstrip data link capabilities and allow UAVs to relay the *results* of their data, vice the data itself, to the ground for decision making. At that point, the requirement for data link rates in certain applications, particularly imagery collection, should drop significantly.

Meanwhile, data compression will remain relevant into the future as long as band-limited communications exist, but it is unlikely compression algorithms alone will solve the near term throughput requirements of advanced sensors. A technology that intentionally discards information is not the preferred technique. For now, compression is a concession to inadequate bandwidth.

In the case of radio frequency (RF) data links, limited spectrum and the requirement to minimize airborne system size, weight, and power (SWAP) have been strong contributors for limiting data rates. Rates up to 10 Gbps (40 times currently fielded capabilities) are considered possible at current bandwidths by using more bandwidth-efficient modulation methods. At gigahertz frequencies however, RF use becomes increasingly constrained by frequency congestion, effectively limiting its upper frequency to 10 GHz. Currently fielded digital data links provide an efficiency varying between 0.92 and 1.5 bps/Hz, where the theoretical maximum is 1.92.

Airborne optical data links, or lasercom, will potentially offer data rates two to five orders of magnitude greater than those of the best future RF systems. However, lasercom data rates have held steady for two decades because their key technical challenge was adequate Pointing, Acquisition, and Tracking (PAT) technology to ensure the laser link was both acquired and maintained. Although mature RF systems are viewed as lower risk, and therefore attract investment dollars more easily, Missile Defense Agency (formerly BMDO) funding in the 1990s allowed a series of increasingly complex demonstrations at Gbps rates. The small apertures (3 to 5 in) and widespread availability of low power semiconductor lasers explains why lasercom systems typically weigh 30 to 50 percent that of comparable RF systems and consume less power.

Although lasercom could surpass RF in terms of airborne data transfer rate, RF will continue to dominate at the lower altitudes for some time into the future because of its better all-weather capability. Thus, both RF and optical technology development should continue to progress out to 2025. Projected growth areas for airborne data links are shown in Figure 4.3-1.

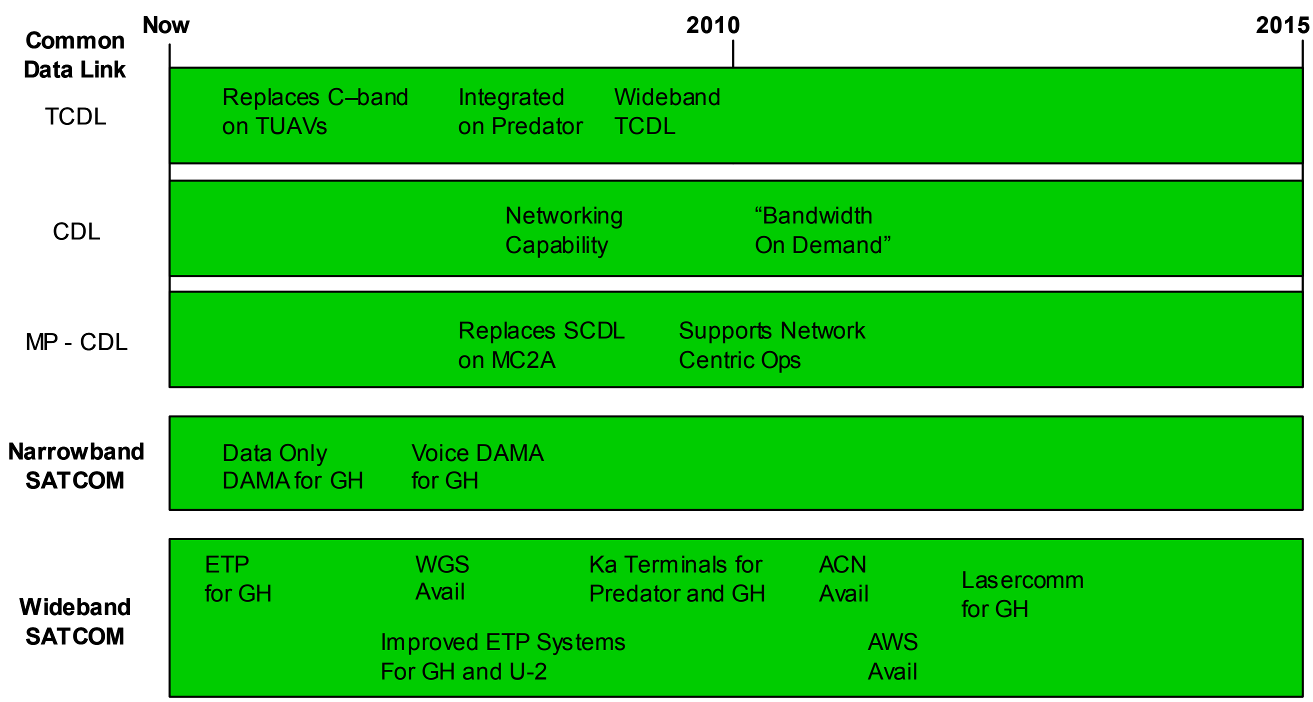


FIGURE 4.3-1: AIRBORNE COMMUNICATION TECHNOLOGY FORECAST.

4.4 Processors

Increased onboard processing will be the key enabler of more responsive flight control systems, onboard sensor data processing, and autonomous operations (AO) for future UAVs. AO is a current capability-push by the Navy in the Office of Naval Research's AO Future Naval Capability initiative and by the Air Force as part of the Air Force Research Laboratory's (AFRL) Sensorcraft initiative. The Autononmous Control Levels (ACLs) used in Figure 4.4-1 were developed in response to the OSD Fixed Wing Vehicle (FWV) Initiative's need for an autonomy metric in 2000. In parallel with developing the technology for AO, the Services must also evolve their doctrines for employing it. Scalable levels of AO will probably be necessary to accommodate varying rules of engagement (ROEs) for contingencies from peacekeeping to force-on-force.

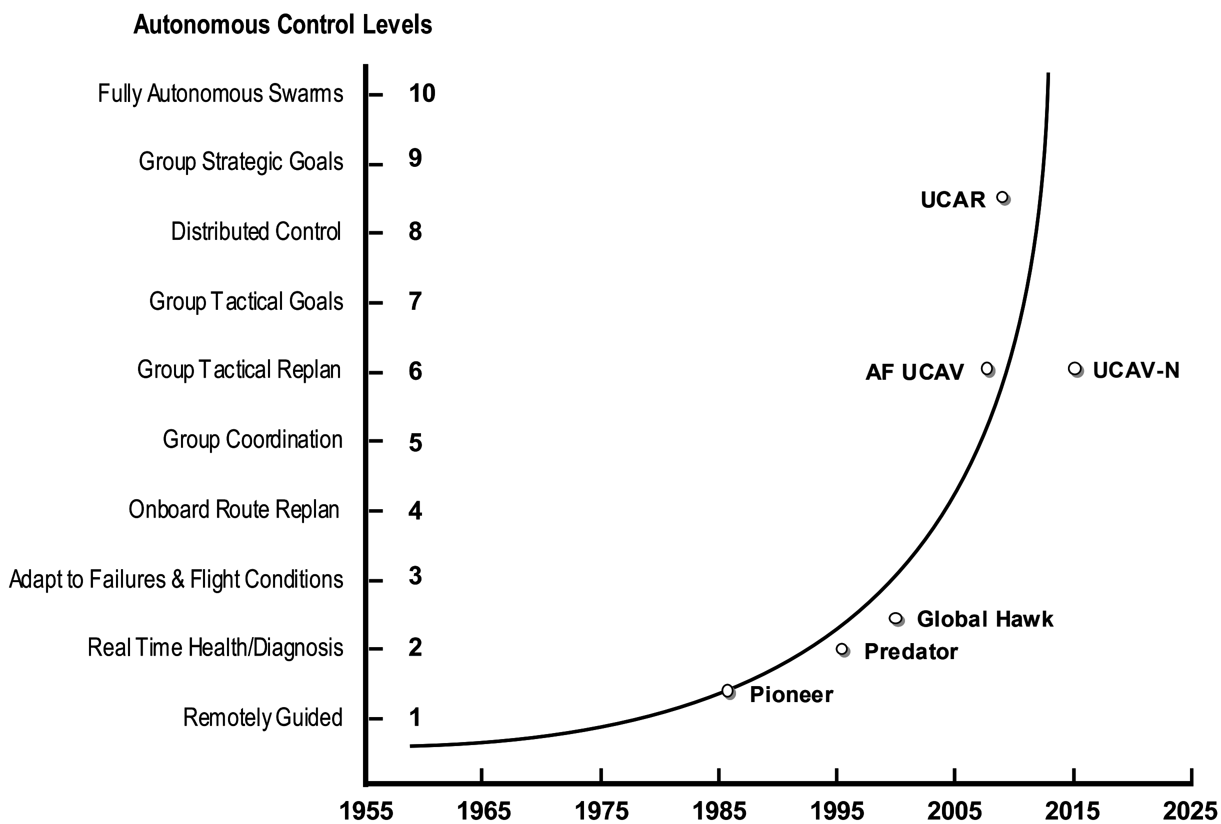


FIGURE 4.4-1: AUTONOMOUS CONTROL LEVEL TREND.

These advances in UAV capabilities hinge on the commercial sector's continued progress in manufacturing increasingly capable processors. Moore's Law states the number of transistors on a microprocessor will double approximately every 12-18 months, enabling a corresponding increase in computing power. This "law" is based on an observation made by Gordon Moore, Chairman Emeritus of Intel Corporation, in 1965 and has been remarkably accurate for the past 35 years. It has been the basis for many performance forecasts and is used here to project the trend in microprocessor speeds for the next 25 years. These speeds directly determine whether warfighters can receive their information in real time (RT), near-real-time (NRT), or the next day (ND). Figure 4.4-2 illustrates this trend in microprocessor speed and extrapolates a trend based on speeds doubling every 18 months. From it, Terahertz (1000 GHz) processors should become commercially available in the 2015-2020 timeframe.

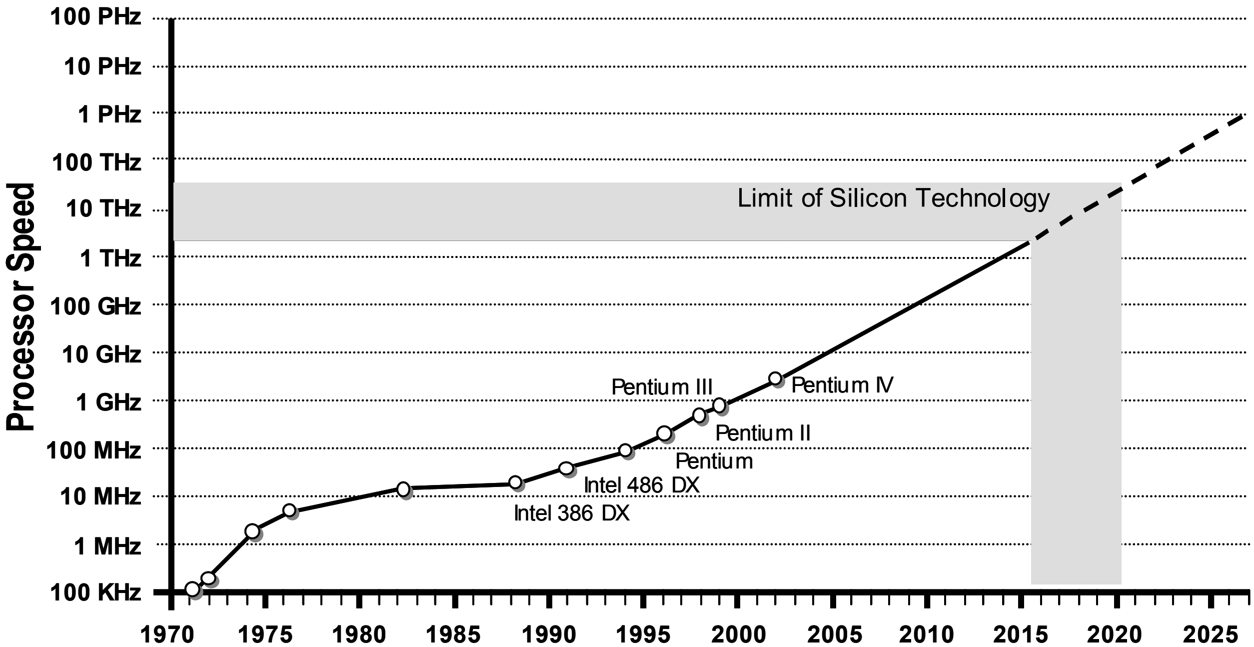


FIGURE 4.4-2: PROCESSOR SPEED TREND.

However, advances in silicon-based microprocessors have a finite limit dictated by the laws of physics, known as the "point-one limit." This refers to the smallest dimension (0.1 micron) of a transistor achievable before, according to quantum theory, the information-carrying electrons traveling among the transistors can tunnel through this distance of a few atoms, negating the on/off purpose of the transistor and corrupting data. Moore's Law predicts this limit will be reached in the 2015-2020 timeframe. Even before this limit is reached, the cost of manufacturing silicon chips to ever increasing precision and tolerances should begin increasing exponentially, reversing the cost/benefit ratio of each new generation of microchip historically enjoyed by consumers.

Forecast progress over the next 25 years in processor technology is depicted in Figure 4.4-3. Three avenues for extending silicon's deadline are converting microchips to "microcubes," replacing the silicon chip with one made of gallium arsenide, and developing new manufacturing processes for chip production. Silicon microcubes offer the simplest way to increase the number of transistors while decreasing the distance electrons have to travel, but will generate so much heat that elaborate (i.e., expensive) cooling techniques will be required. Microchip substrates made of gallium arsenide offer ten times the speed of silicon ones due to electrons traveling more easily through its crystalline architecture, but will eventually face the same point-one limit as silicon. Finally, the current manufacturing process (lithographic etching by ultraviolet laser) will need to be replaced by one capable of finer etching, such as that by shorter wavelength x-rays or electron beams. However, the new manufacturing technology needed to etch the silicon to even reach the point-one limit is not available today. Once this limit is reached, improvements in microprocessor speeds must come from alternative technologies. Four such alternative technologies currently being researched are optical, biochemical, molecular, and quantum processing.

Present	2003-2007	2008-2017	2018-2027
Silicon Microchip Electronic Processor	GaAs Microchip Optical Processor	Microcubes Biochemical Processor	X-ray/Electron beam Lithography Molecular Processor Quantum Processor

FIGURE 4.4-3: PROCESSOR TECHNOLOGY FORECAST.

5.0 Operations

5.1 Operational Concepts Development

The potential for UAVs to be used in new and innovative ways has long been acknowledged by many in the military establishment. It is the function of the Service battle labs outlined in Section 2 to convert such assumptions into demonstrations of practical application. Originally an Army concept (1992), battle labs have been recently established by the Services to address, in the Army's words, "categories of military activity where there appears to be the greatest potential for change from current concepts and capabilities, and simultaneously, the areas where new requirements are emerging." The dynamic nature of these emerging requirements underscores the importance of continued funding for these organizations. UAV employment has figured prominently in the short history of these organizations.

5.1.1 Army

The Army's **Advanced Aviation Technology Directorate (AATD),** an element of the U.S. Army Aviation and Missile Command's Aviation & Missile Research, Development, & Engineering Center, is located at Ft Eustis, VA. AATD is focused on developing, integrating, and demonstrating new technologies for future UAVs, specifically the integration of manned and unmanned aviation. It operates four *Vigilante* UAV testbeds and is in the process of converting an AH-1F Cobra into its optionally piloted Unmanned Combat Airborne Demonstrator (UCAD). It is also developing the Wing Store UAV (WSUAV) for launch from 2.75-inch rocket pods carried on helicopters.

The Army's **Night Vision Electronic Sensors Directorate (NVESD)** at Ft Belvoir, VA, employs six *Pointers*, six *Night Hawks*, two *Flight Hawks*, and one *Setter* mini-UAVs, as well as two *Camcopter* rotary wing UAVs, as testbeds for evaluating various night vision and mine countermeasure sensors. NVESD also assumed responsibility for developing the initial Dragon Warrior prototype, the Sikorsky *Cypher II*, from MCWL in late 2000 for further testing and is currently helping develop the *Buster* mini-UAV.

Although none of its six battle labs begun in 1992 is dedicated to UAVs, the majority of the Army's battle labs have been involved in exploring various UAV operational concepts. The **Air Maneuver Battle Lab** at Ft. Rucker, AL, operates some 30 Exdrones for developing combined UAV/helicopter tactics. The **Dismounted Battle Space Battle Lab** at Ft. Benning, GA, working in concert with the MCWL, has evaluated UAVs (Camcopter and Pointer) and micro air vehicles in urban warfare scenarios at the Military Operations in Urban Terrain (MOUT) McKenna Facility. The **Mounted Maneuver Battle Lab** at Ft Knox, KY, which focuses on brigade-level-and-below, has an extensive resume of involvement with small UAVs for the scouting role and with UAV modeling. **TRADOC's Systems Manager (TSM)** for UAVs at Ft. Huachuca, AZ, is the Army's central manager for all combat development activities involving UAVs.

5.1.2 Navy and Marine Corps

The **Naval Research Laboratory (NRL)** in Washington, DC, has a history of exploring new aerodynamic and propulsion concepts for maritime UAVs. Among its innovative UAV concepts have been in-flight deployable wings, hovering tethered ship decoys, and advanced miniature electric motors. Besides the Dragon Eye and Finder projects described above, the NRL has built and flown over a dozen different, original small and micro UAV designs in recent years and is currently preparing the Dragon Warrior prototype for flight testing this summer.

The **Naval Air Warfare Center Aircraft Division (NAWC/AD)** at NAS Patuxent River, MD, maintains a small UAV test, development, and demonstration team at Webster Field, Maryland that operates a fleet of various types of small UAVs. NAWC/AD's Maritime Unmanned Development and Operations (MUDO) team has 45 Exdrones, 10 Pointers, 3 Aerolights, 2 Aeroskys, and 1 Aerostar. MUDO managed the evolution of the Exdrone into the Dragon Drone for use by the Marine Corps Warfighting Lab (MCWL). It has also supported the Maritime Battle Center during recent Fleet Battle Experiments by providing small UAV systems and operations expertise.

The **Marine Corps Warfighting Lab (MCWL)** was created at Quantico, VA, in 1995. It is responsible for developing new operational concepts, tactics, techniques, procedures, and technologies to prepare Marines for future combat. It has participated in UAV development for integration into battalion-level-and-below forces. In addition to integrating Dragon Drone UAVs into its recent series of Limited Objective Experiments (LOEs) supporting Capable Warrior, MCWL has funded development of Dragon Warrior and Dragon Eye prototypes, each tailored to specific requirements supporting the Operational Maneuver From The Sea (OMFTS) concept.

The **Naval Strike and Air Warfare Center (NSAWC)** at NAS Fallon, NV, began supporting concept of operations development for integrating RQ-1/Predators into Fleet training exercises in 1998. To date, these efforts have focused on the time critical targeting and battlespace dominance missions. It participated in the naval utility evaluation of the RQ-4/Global Hawk during its ACTD by serving as a node to receive imagery during Global Hawk's flight to Alaska in 1999. In 2001, NSAWC completed a Naval Tactics, Techniques, and Procedures document entitled "UAV Integration into Carrier Air Wing Operations" (NTTP 3-01.1-02) which can be accessed at www.nsawc.smil.mil.

The Naval Warfare Development Command's **Maritime Battle Center (MBC)**, established at Newport, RI, in 1996, conducts a Fleet Battle Experiment (FBEs) each year to explore new technologies and operational concepts in both live and virtual scenarios. UAVs have participated in FBE-Echo (Predator in 1999), FBE-Hotel (Aerolight, Pioneer, and Dakota II in 2000), FBE-India (Aerolight), and FBE-Juliet (Sentry and Predator).

The Naval Postgraduate School hosts the **Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS)** in Monterey, CA. CIRPAS operates and maintains the Pelican optionally piloted aircraft and two Predators previously procured by the Navy. U. S. Joint Forces Command (USJFCOM) controls their priority for use to meet Joint Operational Testbed System (JOTBS) requirements. JOTBS is a tool to conduct UAV interoperability experimentation without Service doctrine or policy constraints.

5.1.3 Air Force

The **Air Force Research Laboratory** (AFRL) is actively pursuing UAV-applicable technologies for both specific UAV programs and for unmanned flight in general. Its Vehicles Directorate is exploring autonomous see and avoid and flight control systems. Its Sensors Directorate is developing more capable, smaller radar and electro-optical capabilities. AFRL has contracted a concept development study for their Sensorcraft concept, a UAV optimized for the sensor suite it would carry.

The Air Force established its **UAV Battlelab** (UAVB) in 1997 at Eglin AFB, FL, to explore and demonstrate the worth of innovative UAV operational concepts (as distinct from new systems or tactics) in key emerging areas. Its goal is to create opportunities, with minimal investment, for the Air Force to impact current UAV organizations, doctrine, training, and future requirements and acquisitions. The UAVB conducts four to six "experiments" annually, employing a variety of UAVs and UAV surrogates. Notable firsts among its efforts have been applying the Traffic Collision/Avoidance System (TCAS) to better integrate manned and unmanned flight operations; evaluating UAVs to supplement base security forces (in conjunction with the Air Force Force Protection Battlelab); using UAVs as the "eyes" for an E-8/Joint Surveillance, Targeting, and Attack Radar System (JSTARS) in coordinated Scud missile hunts; and proving the military utility of real time UAV reconnaissance support to Special Tactics Teams. One recent experiment conducted with the Joint Combat Identification Evaluation Team at Ft. Stewart, GA, data linked the location of tanks found by a Hunter UAV through its ground station to F-16s to steer them in for an attack. This same capability was also used to abort attacks on friendly forces.

Air Force Special Operations Command (AFSOC) at Hurlburt Field, FL, acquired 15 Exdrones from NAWC/AD in 2000. Operated by the 720th Special Tactics Group, they are used to explore UAV concepts of operation and special payloads for special operations forces. AFSCO also sponsored, in conjunction with the UAV Battlelab, a demonstration of controlling a UAV from an airborne MC-130 and is currently working the Sky Tote concept for resupplying special forces in the field.

5.1.4 Joint/Other

USJFCOM, located in Norfolk, VA, is responsible for the Joint Operational Test Bed System (JOTBS), composed of a Predator system with two aircraft originally used for TCS development, which is used to explore UAV and C4I interoperability concepts and procedures that benefit the joint warfighter.

The Office of the Assistant Secretarty of Defense for Command, Control, and Intelligence's (OASD(C^3I)) **Joint Technology Center/System Integration Laboratory (JTC/SIL)** was established by the former Defense Airborne Reconnaissance Office (DARO) in 1996 at the Redstone Arsenal in Huntsville, AL. Its mission is to provide technical support for virtual prototyping, common software and interfaces, software verification and validation, interactive user training, and advanced warfighting experiments (AWEs) for a broad variety of tactical and strategic reconnaissance assets, as well as C^4I systems and interfaces. It has focused on two programs supporting UAVs, the TCS and the Multiple Unified Simulation Environment (MUSE). MUSE is being used to explore operational concepts and train for the Army's Tactical UAV.

Although neither a joint nor a Defense Department organization, the U.S. Coast Guard has been very active in exploring potential applications of UAVs to their missions. Five UAV experiments have been sponsored recently by the **Coast Guard Research and Development Center (RDC)** at Groton, CT. These have included alien and drug interdiction along the Texas coast and in the Caribbean, as well as tests of UAV launch and recovery systems suspended beneath a parasail as a technique to allow UAV operations from otherwise non-air-capable cutters. A test of the utility of small UAVs to locate and identify various types of boats in open water areas has also been conducted.

The Office of the Secretary of Defense's (OSD) **Joint UAV Joint Test and Evaluation (JUAV-JTE)** was chartered in October 2001. This Navy-led Joint Test Force is based at NAS Fallon, Nevada, and is tasked with developing standardized joint tactics, techniques and procedures for tactical employment of UAVs in support of dynamic time sensitive operations. The three-year test will explore various command and control options for UAVs across Air Interdiction, Fire Support and Personnel Recovery mission areas. The JUAV Joint Test also functions as an OSD UAV tactics clearinghouse, working with all the services on cutting edge UAV tactical employment. Further information can be obtained at www.jte.osd.mil/juav.

5.2 Reliability[3]

The reliability and sustainability of UAVs is vitally important because it underlies their affordability (an acquisition issue), their mission availability (an operations and logistics issue), and their acceptance into civil airspace (a regulatory issue). Improved reliability offers potential savings by reducing maintenance man-hours per flight hour (MMH/FH) and by decreasing the number of spares and attrition aircraft procured. Enhancing reliability, however, must be weighed as a trade-off between increased up-front costs for a given UAV and reduced maintenance costs over the system's lifetime.

Affordability. The reliability of the Defense Department's UAVs is closely tied to their affordability primarily because the Department has come to expect UAVs to be less expensive than their manned counterparts. This expectation is based on the UAV's generally smaller size (currently a savings of some $1500 per pound) and the omission of those systems needed to support a pilot or aircrew, which can save 3000 to 5000 pounds in cockpit weight. However, beyond these two measures, other cost saving measures to enhance affordability begin to impact reliability.

Availability. With the removal of the pilot, the rationale for including the level of redundancy, or for using man-rated components considered crucial for his safety can go undefended in UAV design reviews, and may be sacrificed for affordability. Less redundancy and lower quality components, while making UAVs even cheaper to produce, mean they become more prone to inflight loss and more dependent on maintenance, both impacting their availability and ultimately their life cycle cost (LCC).

Acceptance. Finally, improving reliability is key to winning the confidence of the general public, the acceptance of other aviation constituencies (airlines, general aviation, business aviation, etc.), and the willingness of the Federal Aviation Administration to regulate UAV flight. Regulation of UAVs is important because it will provide a legal basis for them to operate in the National Airspace System for the first time. This, in turn,

[3] This section is extracted from OSD's UAV Reliability study, released in 2003.

should lead to their acceptance by international and foreign civil aviation authorities. Such acceptance will greatly facilitate obtaining overflight and landing privileges when our larger, endurance UAVs deploy in support of contingencies. Regulation will also save time and resources within both the DoD and the Federal Aviation Administration (FAA) by providing one standardized, rapid process for granting flight clearances to replace today's cumbersome, lengthy (up to 60 days) authorization process. A third benefit of regulation is that it will encourage the use of UAVs in civil and commercial applications, resulting in potentially lower production costs for the military market.

Because the various types of UAVs used by the Services are built by competing manufacturers, maintained by different branches of the military, and operated in a wide variety of mission profiles, the type of reliability and maintenance data that is collected, as well as the methods in which that data is tracked, are not standardized and cannot be easily used to compare UAV reliability across Service lines. This is underscored in that the equations used by each Service for determining the various measures of reliability for its UAVs are different. **The reliability information collected and maintained for all Services' UAVs should be standardized.** By not doing so, cross-Service failure trends can be overlooked or exaggerated.

For ease of comparison, the following four metrics are commonly used to represent aircraft reliability. Every effort has been made to reconcile varying Service and contractor methods of calculating these metrics to achieve an "apples versus apples" comparison in Table 5.2-1.

1. Mishap Rate (MR) is the number of accidents occurring per 100,000 hours of fleet flight time, expressed as mishaps per 100,000 hours. Figure 5.2-2 depicts the historical MR trend for the Navy Pioneer, Army Hunter, and Air Force Predator. For comparison, in a recent year, Marine AV-8 Harriers had a Class A mishap rate of 10.5 per 100,000 hours and Air Force F-16s 3.5. Using the logic that aircraft mishap rates tend to be inversely proportional to their acquisition costs, current UAVs still have a reliability gap to close. **A Department-wide effort should be implemented to decrease the annual mishap rate of larger model UAVs to less than 25 per 100,000 flight hours by FY09 and less than 15 per 100,000 flight hours by FY15 while minimizing system cost growth.** For smaller UAVs, the interplay of the aerodynamics at low Reynolds Numbers (a non-scaling factor relating altitude, speed, and aircraft size) and flight controls is not well understood. In this case, flight control insufficiency, vice failure, may be a contributor to small UAV mishaps. **Low Reynolds Number aerodynamics, with a focus on improving digital flight control systems optimized for small (i.e., having Reynolds Numbers less than 1 million) UAVs, needs additional investment.**
2. Mean Time Between Failure (MTBF), in some cases called Mean Time Between Mission-Affecting Failure (MTBMAF), is essentially the ratio of hours flown to the number of maintenance-related cancellations and aborts encountered; it is expressed in hours.
3. Availability (A) is the number of times a given aircraft type is able to perform its mission compared to the number of times it is tasked to do so, often measured as the ratio of hours (or sorties) flown to hours (or sorties) scheduled; it is expressed as a percentage.

4. Reliability (R) is one hundred minus the percentage of times a launched mission is either canceled before take-off or aborted during flight due to maintenance issues; it is expressed as a percentage.

Availability describes the performance of a system while on standby, and reliability describes the performance of a system while in operation.

Table 5.2-1 shows the calculated values of these four metrics for the early and current versions of the Pioneer, Hunter, and Predator.

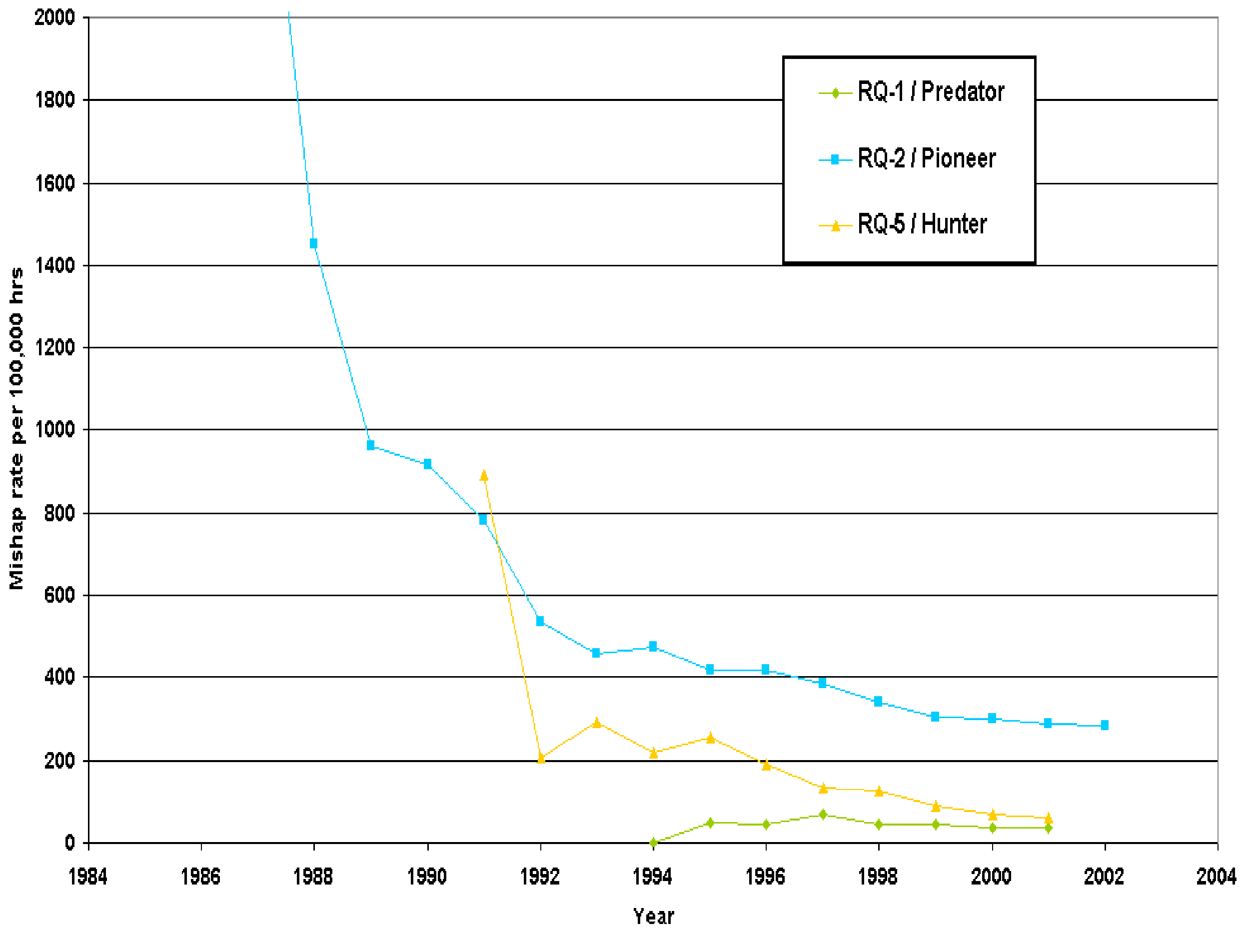


FIGURE 5.2-1: UAV MISHAP RATE TRENDS.

TABLE 5.2-1: RELIABILITY METRICS FOR UAVS.

System	Mishap Rate per 100,000 hours* (cumulative by model/series)	Mishap Rate per 100,000 hours* (cumulative by model)	MTBF (hours)	Availability (percent)	Reliability (percent)
RQ-1A/ Predator	43	32	32	40	74
RQ-1B/ Predator	31		55.1	93	89
RQ-2A/ Pioneer	363	334	9.1	74	80
RQ-2B/ Pioneer	139		28.6	78	91
RQ-5/Hunter (pre-1996)	255	55	n/a	n/a	n/a
RQ-5/Hunter (post-1996)	16		11.3	98	82

* Class A mishaps, defined as those resulting in the loss of the aircraft, or a death, or more than $1 million in damage to the aircraft, are used here.

By late 2002, the three current generation DoD UAV systems – the RQ-1 Predator, the RQ-2 Pioneer, and the RQ-5 Hunter – had accumulated nearly 100,000 flight hours over a combined total of 36 years of operations since 1986. The following breakout (Figure 5.2-2) depicts the primary causes for their combined mishap histories.

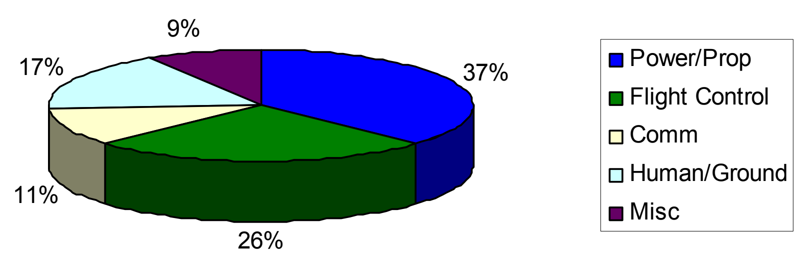


FIGURE 5.2-2: DOD UAV MISHAP CAUSES.

As shown in Figure 5.2-2, three of the areas (flight control systems, propulsion, and operator training) have historically accounted for 80 percent of UAV reliability failures. The implication is the overall mishap rate for UAVs could be significantly reduced by focusing reliability improvement efforts in these areas, which could lead to appreciable savings by having to procure fewer attrition aircraft. Further savings could result from decreased line maintenance by substituting more advanced technologies for existing ones, such as electrical systems for hydraulic ones and digital for analog sensors. The challenge is to make tradeoffs so the recurring savings of a reliability enhancement exceeds the nonrecurring investment, as well as the impact of any potential decreases in performance, incurred in making the enhancement. By focusing on making reliability improvements in propulsion, flight control systems, and operator training/interfaces, the potential savings could likely outweigh the cost of incorporating such reliability enhancements in existing and future UAV designs.

5.3 Operations and Support

The potential savings in operating and support (O&S) costs offered by UAVs could become significant. Today's manned aircraft are flown over 95% (50% for ISR aircraft) of the time for peacetime training of airborne crews because they must practice in their environment to maintain their flying proficiency. Remove the airborne crew, and today's costly training paradigm requires reexamination. UAV crews could receive the majority of their training in simulators, making their training and qualification significantly less expensive in terms of cost and time to qualify. By decoupling flight training from the number of training aircraft available, larger numbers of UAV operators may be trained in a given period. More UAV crews would help mitigate today's low-density/high-demand operational tempo problem.

While the potential for savings in training is generally acknowledged, the extent of such savings has not yet been demonstrated. Some level of actual UAV training flying will be required in peacetime to develop techniques and tactics for cooperative missions with manned aircraft—perhaps more to train the manned aircraft crews to operate with UAVs than for the benefit of the UAV crews. Service-unique operating environments, such as aboard aircraft carriers, will also impact the extent to which savings in training can be realized. In addition to the operators, the "boxed aircraft" concept poses significant challenges for training and maintaining a maintenance/logistics support capability ready to support surge or wartime operations tempos.

A new paradigm for UAV crew training could evolve that more closely parallels that for recent Navy student pilots using Commercial Off-the-Shelf (COTS) flight simulator software to supplement their traditional flight training. Actual flights would of course still support exercises and real world operations (see Figure 5.4-1). However, more initial training, mission qualification, and proficiency training could be conducted in simulators, while most of the aircraft remain in storage for months or years at a time. The DARPA/Air Force UCAV program is exploring this concept by designing the UCAV to be storable for 10 years or more from production delivery.

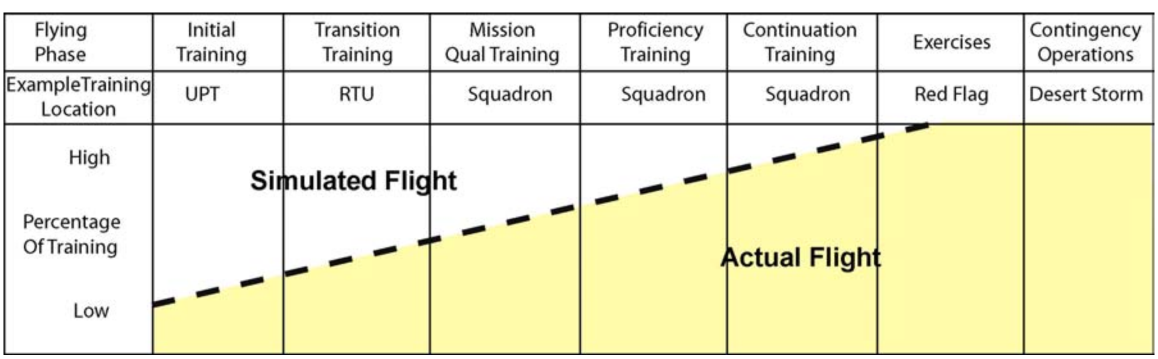


FIGURE 5.3-1: RELATIVE DEMAND IN ACTUAL VS. SIMULATED FLIGHT TRAINING.

While such a "build, store, fly" concept holds promise for reducing UAV operations and support costs (see Section 6.3.3) over their life cycle, it also contains several cautions prior to being adopted, to include:

- Even in such a concept, some critical level of maintenance manpower must be retained to support surge and/or wartime requirements.

- Base infrastructure otherwise not needed to support unmanned operations (altitude chambers, etc.) must be retained to support global mobility requirements for manned assets as well.
- Service "train as you fight" doctrines will require unmanned assets to fly training missions with manned assets to train their aircrews in cooperative tactics, regardless of the needs of the UAV crews.

5.4 Cooperative UAV Flight

Brig Gen Daniel P. Leaf, commander of the USAF Air Expeditionary Wing at Aviano, Italy, during Operation Allied Force, identified three capabilities needed by UAVs to fly safely and effectively with manned aircraft, based on his experience with both over Kosovo:

- Massing – the ability to come together as a formation to overwhelm defenses and minimize losses;
- "Rolexing" – the ability to adjust mission timing on the move to compensate for inevitable changes to plans and still make the time-on-target;
- Situational Awareness (SA) – expanding the soda-straw field of view used by current UAVs that negatively affects their ability to provide broad SA for themselves, much less for others in a formation.

Although manned versus unmanned flight was deconflicted by *segregated* airspace over Kosovo, the goal of cooperative UAV flight is to conduct operations in *integrated* airspace. UAVs will have to communicate and interact with each other and with manned aircraft to achieve maximum effectiveness. Consequently they will be required to position themselves when and where needed for optimum use. This positioning will range from station keeping in wide spread constellations to close formation with other UAVs and/or manned aircraft to aerial refueling. Such cooperation will enable survivable penetration of defended airspace and permit time-compressed, coordinated target attacks. All the Services and DARPA are currently looking at cooperative flight and have formed the Intelligent Autonomy Working Group to share results. An initial demonstration of formation flight by two unmanned aircraft is planned by the DARPA/Air Force X-45 program in Summer 2003, to be followed by aerial refueling of an unmanned aircraft. The DARPA/Army UCAR program plans to demonstrate collaboration between multiple aircraft to acquire, identify, and prosecute targets in 2007-08. The development of the necessary command and control, communications, sensor and weapon technologies, along with their associated software, will be central to fielding these breakthrough capabilities. **Specifically, the development of a common air vehicle interface providing critical situational awareness data including precise location data is a key component for integration of UAVs with manned systems.**

5.5 Tactical Control System (TCS)

The TCS is an open architecture, common interoperable control system software for UAVs and supported Command, Control, Communications, Computer, and Intelligence (C4I) nodes currently in EMD. TCS will provide five scalable levels of UAV vehicle, sensor, and payload command and control, from receipt of secondary imagery (Level 1) to full control of the UAV from takeoff to landing (Level 5). It will also provide dissemination of imagery and data collected from multiple UAVs to a variety of Service and Joint C4I systems. *http://uav.navair.navy.mil/tcs*

6.0 Roadmap

This section brings together the requirements and desired capabilities (Section 3) with emerging technological (Section 4) and operational opportunities (Section 5) in an effort to stimulate the planning process for Department UAV development over the next 25 years. It attempts, through a limited number of examples, to demonstrate a process for selecting opportunities for solving selected shortfalls in capability and incorporating these solutions in Service-planned UAV systems (see Figures 6.1-1 and 6.2-1). Two roadmaps, one addressing technology-driven capabilities (Section 6.1) and the other operations-driven missions (Section 6.2), provide guidance for UAV development efforts by the Services and industry. Subsequent sections analyze the cost of unmanned aircraft (Section 6.3) and list goals for unmanned aviation to achieve over the next 25 years (Section 6.4). The key question addressed in this section is: *When will the capabilities required to enable the theater Commanders' desired requirements become available?*

6.1 UAV Capabilities Roadmap

To relate the priorities expressed by the theater Commanders in Section 3 to the technologies coming available within the next 25 years (Section 4), a number of *capability metrics* (see Table 6.1-1) were devised for this Roadmap. They identify timeframes for anticipating future capabilities to satisfy the warfighters' requirements. All references to years are for dates when these capabilities are expected to become available for fielding based on the forecast trends developed in Section 4 and the appendices. Some of the capabilities described have already been demonstrated in labs; others, primarily in the communications and processing areas, will soon be emerging in commercial applications.

TABLE 6.1-1: OPERATIONAL METRICS.

Component	Requirement	Capability Metrics	Availability Timeframe
Platforms	Endurance	1. Field a diesel-powered tactical UAV (logistics savings)	2005
		2. Achieve 30% increased time-on-station with same fuel load	2010
		3. Achieve 40% increased time-on-station with same fuel load	2015
	Signature	4. Field a UAV inaudible from 500 to 1000 ft slant range	2004
Payloads	Resolution	5. Field a sensor for detecting targets under trees	2007
		6. Distinguish facial features (identify individuals) from 4 nm	2005
		7. Achieve 3 in SAR resolution over a 10 nm wide swath	2005
		8. Achieve 3 in SAR resolution over a 20 nm wide swath	2010
Data Links	Data Rate	9. Relay entire COMINT spectrum in real time	2005
		10. Relay entire ELINT spectrum in real time	2025+
		11. Relay 100-band hyper-spectral imagery in real time	2010
		12. Relay 1000-band ultra-spectral imagery in real time	2025+
Information Processing	Processor Speed	13. Map surf zone sea mines in near-real-time (<20 min)	2002
		14. Map surf zone sea mines in real time	2016
		15. Reduce DTED level 5 data in near-real-time (<20 min)	2009
		16. Reduce DTED level 5 data in real time	2022

By bringing together a plot of the predicted appearance of the listed capabilities in Table 6.1-1 with the timeline of current/planned DoD UAV programs (shown earlier in Fig. 2.0-1), a roadmap of opportunities for applying emerging capabilities to forthcoming UAVs is created. This "UAV Capabilities Roadmap" (Fig. 6.1-1) displays 16 such opportunities over the next 25 years. The upper half of Figure 6.1-1 plots the predicted appearance of these 16 capabilities over the next 25 years, with the date of each centered within a 5-year window of estimated initial availability for fielding. As an example of its use (see dotted lines on Figure 6.1-1), the information processing speed needed to extract the presence of sea mines in surf zones in real time from UAV video (some 1.8 THz from Figure 4.4-2) should become available in 2016, which corresponds to the planned IOC date for the UCAV-N, making this a reasonable capability to expect in the timeframe of the UCAV-N's introduction.

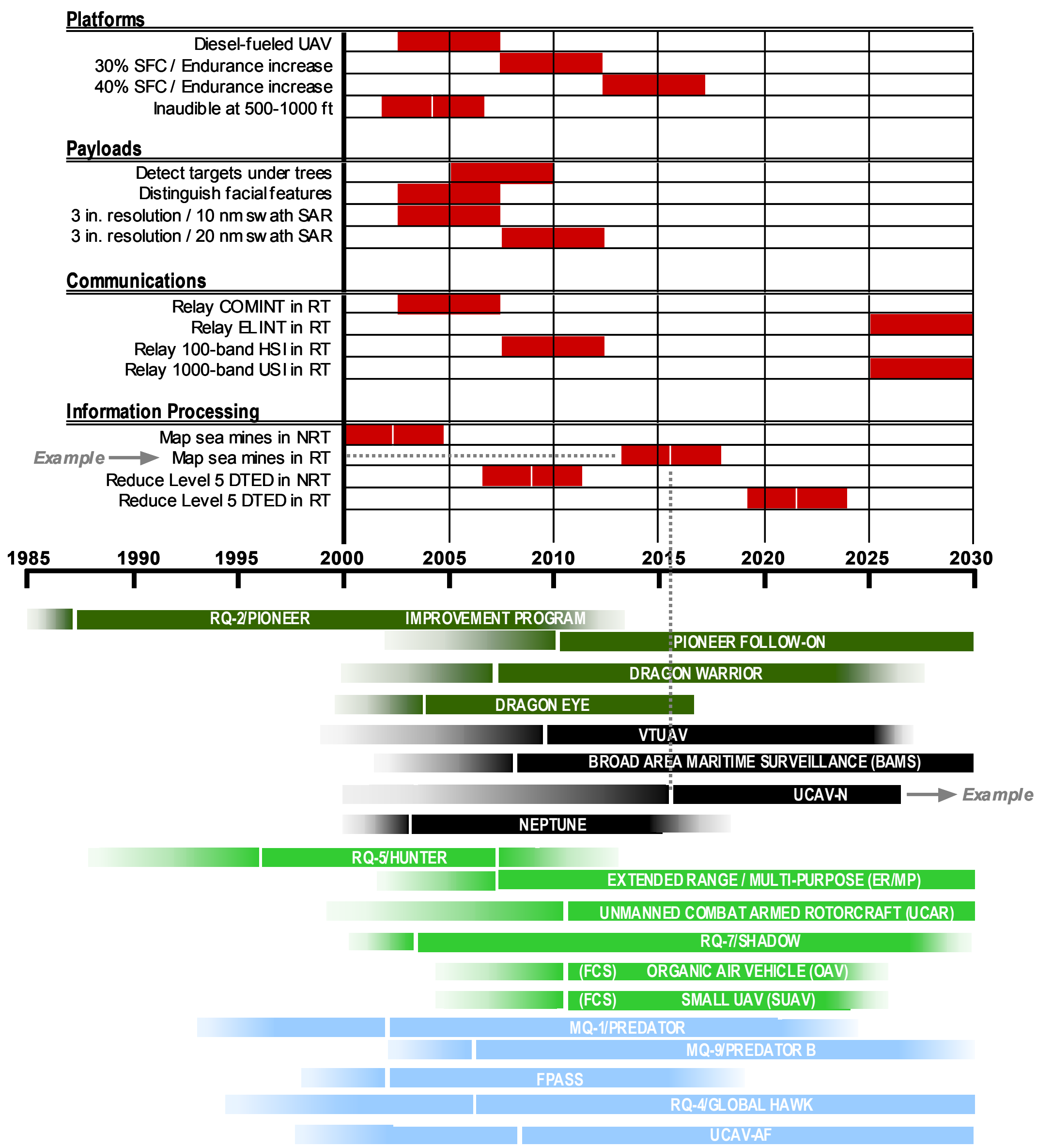


FIGURE 6.1-1: UAV CAPABILITIES ROADMAP.

6.2 UAV Missions Roadmap

Unmanned aviation has historically been limited to the reconnaissance (Firebee, Global Hawk) and strike (DASH, Predator) missions. Reconnaissance is now a well-established mission for UAVs, complementing manned aircraft in this role. Recently, the Air Force, the Army, and the Navy have focused separate efforts on developing more sophisticated UAVs, referred to as UCAVs, dedicated to the strike and SEAD missions. As evidenced by their DARPA origins, these UCAV programs are attempting to automate the most human-machine interaction (HMI)-intensive mission in aviation, and, in so doing, are pushing the technology of UAVs beyond that required for performing many other missions that they could potentially fulfill. As shown in the "UAV Missions Roadmap" (Figure 6.2-1), two major 'families of missions,' one emphasizing payload capacity and persistence and the other autonomy, survivability, and weapons employment, need to drive UAV design and development over the next 25 years. A start in these two directions has been made.

The first family of missions (shown in the upper half of Figure 6.2-1) employs endurance UAVs as communication relays, SIGINT collectors, tankers, surveillance and patrol aircraft, and, eventually, airlifters. Design-wise, these roles may use one common platform or different ones, but they must provide significant payload capacities (power as well as weight) and endurances greater than 24 hours. The DARPA Adaptive Joint C4ISR Node (AJCN), with the potential to deploy a Global Hawk-based communication relay payload in the 2005-2010 timeframe, represents a first step in the "payload with persistence" direction for UAVs. From there, the mission similarities of the AJCN and the Global Hawk imagery reconnaissance UAVs could be combined in an unmanned SIGINT collection platform, first by transitioning the mission crews ("backend") of the Rivet Joint, ARIES II, and Senior Scout aircraft to vans on the ground, followed eventually by the aircrews. The profile of the SIGINT collection mission, long duration orbits along the periphery of hostilities, resembles that for aerial refueling but adds the complexity of manned (receiver) and unmanned (refueler) interaction. The surveillance/patrol mission could be transitioned to UAVs in much the same way as for SIGINT collectors, by first relocating the mission crew to the ground, followed by the aircrew. Unmanned airlift hinges on overcoming a psychological and a policy barrier, the former being that of passengers willing to fly on a plane with no aircrew and the latter on foreign countries allowing access to their airports by robotic aircraft. In all cases, the technology to fly large robotic aircraft has been demonstrated; NASA flew an unmanned Boeing 720 in 1985, and Global Hawk routinely navigates around the ground at Edwards AFB.

The second family of missions (lower half of Figure 6.2-1) for future UAVs employs them in weapon delivery roles, graduating from electronic warfare to air-to-ground to air-to-air in complexity. How close to reality are such missions for UAVs? In addition to the DARPA UCAV programs mentioned previously, the LEWK (see Section 2.3.2) is an ongoing ACTD developing a UAV capability to either jam or destroy hostile radars then recover for reloading for subsequent sorties. By adding a recovery system to the latest Tomahawk variant, which features inflight retargeting, current cruise missiles could be "retargeted" to return home after delivering their ordnance. Progress in the weapon delivery direction for UAVs, because of the large number of decisions in a short span inherent in these missions, hinges on development of increasing levels of autonomy (see Section 4.4).

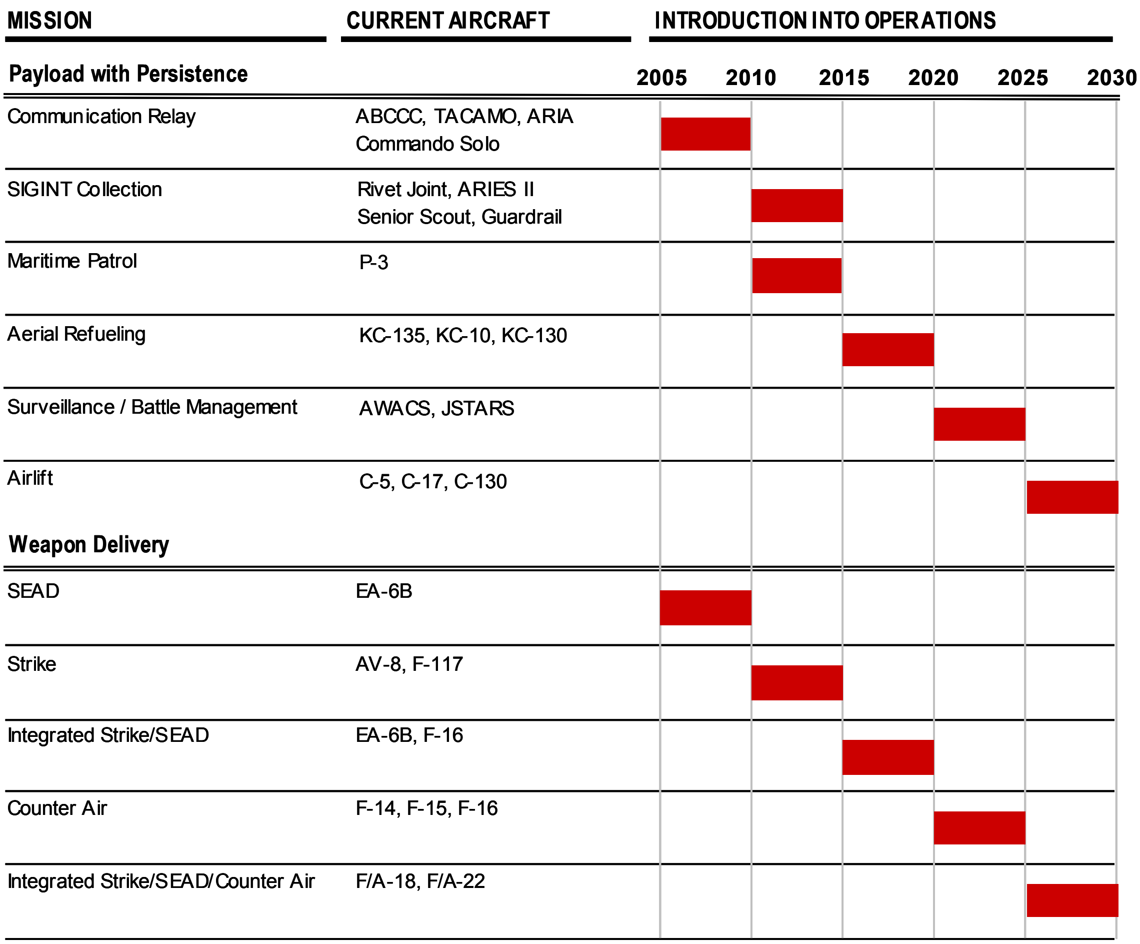


FIGURE 6.2-1: UAV MISSIONS ROADMAP.

6.3 Comparative Costs of Manned vs. Unmanned Aircraft

Any full and fair comparison of manned and unmanned aircraft costs must consider the three phases of any weapon system's life cycle cost: development, procurement, and Operating and Support (O&S). Any such comparison should also ensure equivalency in scenarios and missions are used, but without making one conform to the other's tactics or mode of operation. It is not necessary that a single UAV replicate its manned counterpart's performance; what matters is whether the UAV can functionally achieve the same mission objectives more cost effectively.

6.3.1 Development Costs

UAVs have been developed for DoD use through (1) contractor initiatives, (2) defense acquisition (milestone) programs, and (3) Advanced Concept Technology Demonstrations, or ACTDs. The shorter ACTD timelines (3-5 years vice a decade or more) and lessened oversight requirements have provided an alternative means for several recent UAV programs to rapidly reach Milestone II. The comparisons below (Table 6.3.1-1) show the adjusted costs to reach first flight, whether for manned or unmanned aircraft, by traditional or ACTD approach has historically been essentially the same. This is reasonable given that the engineering required to get to first flight is driven more by aerodynamics (i.e., flight control software development) and propulsion than by human factors and avionics.

TABLE 6.3-1: MANNED VS. UNMANNED AIRCRAFT DEVELOPMENT COSTS.

Mission/Aircraft	Program Start	First Flight	Interval	Type of Program/ Program Sponsor	Cost to First Flight
					($FY00)
Reconnaissance					
U-2	Dec 54	Aug 55	8 mos	SAP*/CIA	$243M
RQ-4/Global Hawk	Oct 94	Feb 98	41	ACTD/DARPA	$205M
Attack/Strike					
F-16	Feb 72	Jan 74	23	DAB*/Air Force	$103M
X-45/UCAV	Apr 98	May 02	49	ATD/DARPA	$173M
Reconnaissance, Penetrating					
SR-71	Aug 59	Apr 62	32	SAP/CIA	$915M
D-21	Mar 63	Feb 65	23	SAP/Air Force	$174M
Stealth					
XST/Have Blue (F-117)	Nov 75	Dec 77	25	SAP/Air Force	$103M
RQ-3/DarkStar	Jun 94**	Mar 96	21	ACTD/DARPA	$134M

*SAP = Special Access Program; DAB = Defense Acquisition Board (Milestone Process)
**DarkStar built on a classified program activity prior to this contract award date.

6.3.2 Procurement Costs

The aviation industry has long recognized an informal rule, based on historical experience, that the production cost of an aircraft is directly proportional to its empty weight (before mission equipment is added). That figure is currently some $1500 per pound (based on JSF in FY94 dollars). Estimates of the weight attributable to the pilot (ejection seat, displays, oxygen system, pressurization system, survival equipment, canopy, etc.) are 3000 lbs for single seat aircraft and 5000 lbs for a dual seat cockpit, or 10 to 15 percent of the manned aircraft's empty weight. The implied savings of $4.5 to 7.5 million, however, must be applied to the "remote cockpit" of the UAV aircrew and the leasing of its requisite communication links. Conversely, this control station can be capable of simultaneously flying multiple UAVs, somewhat restoring the advantage in cost to the unmanned system. Additionally, the control station is a one-time procurement cost for any number of UAVs fielded during the life cycle of a particular system.

Because UAVs replace many of the pilot functions with computers, software development and maintenance become additional "overhead" expenses in procuring UAVs. Flight critical software costs $500-600 per line of code and mission critical software $200. A fighter-type digital flight control system may employ over a million lines of code, requiring a substantial investment solely for a program's software.

6.3.3 Operations & Support Costs

Merely subtracting out that weight directly attributable to the aircrew being onboard (i.e., de-manning an existing aircraft type) does not encompass the total savings offered by a "clean sheet" unmanned design optimized for the same mission. Compare the DARPA/Air Force/Boeing UCAV objective system to using present day SEAD/Strike mission platforms. The UCAV weapon system performance is to be much greater and have a significantly reduced total life cycle cost. The UCAV is to have a design life of 4,000 hrs, half of which could be spent in combat operations under a form of build, store, fly CONOPS. Today's SEAD/Strike platform will spend 95 percent of its 8,000 hour in-flight life conducting training sorties, accumulating some 400 hours supporting combat operations before retirement. The depreciation rate, in terms of dollars per combat hour flown, of the UCAV is significantly less than that of current platforms, implying that UCAVs could suffer greater combat loss rates and still be cost effective by the standards applied to today's manned fighters. Cost goals for the AF UCAV X-45C program are currently being updated, and will be available by December 2003.

Seventy percent of non-combat aircraft losses are attributed to human error, and a large percentage of the remaining losses have this as a contributing factor. Although aircraft are modified, training emphasized, and procedures changed as a result of these accidents, the percentage attributed to the operator remains fairly unchanged. Five factors should combine in unmanned operations to significantly reduce this percentage.

First, UAVs today have demonstrated the ability to operate completely autonomously from takeoff through roll out after landing; Global Hawk is one example. Software-based performance, unlike its human counterpart, is guaranteed to be repeatable when circumstances are repeated. With each UAV accident, the aircraft's software can be modified to remedy the situation causing the latest mishap, "learning" the corrective action indelibly. Although software maturity induces its own errors over time, in the long-term this process could asymptotically reduce human-error induced losses to near zero. Losses due to mechanical failures will still occur because no design or manufacturing process produces perfect parts.

Second, the need to conduct training and proficiency sorties with unmanned aircraft actually flying could be reduced in the near term with high fidelity simulators. Such simulations could become indistinguishable from actual sorties to the UAV operator with the use of virtual reality-based simulators, explored by AFRL, and physiologically-based technology, like the Tactile Situation Awareness System (TSAS). The Navy Aerospace Medical Research Laboratory (NAMRL) developed TSAS to reduce operator saturation by visual information. It has been tested in various manned aircraft and has potential applicability for UAV operators. The system uses a vest with air-actuated tactors to tap the user in the direction of drift, gravity, roll, etc.; the tempo of the tapping indicates the rate of drift. Results have shown that use of the TSAS increases operator situational awareness and reduces workload.

Third, the UAV control stations could double as simulators, eliminating the expense of developing and maintaining separate simulators, as is the case for manned aircraft.

Fourth, with such simulators, the level of flying training required by UAVs can be reduced, resulting in reduced maintenance hours, fewer aircraft losses, and lowered attrition expenditures. Of 265 total U.S. F-16 losses to date, 4 have been in combat and the rest (98 percent) in training accidents. While some level of actual UAV flying will be required to train manned aircraft crews in executing cooperative missions with UAVs, a substantial reduction in peacetime UAV attrition losses can probably be achieved.

Fifth, continuing with the F-16 as an example, 1.5 percent of the F-16 fleet's maintenance man-hours in FY02 were for maintenance actions related to maintaining aircrew-unique items, such as canopies, ejection seats, oxygen systems, cockpit instruments, and survival equipment. These maintenance actions accounted for 1.6 percent of the F-16s' total not mission capable (TNMC) time in 2002. The cost associated with maintaining these items (83, 300 hours of maintenance labor in this one case) will be saved in UAVs.

6.4 Goals for Unmanned Aviation

The following capability, cost, and standardization goals for unmanned aviation are a consolidation of those identified within the previous text and the following appendices. Bolded goals have priority and have been assigned a Service or Defense Agency as an Office of Primary Responsibility (OPR) to oversee their accomplishment and a due date. These goals are consistent with the current Defense Planning Guidance (DPG) and will be further refined in the upcoming cycle. In some cases, goals addressed in this document have been directly cited in the DPG, such as the direction for development and demonstration of Unmanned Combat Air Vehicles. In many other cases the goals to follow are at a detail level below that appropriate to the DPG. The DPG will always take precedence, however this document will be used to provide additional definition and direction for UAV and UCAV technology areas. These goals should be considered directive, and OSD, in conjunction with the Services and Defense Agencies will strive to develop, demonstrate, and operationally assess these capabilities in the timeframes indicated. Progress reports on each goal will be submitted by the respective OPRs during the first quarter of each fiscal year.

6.4.1 Platform Goals

1. **Develop and operationally assess for potential fielding a UCAV capable of performing several missions including SEAD/Strike/Electronic Attack; emphasize early fielding of an EA capability with growth to other missions. OPR: UCAV Joint Program Office (DARPA, USN, USAF). Due: FY10.**
2. **Develop and demonstrate a tactical UAV-class aviation heavy fuel engine suitable for use in UAVs such as Shadow, Pioneer and A-160. Growth potential to larger UAVs in the Predator class including Extended Range Multi-Purpose and LEWK, and options for the small UAV class are also required. OPR: DARPA, USA, USN/USMC. Due: FY05/07.**
3. Demonstrate a fuel cell propulsion system suitable for use on tactical UAVs delivering 30 kW (40 hp) with a mass specific power of 0.746 kW/lb or better.
4. **OSD, Joint Staff, and the Services should develop capability and/or capability-performance metrics (such as those in Section 4.1) to evaluate UAV program costs. Program managers should provide Joint Staff and OSD written justification at Milestone B and C reviews when these metrics are exceeded, and provide appropriate management organizations with options for reducing costs to align costs with these metrics when this occurs. OPR: OSD. Due: FY03.**
5. Reduce wing and fuselage costs through incorporation of state of the art commercial composite molding technology.
6. Develop technology solutions for a persistent, anti-access UAV system.

6.4.2 Sensor Goals

7. **Demonstrate High Definition Television (HDTV) capability with real-time precision targeting capability on a UAV. OPR: NIMA, USN, USAF. Due: FY05.**

8. Develop a tactical UAV-compatible capability to detect one single tank (threshold)/one heavy machine gun (objective) concealed under trees.

6.4.3 Communication Goals

9. **Migrate all tactical (Shadow 200) and above UAVs to Common Data Link (CDL)-compatible formats for LOS and BLOS communication by FY06. OPR: USAF, USN, USA. Due: FY06.**
10. Standardize on a means to ensure larger UAVs' data link security costing no more than 20 percent (threshold)/10 percent (goal) of the equivalent unsecure data link's price by FY08.
11. Implement Tactical Common Data Link (TCDL) Ku-band in 2003 for Shadow 200.
12. Integrate a TCDL capability for LOS use for Predator in lieu of the current C-Band LOS data link.
13. Evaluate, and if feasible for Predator environment, integrate a Ka-band terminal on the Predator for use with the Wideband Gapfiller System (WGS); complete evaluation in FY04, fund installation in FY05, and demonstrate in FY06.
14. Integrate a Demand Assigned Multiple Access (DAMA) voice and secure voice capability for Global Hawk by FY05.
15. Integrate the capability to transmit command and control data over the Extended Tether Program (ETP) sensor data link for Global Hawk by FY04.
16. Add to the ETP ground structure to support the accelerated fielding of Global Hawk.
17. Develop the NSSA-recommended Airborne Communication Network with UAV-mounted L- or S-band payloads providing wideband data and narrowband voice/data for broadcast, multicast, and point-to-point communication.

6.4.4 Technology Goals

18. Develop and demonstrate conformal wideband data link apertures with equal (threshold)/50 percent greater (goal) gain than current steerable dish antennas on Predator and Global Hawk.
19. Develop a directed energy weapon system compatible with Predator B-size UAVs.

6.4.5 Small UAV Goals

20. **Investigate low Reynolds Number aerodynamics with a focus on improving digital flight control systems optimized for small UAVs (i.e., those having Reynolds Numbers less than 1 million). OPR: USA, USN, USAF. Due: FY06.**

6.4.6 Standards Goals

21. **Define a standard UAV interface providing critical situational awareness data including precise location data. OPR: OSD, USJFCOM. Due: FY04.**
22. Standardize on a common UAV mission planning architecture by FY05.
23. Develop standards to maximize interoperability within each class of UAV and to maintain an appropriate degree of interoperability between classes of UAVs.
24. Integrate joint UAV interoperability goals/assessment objectives from the USJFCOM JOTBS Strategic Plan into Service UAV Tactics, Techniques, and Procedures.

6.4.7 Airspace Goals

25. Coordinate revising FAA Order 7610.4 to replace the requirement for using the COA process for all UAVs with one for using the DD175 form for qualifying UAVs. OPR: USAF. Due: FY03.

26. Work with the FAA to define appropriate conditions and requirements under which a single pilot would be allowed to control multiple (up to four) airborne UAVs simultaneously.
27. Document and disseminate any UAV-unique lessons learned from certifying the RQ-4 Global Hawk as airworthy by means of the OSS&E process. Formal documentation as a DoD Instruction for guiding future ROA airworthiness certifications should be considered.
28. Establish a joint program, or designate a joint office, for developing and evaluating automated see-and-avoid and collision avoidance systems.
29. Equip DoD UAVs intended for Instrument Flight Rules (IFR) operations with a stand-alone, hot backup, ground-based navigation system and establish a standardized lost link procedure.

6.4.8 Task/Process/Post/Use Goals

30. Develop decision aids that enable automated machine-to-machine cross cueing.
31. Allocate sufficient funds to develop the necessary hardware, software, standards, procedures, and practices to make multi-level security possible.
32. Determine who has the authority and responsibility to mandate standards, procedures, and practices concerning multi-level security from disparate sensors/sources.
33. Develop training programs for newly assigned and current personnel in the use of new UAV sensors and exploitation techniques and equipment.
34. Fund for new exploitation software required by the introduction and upgrade of UAV sensors and exploitation platforms.
35. Maintain the current funding level for mensuration/positioning software.
36. Develop a common sensor tasking standard for all DCGSs to task all UAV sensors.
37. Establish a joint program office to develop automated decision systems to aid in the exploitation, fusion, and evaluation of multiple intelligence data.
38. Develop software that will allow sensors to automatically cross-cue one another on-board in real time.
39. Develop a scheme, using standard formats, messages, and products, by which an operator can easily and quickly find and retrieve both products and raw data.

6.4.9 Weaponization Goals

40. Define and implement security measures required for positive control of weapons employment on weaponized UAVs. OPR: USAF. Due: FY08.

41. Demonstrate equivalent P_k for a 250lb Small Diameter Bomb (SDB) comparable to that of a 500 lb Joint Direct Attack Munition (JDAM).

6.4.10 Reliability Goals

42. Decrease the annual mishap rate of larger model UAVs to less than 20 per 100,000 flight hours by FY09 and less than 15 per 100,000 flight hours by FY15. OPR: USAF, USN, and USA. Due: FY09/15.

43. Standardize the data collected and the metrics used for reporting UAV reliability and availability across all Services.
44. Perform a cost-benefit trade study for incorporating/retrofitting some or all of the planned Predator B's reliability enhancements into production Predator A models.
45. Perform cost-benefit trades for low and high level COTS approaches (see Table J3) to improve reliability for each fielded UAV design.
46. Review industry Reliability Specifications Standards for applicability to UAV design.
47. Incorporate the emerging technologies identified in Table J3 into the Defense Technology Objectives and the Defense Technology Area Plan.
48. Incorporate and/or develop all-weather practices into future UAV designs
49. Investigate the potential role of advanced materials and structures for enhancing UAV reliability and availability.

6.5 Future Directions

Although this roadmap is specifically focused on the Department's UAV development and fielding efforts, a much large perspective is emerging requiring a guiding document similar to the UAV roadmap. This larger perspective is encompassed by all Unmanned Systems (USs), whether UAVs, Unmanned Ground Vehicles (UGVs), or Unmanned Surface and Undersea Vehicles (USVs and UUVs). This family of emerging technology and capability shares many similar attributes and will in all likelihood operate in close coordination, even as a team. Many of the efforts within the UAV realm have equal interest and application for other USs within the Department. To facilitate coordinated future development of technologies and common operational issues, related US roadmap documents are posted at the following locations:

UGVs are addressed in the Joint Robotics Master Plan at
http://www.jointrobotics.com/activities_new/masterplan.shtml

UUVs are addressed in the Navy UUV Master Plan at
http://www.onr.navy.mil/02/baa/baa01_012/pip/uuvmp.pdf

The requirement for interoperability *among* UAVs is equally important for *between* UAVs and manned systems as well as other US types. The need for a UAV to communicate and interact with a UGV is not far off. The Army's Future Combat System (FCS) program is exploring such concepts. In all likelihood, future UUVs may themselves deploy UAVs to extend their capabilities and improve overall system performance. Small UAVs that become unattended ground sensors will blur the distinction between the classes of USs. These simple examples argue that, to the maximum extent possible, the common UAV vehicle interface now in development should be investigated for applicability to other USs. The ultimate goal is seamless integration into the battlespace of humans and unmanned, UAV or otherwise, systems.

Broad efforts to establish and expand interoperability and standardization will support overall US interoperability. Global Information Grid initiatives will establish communications standards and provide infrastructure and components to support network-centric sharing of data among platforms. Joint Command and Control interfaces will provide standard message sets and procedures for exchange of situational awareness and taskings among US platforms. ISR and other application specific data and product standards will further support the exchange of relevant information, with horizontal fusion initiatives in particular providing a major multiplier effect through a coordinated application of resources across diverse platforms. US developers must engage and build upon these broader efforts to provide the greatest level of interoperability, as required to support unified operations.

Several ongoing service and industry activities are specifically focused on US interoperability. For example, the Joint Robotics Program (JRP) is focusing on the technology required to enable tightly coupled UAV and UGV assets to deliver a significant portion of the warfighting capability envisioned for the Army's FCS. The JRP has established a working group and produced a draft Joint Architecture for Unmanned Systems (JAUS). Initially developed to support ground systems, the JAUS architecture has been expanded to extend across the full spectrum of USs. Several DARPA ACTDs and ATDs are focusing on the integration of UGVs and UAVs. The ASD(C3I)/USJFCOM UAV Interoperability IPT is reviewing existing interface standards developed for manned and unmanned systems, to include ground, space, surface, and underwater systems, to identify shortfalls that must be addressed by additional standards to support required and projected levels of interoperability. In general, efforts to integrate across the US domain to date have been very limited.

The Department is taking a much broader view of the entire unmanned systems landscape and the opportunities that exist for military transformation. Clearly this is a technology realm that is difficult to predict. However, several overarching concepts seem to appear.

1. Integration within unmanned systems (and with manned systems) will be high, necessitating a greater degree of interoperability from the outset, not added later as an afterthought.
2. The trade space between capability and cost will become much greater, offering a wider range of options, but producing much more complex and integrated systems, challenging our current "platform" focus on weapons acquisition.
3. USs may be grouped more by technology, and less by traditional classifications; i.e. small UAVs may have more in common with UGVs than with larger UAVs
4. USs needs a roadmap to focus development and employment and maintain critical interfaces with both manned and other unmanned systems.

It is the goal of the Department to develop a broad US roadmap that serves as an umbrella document covering all US roadmaps, including this document, to assure appropriate interfaces are maintained. This will be a challenge. However, to do otherwise squanders a tremendous opportunity to transform the United States' military capability to allow more precise, lethal, and rapid employment of force with reduced risk to humans at lower acquisition and sustainment costs.

Appendix A: Platforms

Overview

The UAV platform is the most apparent component of a modern UAV system and in most cases can be considered the "truck" for the payload. Platforms can vary in size and shape from the micro with a wing span of 6 inches, to the behemoth with a wing span of 114 feet. The platform must be able to accommodate all the requirements, e.g. size, weight, and power, of the payload(s). The platform must also be designed with the capabilities required for the environment in which it will operate. Speed, endurance, signature, survivability and affordability are factored together to provide an integrated solution to meet mission requirements. While the platform is the most apparent component of a UAV system, in the broad perspective, air vehicles will become less of a long-term sustainable resource. Replacement of platforms within the larger UAV system can be expected to increase as more emphasis is placed on spiral acquisition and integrated capabilities. It is unlikely that sustainment of many UAV airframes for more than a few decades will be cost effective.

This appendix first considers UAV platform missions and capabilities current and planned. Secondly, this appendix examines critical technology areas that are considered enablers toward making platforms more suitable and effective. Finally, OSD goals for platforms will be addressed.

Missions

Intelligence, Surveillance and Reconnaissance (ISR). A variety of platforms provide the U.S. with a wide and diverse ISR collection capability. Space, surface and airborne platforms provide a synergistic and redundant system collection capability that feeds both National and Service Intelligence systems. Airborne systems are one of the primary sources of ISR capabilities available to support a broad range of information requirements. These airborne systems, both manned and unmanned have varying, but complementary, operating characteristics and UAV systems are capturing an ever increasing segment of this mission area. UAVs are a key component within a larger ISR architecture as they are ideal platforms to carry a wide variety of sensors and other payload systems without risk to aircrews for extended flight durations. UAVs provide a wide range of platform capabilities making them ideally suited to many ISR missions. Depending on the specific mission requirements, capabilities such as endurance, altitude, size, survivability, and cost can be optimized to provide capabilities that are not possible with any other collection means. Additionally all UAV's eliminate the human risk of exposure to air defense and counter air threats. Furthermore, UAVs are highly immune to contaminated conditions which would pose a risk to aircrews.

a. Stand-off: During peacetime, the majority of airborne ISR missions are accomplished using standoff techniques. The standoff mode is also used during military operations when the risk is too great to expose platforms to a high probability of loss, or political sensitivities mandate constraint. In this instance, UAV design needs to reflect the attributes of high altitude and long endurance;

high altitude to maximize the sensor range and long endurance to maximize time-on-station. Typical collection capability for this operational concept is still imagery, both SAR and EO/IR/Multi-Spectral Imagery(MSI)/Hyperpectral Imagery (HSI), Signals Intelligence, and other less frequent collections including atmospheric sampling. The UAV design must also have the ability to carry the required payload to altitude and the propulsion system must have the capacity to generate both air-vehicle flight and electricity necessary to support the payloads.

b. Overflight: There are some cases where over-flight for collection purposes is required. This can occur during peacetime where political conditions support such missions such as peacekeeping or in combat where a sufficient reduction in hostile air defenses has occurred. Typical UAV design for operations at in these scenarios vary considerably but generally require extended endurance, multiple operating attitudes to support broad collection capability, streaming video and very high resolution imagery for positive target identification. As with the high altitude platform, payload, and electrical output are generally attributes to be maximized. Additionally, because weather conditions will be encountered at some of these altitudes, the UAV design must support operation in all types of weather especially icing conditions.

c. Denied Access: In limited cases, access to denied areas is required to support combat or national requirements. Generally this is achieved with national collectors; however it is advantageous to have an airborne penetrating capability to prevent an adversary from denying collection of overhead assets based on the predictable nature of orbiting systems. These capabilities have been embodied in manned platforms, most notably the U-2 and SR-71 systems although many other manned platforms of various types have been used on occasion. Clearly the disadvantage of manned platforms in a denied access collection role is the high potential for loss of the aircraft and crew, and failure of the mission. UAV's are ideally suited to this mission area and have served as collectors in the past, e.g. the D-21 and AQM-34 Firebee drones. More recently, the Darkstar UAV system was also designed to operate in this environment. Platform attributes of reduced signature, extended endurance, speed, sensor support including reduced signature apertures and operating modes are requirements for this mission area.

Strike/SEAD. Recent action in Operation Enduring Freedom has shown the value of arming UAVs. The addition of lightweight weapons to the long endurance Predator vehicle made possible rapid reaction to detected targets of opportunity. The armed Predator's mission could arguably be termed Armed Reconnaissance, as it played more upon the surveillance capability of the UAV than upon its weapons prowess.

As opposed to the Armed Reconnaissance mission, the SEAD and strike missions make new demands upon UAV developers. Performance of SEAD and strike will demand a more robust capability in terms of weapons load and survivability. These missions require the development of a true Unmanned Combat Air Vehicle (UCAV).

The UCAV brings several unmanned vehicle attributes that are attractive for the SEAD and strike missions when compared to manned assets:

1. Eliminate risk of loss life of an air crew.

2. Potential for greater survivability.
3. Greater endurance for persistence over the target area.
4. New CONOPS enabled by the use of unmanned systems.
5. Reduced acquisition & support cost.

In addition, the UCAV brings several challenges:

6. Rules of Engagement considerations that may require the intervention of a human operator.
7. The prosecution of advanced Integrated Air Defense Systems (IADS) and time critical targets through as yet unperfected Automatic Targeting and Engagement Process or by a human operator outside the vehicle.
8. The integration, interoperability, and information assurance required to support mixed manned/unmanned force operations.
9. Secure, robust communications capability, advanced cognitive decision aids and mission planning.
10. Adaptive autonomous operations and coordinated multi-vehicle flight.

a. Strike: A strike mission may be against a heavily or a lightly defended target. The level of threat determines which UAV attribute is most influential in the argument for filling the mission need with an unmanned asset. In either case, if the level of activity rises above the occasional need to hold a very few lightly defended targets as risk, a dedicated UCAV vice a lightly armed conventional UAV is required to perform the mission. The target threat level will largely determine the UCAV platform characteristics; although in some cases a compromise between multiple design drivers may be found.

    UCAVs will be used against heavily defended targets for two reasons. First, an unmanned air vehicle can theoretically achieve levels of survivability that manned aircraft cannot. Signature control without the need for human caretaking becomes less difficult, and maneuverability can be increased beyond human tolerances should that be required to enhance survivability. The design driver for this case is survivability, however it is achieved. Secondly, should survivability measures fail, the use of a UCAV removes the risk of losing a human life. Arguably, the strongest argument for UCAV is this ability to offer a risk-free use of force.

    For lightly defended targets, the argument for use of a UCAV shifts to the cost of conducting warfare. There are predictions of significant reductions in procurement, operations, and support costs for UAVs over manned aircraft. If these predictions are correct, the cost effectiveness in the strike mission will depend largely upon payload capacity as compared to manned strike assets. Weapons payload type and weight then becomes the driving design factor in this case. It should be noted, however, that a UCAV of sufficient size to be cost effective in the lightly armed case would probably not be a low cost UAV solution. In the higher range of UCAV costs, it would make sense that the vehicle have enhanced survivability features and be effective against heavily defended as well as lightly defended targets.

If a UCAV is to reduce the numbers of manned strike assets required, it will have to offer a robust weapons mix and a payload capacity similar to that of manned strike assets, however at much reduced operational and support costs. In addition, compatibility with the existing and planned weapons inventory for manned strike aircraft will be essential to keep overall armament development and support costs low.

b. SEAD: SEAD may be analyzed as two different types of missions. The first is pre-emptive SEAD in which a pathway is cleared by pre-emptive destruction of enemy defenses prior to the ingress of strike aircraft. The other type is reactive SEAD, in which the SEAD asset must react rapidly to enemy air defenses during the execution of a strike. The SEAD mission implies a somewhat capable enemy. Since closing that enemy will be required (as described below), the survivability of the vehicle must be assured through speed, stealth technology, high maneuverability or a combination of all three.

Execution of the both the pre-emptive and the reactive SEAD mission imply several critical design criteria for the UCAV platform and mission control system:

Mission reliability must be extremely high, as manned assets will depend upon the UCAV for protection.

Extensive Bomb Hit Assessment will be required so that operational commanders can properly determine whether strike "go/no-go/continue" criteria have been met.

A pre-emptive SEAD mission is a strike mission with the addition of the following complication: the target can always shoot back. For modern threats this usually means that the UCAV must successfully get weapons through a substantial engagement envelope. This can be accomplished by designing a stealthy UCAV that reduces the normal "threat ring" (range at which the enemy defenses are effective) to a much smaller range that allows the employment of direct attack (short range) munitions. Conversely, the UCAV may employ stand-off weapons that do not require penetration of the enemy air defense system's effective range.

The use of direct attack munitions instead of more expensive stand-off weapons is a major driver in cost savings.

If stand-off weapons are utilized, the problem of target identification, location and BDA may still require the penetration of the threat system's engagement envelope.

Execution of the reactive SEAD mission implies further design criteria:

- Enemy defensive systems operations must be detected rapidly.
- Reaction time from detection to neutralization of the enemy defenses must be very short.
- When using Electronic Attack (EA) to neutralize defenses in support of manned strike forces it will be critical for the UCAV to be within sufficiently short range to be effective. A trade-off between EA effectiveness and survivability needs to be fully understood.

- When using weapons to neutralize defenses, the time of flight of the weapon must be reduced by the ability to stand in close to the target system (high survivability) or by the use of a high-speed weapon.
- Robust, anti-jam, data-links are required.
- Reactive SEAD will require low latency human interaction with the system – or high autonomy within the system for determination of ROE criteria.
- Reactive SEAD implies the integration of manned and unmanned aircraft in a single strike event.

Summary: The era of UCAV contribution to SEAD and strike missions is just dawning. Their availability will add new options in the application of force, and promises to reduce the cost of our armed forces. It should be noted, however, that for the foreseeable future UCAVs are not a complete replacement for manned aircraft. A UCAV can bring enhancements to mission capability (e.g. risk-free close approach to heavily defended targets) but will continue to only satisfy a portion of the many missions strike assets cover. Close Air Support is an example of one such area. The use of a UCAV to deliver ordnance in very close proximity to friendly forces will face technical and culture barriers that imply at least in the short-term, that manned aircraft programs must continue. There will, however, be an impact on the total numbers of manned systems that must be acquired.

Electronic Attack. EA is the use of electromagnetic energy to confuse or disable threat defensive systems. Several attributes make the use of unmanned vehicles for the EA mission attractive. First, an unmanned air vehicle can theoretically achieve levels of survivability that manned aircraft cannot. Signature control without the need for human caretaking becomes less difficult. In addition, maneuverability could be increased beyond human tolerances to enhance survivability. Secondly, should survivability measures fail, the use of an unmanned system removes the risk of losing human life. Arguably, the strongest argument for UCAV is this ability to offer a risk-free use of force. Many challenges remain for developers and tacticians, but the Electronic Attack (EA) mission is being considered for both the Air Force and Navy Unmanned Combat Air Vehicles. EA concepts of employment are still being developed, and may include jamming or employment of expendables from the UCAV.

In developing unmanned systems for the EA mission, the following unmanned vehicle attributes are being considered:

- The ability to build a very stealthy unmanned vehicle could mean closer approaches targeted systems, requiring less radiated power to complete the EA mission and the ability to detect and exploit much lower levels of targeted system radiation.
- Pre-planned EA in which the targeted system is known and the planned attack is simple lends itself well to a pre-programmed unmanned system. In some cases reaction time may be improved over manned systems.
- The potential use of higher power Directed Energy (DE) weapons or Electromagnetic Pulse (EMP) weapons in future EA missions argues for the use

of an unmanned platform, since the weapon may pose a significant risk to the delivery vehicle and crew as well as the target.

- Unmanned systems offer potential savings in acquisition & support costs.

The use of unmanned systems in the EA mission also brings several challenges:

- The unmanned system is more dependent upon outside communications than manned systems. Self-jamming (interference with command and control communications by electronic attack emissions) could limit the ability to change the unmanned systems' planned mission once the electronic attack has begun.
- The potential for self-jamming and increased vulnerability due to a dependence upon communications mean a great degree of autonomy will be required in the unmanned EA system.
- A manned EA aircraft provides the ability for a trained crew to evaluate large amounts of tactical data on the threat environment and to change the mission plan as required for strike support. The appearance of previously unknown threat defensive system modes, frequencies, or tactics may only be detected by the human operator's ability to recognize patterns in the context of previous experience – a very difficult and as yet undeveloped ability for autonomous systems.
  - Without the development of autonomous EA operating capability, the transmission of large amounts of data describing the tactical environment must be provided to remote human operators in real time. These large transmissions would be limited by available bandwidth and self-jamming and could increase the unmanned system's vulnerability.
- A signature-controlled vehicle loses the advantage of stealth when radiating. "Home On Jam" threat systems could put the unmanned EA vehicle at risk.

Execution of the Electronic Attack mission implies several critical design criteria and questions for the unmanned platform and mission control system:

- Mission reliability must be extremely high, as manned assets will depend upon the UCAV for protection.
- The trade-off between effective apertures for the radiation of jamming electronic energy will have to be balanced against the negative impact on the signature and survivability of the unmanned system.
- The EA mission will require a highly autonomous system that can operate and handle vehicle-related and mission-related contingencies while unable to communicate with the mission control system (due to self-jamming and covert operations).
- Reaction time from detection to neutralization of the enemy defenses must be very short.
  - Enemy defensive system operations must be detected and countered rapidly.
  - When using Electronic Attack (EA) to neutralize defenses in support of manned strike forces it will be critical for the UCAV to be within sufficiently

short range to be effective. A trade-off between EA effectiveness and survivability needs to fully explored.

- The EA mission implies the integration of manned and unmanned aircraft in a single strike event.
- Robust, anti-jam data links are required.
- The amount of energy required for effective Electronic Attack is large unless the delivery platform is in very close proximity. The ability to generate this large amount of power could drive up vehicle size and cost. In addition, a vehicle small enough to be unobserved in close proximity to the target may not have the mobility (speed and range) to close the target or to persist in the target area for a sufficient amount of time. These considerations argue for the use of expendable jammers from unmanned vehicles as one means of delivering low cost EA performance.

Summary: The Department of Defense is beginning the development of unmanned EA missions. Initial study indicates that there are both significant potential unmanned system strengths and significant challenges to be overcome for this mission. New unmanned systems will add new options in the application of force, and promises to both reduce the cost of our armed forces and to decrease the risk of friendly losses. It should be noted, however, that unmanned EA systems are not a complete replacement for manned EA aircraft. An unmanned EA vehicle can bring enhancements to mission capability (e.g. risk-free close approach to heavily defended targets) but will not have the autonomy required to completely replace manned systems in the foreseeable future.

Communications Node/Data Relay. To perform the communications relay mission, the UAV platform must have a capability of extremely long endurance, high altitude, and generate adequate power. It will provide an airborne augmentation to current tactical and operational organic ground relevant frequencies both beyond line-of-sight and line-of-sight retransmission capability. Support of the communications relay mission will require continuous Line-of-Sight/Non-Line-of-Site/Beyond the Line-of-Sight (LOS/NLOS/BLOS) coverage in a 24-hour period.

The UAV should relay VHF/UHF BLOS for battlefield communications (to include helicopter operations) and remote sensor data. Communications relay must support extended range operations with a communications on the move capability for ground forces. These payloads for extended periods of time ideally should be small enough to be permanently mounted on each UAV. In the near-term, however, they will have to fit within the available payload capacity of the UAV. Platforms should incorporate a robust antenna and power suite to facilitate rapid payload reconfiguration and integrate advanced technology as it becomes available. Communications relay payloads should be constructed in modules that contain specific communications capabilities that can be added or removed without affecting the remainder of the payload. The payload must be interoperable with other UAV communications payloads at all echelons.

While functioning on board the UAV, communications relay will provide BLOS for Single Channel Ground and Airborne Radio System (SINCGARS) and Enhanced Position Location Reporting System (EPLRS) radios, as well as remote sensors. The remote sensor relay can be either through the Communications/Data Relay equipment, or, objectively, through the CDL. These payloads will be capable of autonomous preplanned operations or of being dynamically reprogrammed during a mission.

The platform will provide BLOS relay for battlefield communications to include legacy Army Common User System (ACUS), Tactical Internet (TI) systems, and future Warfighter Information Network - Tactical (WIN-T). The system must be compatible with the Warfighter Information Network for a Joint Task Force operating in a specified theater of operations as provided for in the WIN-T ORD (objective). This capability will support interim and objective force extended battlespace operations with a command and control on-the-move (C2OTM) capability. These payloads will be fully interoperable with the emerging Joint Tactical Radio System (JTRS) compliant waveforms. The TI range extension payload will be interoperable with tactical communications relay payloads. Platforms must be capable of supporting ACN ground based subscribers at some capability in the absence of Global Hawk equipped platforms.

The platform will be capable of relaying VHF and UHF radio voice/data communications (secure during wartime) from the control station via CDL through the platform to Air Traffic Control (ATC)/Air Traffic Service (ATS) agencies, Airborne Warning and Control System (AWACS), Airborne Communications Network (ABCCC) and other manned or unmanned aircraft (threshold). These systems must be operable from the controlling station to include the ability to change radio frequencies.

The platform will be capable of relaying VHF-AM radio voice communications using an International Civil Aviation Organization (ICAO) Standard And Recommended Procedures (SARPs) compliant radio operating with 8.33 kHz channel spacing from the Control Station to airspace controller communication (threshold).

Critical Platforms Technologies

Propulsion.

a. Integrated High Performance Turbine Engine (IHPTET) Program: Unmanned Aerial Vehicles (UAVs) are rapidly being developed for eventual integration into the Army, Navy and Air Force fleets. Today's battlefield contains air vehicles that have two classes of turbine engines: 1) man-rated for manned platforms and 2) expendables for cruise missiles. UAV service has brought about a third limited-life class, which must support the unique role of UAVs. The current development of systems such as Global Hawk and UCAV, which occupy ISR, SEAD and deep strike missions, have shown that existing "off-the-shelf" propulsion systems are placed under such heavy demands that mission capability and operational utility can be severely limited. Future UAVs will address combat scenarios and are projected to require even greater demands for better fuel consumption, thrust, power extraction, cost, and distortion tolerance. The Integrated High Performance Turbine Engine (IHPTET) program is a joint service, NASA, DARPA and industry initiative began in 1987, is a three-phase program with goals of doubling propulsion capability. IHPTET is a National program, and is the cornerstone of U.S. military turbine engine technology development. One of the three IHPTET classes of engines is the Joint Expendable Turbine Engine Concept (JETEC) program, a joint Air Force/Navy effort, will demonstrate several key UAV-applicable technologies including advanced aerodynamics, lubeless bearings, high-temp low cost hot sections, and low-cost manufacturing techniques. Using data from laboratory research, trade studies, and existing systems, the payoffs/tradeoffs for each of the critical technologies will be analyzed in terms of engine performance, cost, and storability.

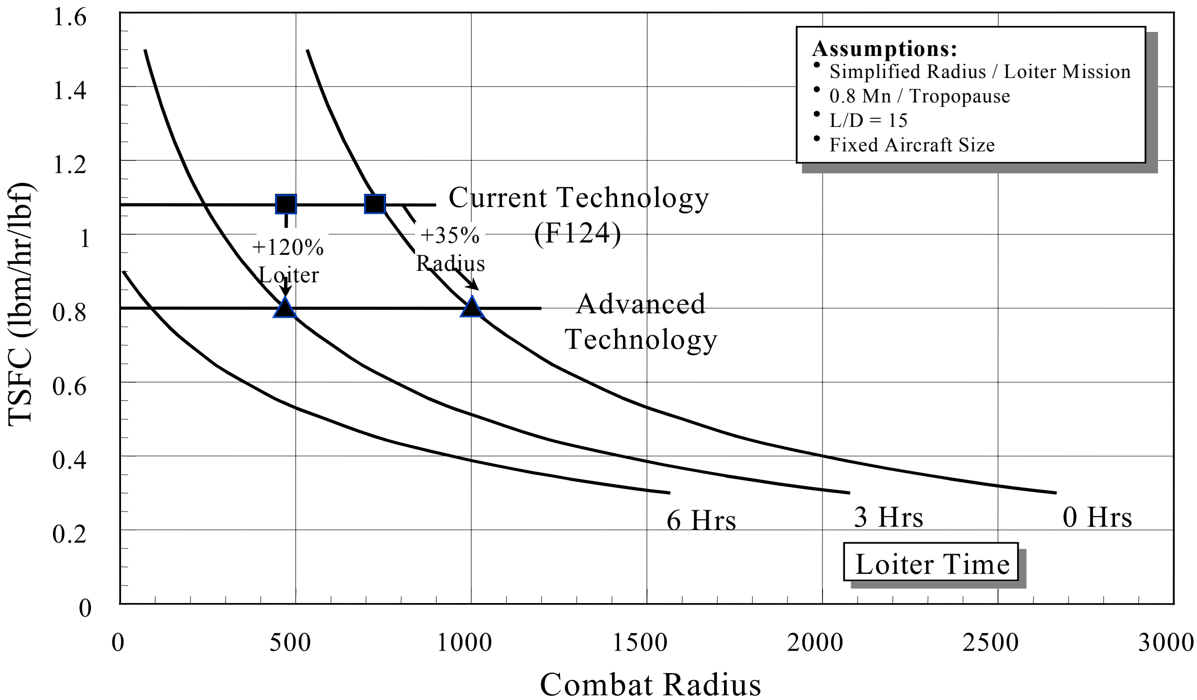


FIGURE A-1: PERFORMANCE PAYOFF OF A NOTIONAL COMBAT UAV UTILIZING TECHNOLOGIES FROM THE JETEC PHASE III GOALS.

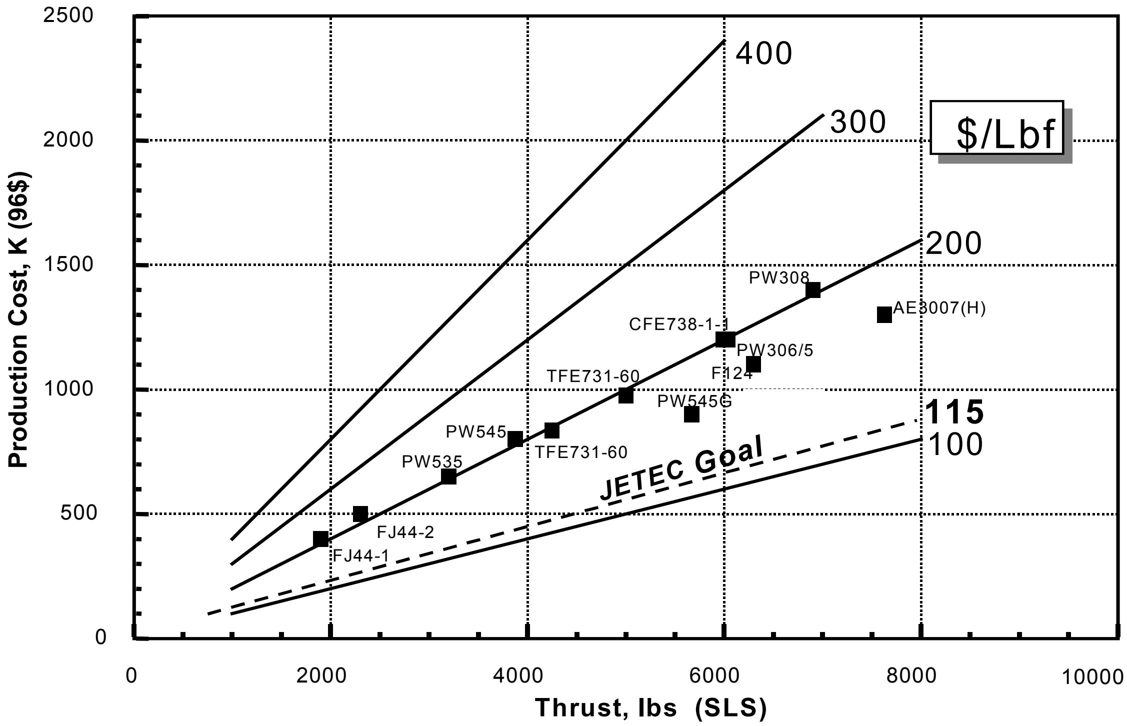


FIGURE A-2: JETEC COST GOAL IN COMPARISON TO EXISTING SYSTEMS.

Reducing production and development costs may be the most critical effort for UAV engine designers. These reductions can be achieved through various means such as advancements in manufacturing techniques, unique component designs, and multi-use applicability. Advanced manufacturing techniques can greatly reduce tooling cost and fabrication time. For example, resin-transfer molding for OMC components can reduce production cost up to 40% over conventional lay-up techniques. JETEC is pursuing this and several other fabrication concepts including gang milling, high-speed milling, bonded castings, bonded disks, metal-injected moldings and inertial welding.

Unique component designs must be pursued to allow UAV engines to provide a high level of sophistication while minimizing cost. Since part count is a major determinant of production cost, design features such as drum turbomachinery, slinger combustors, threaded casings, and integral blisks can reduce part count by an order of magnitude. Low cost seals such as brush and finger designs have shown great promise for replacing large, expensive labyrinth-type seals.

Development costs can inhibit a buyer from pursing a new engine design. This leaves only off-the-shelf systems that typically have less than optimal performance and/or cost for UAVs. These penalties can come in the form of increased maintenance, decreased range or speed, increased production costs, or decreased low observable (LO). To counter this and minimize development costs, industry must examine multi-use concepts where a common-core can be incorporated into UAV *and* commercial propulsion systems such as general aviation, business jet, and helicopter gas generators. The payoffs are enormous for both communities - decreased cost to the military and increased technology for the civilian sector.

b. Versatile Affordable Advanced Turbine Engines (VAATE): As currently planned, the DoD/NASA/DOE Versatile Affordable Advanced Turbine Engines (VAATE) initiative is ramping up over the next several years, and will follow and build upon the IHPTET effort. Unlike IHPTET, which focused heavily on performance, VAATE will build upon the technology advances of IHPTET, and concentrate on improving aviation, marine and even ground-power turbine engine affordability, which proponents define as capability divided by cost. VAATE's affordability orientation will look at technologies cutting engine development, production and maintenance costs. The balance of the VAATE affordability improvements will come from performance capabilities--technologies associated with boosting thrust and cutting weight and specific fuel consumption.

   VAATE is a two-phase program with specific goals. By the end of phase 1 in 2010, a six fold improvement in affordability will be demonstrated, and at the end of phase 2 in 2017, a ten-fold improvement in affordability will be demonstrated. Baselines for the effort are current state-of-the-art power plants such as the Honeywell F124 used in the Boeing X-45A UCAV Demonstrator.

   VAATE work will be concentrated into three focus areas and two pervasive areas. Focus areas will include durability; work on a versatile core and intelligent engine technologies. Pervasive areas, which are really incubators for hatching ideas that should be included in the VAATE focus areas, will be segregated into the categories of high-impact technologies and unmanned aerial vehicles.

Reciprocating Internal Combustion Engines. Reciprocating internal combustion gasoline engines are widely used in fixed wing Unmanned Aerial Vehicles (UAVs) with Take-Off Gross Weights less than 2000 lbs. This is true among legacy UAVs (Pioneer and Predator), developmental UAVs (Shadow 200) and numerous demonstration aircraft from both Industry and Government Laboratories where across the board both two and four cycle engines are used. True diesel cycle engines are precluded due to significantly higher engine weight as compared to the gasoline engines. While each cycle offers advantages and disadvantages, the demonstrated lower cost and better efficiency of these engines precludes developing turboshaft engines to meet these UAV needs. However, these engines do not meet the requirements for a common battlefield fuel as defined in DoD 4000. In addition, they tend to fall short in reliability/durability as compared to man-rated aircraft engines, making them less attractive to warfighters who rely heavily on the data received from their UAV payloads to make real-time decisions. Future small UAVs will continue to utilize these low cost, gasoline engines unless significant advances in weight reduction for true Diesel cycle engines, or successful modification of existing gasoline engines to burn Jet Propellant (JP) fuels with increased reliability, are achieved.

Technology Outlook. The use of both motor gasoline and aviation gasoline in almost all small UAVs is undesirable as it is both logistically very difficult to support and unsafe (JP fuels have a higher flashpoint than gasoline). However, there are no significant technology or development efforts to provide an aviation suitable, small JP5/8 fuel burning engine(s) in the power classes and power to weight ratios being discussed here. These engines do not exist in the commercial market, and typical DoD efforts have utilized Small Business Innovative Research (SBIRs) topics in an attempt to develop these engines. While some of these attempts have shown promise, SBIRs do not provide a basis for a robust effort to meet many of the technical challenges that Heavy Fuel Engines (HFE) present

Reliability. Reliability of current low cost two and four cycle UAV engines is on the order of a few hundred hours, sometimes significantly less. This shortcoming, when compared to turbine engines, is often overlooked due to the low cost of reciprocating engines. Good engine reliability has proven to be a significant factor in user acceptance of UAVs. However, most UAV demonstrations, and even development programs do not prove reliability early in their development, many times resulting in disappointing results in extensive flight and operational testing. Developing reliability in a small HFE will present a large challenge due to the differences in combustion and lubrication between JP fuels and gasoline, and the duty cycles imposed on them for UAV use.

Efficiency (Brake Specific Fuel Consumption, (BSFC)). One of the most desirable traits for any UAV is persistence, and engine fuel efficiency has a major influence on the number of UAVs required for a given time on target coverage. Current gasoline two cycle engines have relatively poor efficiency, while four stroke engines are better but at the cost of increased engine weight. Both engines are significantly better than small gas turbines in this power class. Because of this any effort to develop HFEs will place a large emphasis on efficiency. A HFE that operates on a true diesel cycle could double the endurance of a given UAV which normally uses a two stroke gasoline engine. Currently, two cycle engines still tend to be used extensively in small UAVs, particularly in demonstration efforts as they provide the UAV designer a low cost and lightweight, yet powerful engine. However, due to low cycle efficiency their BSFCs tends to be high, resulting in aircraft with limited endurance capabilities. Existing gasoline engines converted to operate on heavy fuels would not have significantly improved BSFCs, but would operate on the required JP fuels. True diesel cycle engines would offer greatly reduced BSFCs but technological advances are required to reduce the weight of these engines to get them near that of gasoline engines.

Power to Weight. Air vehicles designed around two cycle gasoline engines benefit from a very high power to weight ratio. Developing a HFE for use on any AV utilizing an existing two cycle gasoline engine will require technology advances to approach similar power to weight ratios.

Technology Challenges. There are two approaches to using JP fuels in UAVs designed for lightweight gasoline engines; converting an existing gasoline engine to operate satisfactorily on JP fuels, or developing a true diesel engine light enough to be substituted for an existing gasoline engine. Depending on the approach chosen there are different Technology Challenges described below:

This approach will yield an engine of similar efficiency to that of the current gasoline engines (no improvement in BSFC) but will be close in power to weight and minimize integration efforts. The technological challenges include designing a combustion system that effectively burns JP fuels without using a diesel cycle, and obtaining acceptable engine reliability while using JP fuels.

This approach will yield an engine of much greater efficiency than current gasoline engines but a significant Technology Challenge will be weight reduction in order to even approach that of current gasoline UAV engines while maintaining reliability.

Advancements in materials are needed to allow development of diesel engines to approach the power to weight ratios of gasoline engines. The high cylinder pressures associated with the diesel cycle will require advanced materials not presently found in reciprocating engines. Concurrently, dynamic components such as crankshafts, connecting rods and bearings also need improved weight to strength/wear for suitable use in aviation engines.

Weight reductions in the area of diesel fuel systems and ancillary components will also be required. This includes the fuel injection system, turbochargers, intercoolers, scavenge pumps, cooling systems, etc. Increasing efficiency requires advanced fuel system components such as lightweight high-pressure pumps/fuel injectors and advanced fuel control techniques such as rate shaping. These systems are required for diesel cycle engines operating on JP fuels.

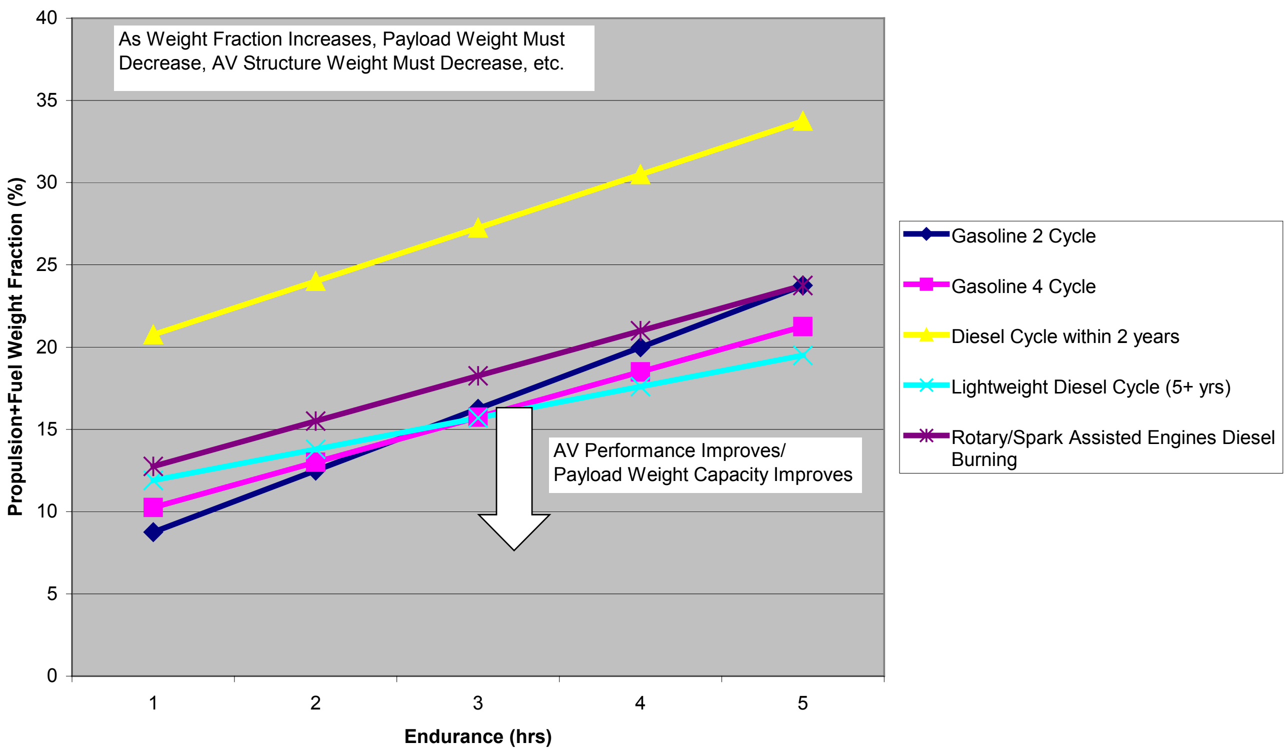


FIGURE A-3: ENGINE EFFECTS ON TAKEOFF GROSS WEIGHT FOR A DESIRED MISSION ENDURANCE

<u>Shortcomings of Current Approaches.</u> There have been a number of proposed solutions to provide a low cost HFE, but most are without merit. From innovative kinematic designs, to low pressure diesel engines and finally to modified gasoline two cycle engines, the current solution set does not provide reliable, efficient, lightweight JP burning engines for use in aviation. The resulting influence on UAV designs (and their inherent capability) of the different design approaches are depicted in Figure 1. Without a indepth technology program the best that can be hoped for are mediocre solutions, that

meet some of our requirements, but fall significantly short in providing the true solution needed.

Alternate Propulsion Technologies. Future-looking efforts for UAV propulsion include the use of fuel cell- or nuclear-based power schemes. Fuel cell development has been pushed by NASA for use in UAVs and by the Army's Natick Laboratory for soldier systems (i.e., small scale uses), and their specific energy performance is approaching that of gasoline engines. The gaseous hydrogen fuel cells being used on NASA's Helios UAV in 2003 have over 80 percent of the specific energy of a two-cycle gasoline engine (500 vice 600 Watt hours/kilogram) and 250 percent that of the best batteries (220 W hr/kg); further improvement is anticipated when liquid hydrogen fuel cells are introduced in 2004. Still in development by NASA are regenerative power systems combining solar and fuel cells in a day/night cycle to possibly permit flight durations of weeks or longer. Additionally, several commercial aviation initiatives are exploring fuel cells for both primary propulsion and auxiliary power units (APUs). In the nuclear arena, the Air Force Research Laboratory has studied the feasibility of using a quantum nucleonic reactor (i.e., non-fission) to power long endurance UAVs, however, this remains a concept study; no prototypes or flight worthy hardware are currently planned.

Gasoline Engine	**Battery Propulsion**	Fuel Cell Propulsion
Fuel Density * Fuel Volume + Engine Wgt/HP * HPreq + Accessories Wgt ---------------------------------- Total Wgt Specific Energy= HP*hr/Total Wgt	Electrolyte Wgt + Cathode & Anode Wgt + Case Wgt + Power Conditioning & Wiring Wgt + Motor Wgt ------------------------------------ Total Wgt Specific Energy= W*hr/Total Wgt	Fuel Density * Fuel Volume + Fuel Cell Wgt + Reformer System Wgt + Power Conditioning & Wiring Wgt + Motor Wgt -------------------------------------- Total Wgt Specific Energy= W*hr/Total Wgt

FIGURE A-4: SPECIFIC ENERGY CALCULATION.

Air Vehicle Structures. Mission, environment and intended aircraft performance attributes are key drivers for UAV structures in the same sense as for manned aircraft. At one end of the “UAV spectrum” aircraft such as the Finder and Dragon Eye diminish the need for durable structures anticipating the possibility of decades of service use. This is contrasted with Global-Hawk class UAVs where individual airframes are planned to be in the Service force structure for periods comparable to traditional manned systems.

Similarly, environmental requirements drive interest in air vehicle structures in three basic directions. UAVs primarily intended for tactical use in the close vicinity of ground forces dedicated to force-protection missions will have modest requirements for systems redundancy. For UAVs intending to be certified to fly in civil airspace, the recognition of redundancy requirements is a factor for the development of systems and integration for the entire aircraft. This tends to drive up the scale of the aircraft and the structures needed to host capabilities and multiple systems needed to support larger scale performance for endurance, altitude and extended reliability. The need for a capability to operate and survive in high-threat areas adds the need for signature control, which becomes a consideration for structures planning.

a. Wing: Keeping targets of intelligence interest under constant and persistence surveillance is increasing valued by operational commanders. This, in turn, drives interest in wing designs that can bring the greatest possible measure of endurance to collection platforms. Technologies being investigated to increase wing performance include airfoil-shape change for multipoint optimization, and active aeroelastic wing deformation control for aerodynamic efficiency and to manage structural loads.
b. Apertures: The demand for increasingly sophisticated sensor and communications systems on airborne platforms continues to grow in the face of stringent space, weight and power (SWAP) constraints. This tension results in the desire to reduce the number of sensors and required antenna systems by combining functions and sharing components. Reducing costs and SWAP demands on platforms as well is key to controlling the size and costs of the sensors themselves. The importance of setting rigorous requirements to specify apertures is a factor in sizing the collection platform itself.
c. Consolidating capabilities on a single platform is envisioned in the Multi-Sensor Command and Control (MC2C) Constellation is, in effect, another means of aperture management. However, the constellation will include associated high- and low-altitude unmanned aerial vehicles where collection systems can be integrated providing far more capability than any single platform. This also affords the opportunity to internet multiple apertures from widely separated platforms into a single system bringing the attributes of ground-based multi-static systems into the airborne environment.
d. Lightweight Structures: Military aspirations for extended range and endurance face the technical challenge of reducing gross weight. Advancing technology in materials as well as increasing the affordability of composite structures is being addressed in Service laboratories. In addition to the airframe, weight issues at the component level such as heat exchangers, sensors and antennas are research priorities. Weight can also be reduced by using aircraft structure and skin components to perform multiple functions such fault detection and as an adjunct to RF capabilities. As manufacturers integrate such materials as composite sandwich structures in new designs and consider such technologies, as the use and role of thermoset and thermoplastic resin matrix materials in advanced composites as well as Fiber Reinforced Plastics composite structures, the penalty of weight will be worked to achieve the best possible performance.

Flight Autonomy. Advances in computer and communications technologies have enabled the development of autonomous unmanned systems. The Vietnam conflict era Remotely Piloted Vehicles (RPVs) were typically controlled by the manned aircraft that launched them or the corresponding ground element. These systems required skilled operators. Some of these systems flew rudimentary mission profiles based on analog computers; but, they were hand flown throughout the missions. The D21, launched from the SR-71, was the first high flyer. These systems flew pre-programmed missions and returned with film-based imagery. In the 1970s the Air Force embarked on the Compass

Cope program to develop a high altitude long endurance system capable of reconnaissance at long range. These systems were still hand flown.

In 1988 Boeing developed the first autonomous system; a high altitude long endurance UAV, CONDOR, with a design goal of 150 hours at 60,000 feet. This vehicle was pre-programmed from takeoff to landing and had no direct manual inputs, e.g. no stick and rudder capability in the ground station. The system flew successfully 11 times setting altitude and endurance records. The level of autonomy in this vehicle was limited to redundancy management of subsystems and alternate runways. It demonstrated these features several times during the flight test program.

a. Programs: DARPA began the development of the next generation of High Altitude Long Endurance UAVs: Global Hawk and DarkStar. These systems built off of the autonomous capabilities demonstrated by the CONDOR system. With the increase in computational power available in airborne LRUs these programs were able to achieve much more sophisticated subsystem, guidance, navigation and control, sensor and communications autonomy than previous systems. Global Hawk is capable of Level 2-3 autonomy today (see Figure A-5). The on-board avionics architecture was dual string for flight critical components and federated into core avionics and mission avionics, similar to manned aircraft. Failure of mission avionics would not impact the ability of the vehicle to fly safely. The ground command, control, communications and dissemination architecture was also federated into workstations responsible for safety of flight and workstations dedicated to communications and payload operation. A major advance in contingency management capability was built into these systems. Contingencies ranged from loss of data links, and loss of navigation components to loss of flight computers. The airborne systems were designed to identify, isolate and compensate for a wide range of possible system / sub-system failures and autonomously take actions to insure system safety. Contingency management was further complicated by responses that varied with the mode of flight. The response to the loss of a flight computer is very different during takeoff roll, versus initial climb, versus once out on a mission, or preparing to land. Each failure has to be assessed for the impact on completing the mission. Preprogrammed decision trees are built to address each possible failure during each part of the mission. For each case identified in this matrix a corrective action needs to be identified and coded into the software. Contingency management is often one of the most difficult software modules to develop requirements for and subsequently is often one of the last modules completed.

   The DARPA A160 program is pushing the state of the art in rotary wing system performance as opposed to autonomous behaviors. A160 is an autonomous UAV with autonomous behaviors similar to the Global Hawk system.

   The DARPA/Air Force and DARPA/Navy UCAV program is extending the work being accomplished by these programs, advancing the state of the art in multi-vehicle cooperation. Cooperation in this context applies to cooperative actions among the UCAVs. UCAVs are envisioned to fly alone or as a forward element of a manned - unmanned mission. The UCAVs will have inter-vehicle data links to allow transfer of information between the UCAVs and between the UCAVs and the manned vehicles. The information may include mission plan updates, target designation information, image chips and possibly other sensor data. Key mission decisions will be made based on the information passed between the systems. Decisions such as: coordinated navigation plan updates, communication plan reassignments, weapons allocations or the accumulation of data from the entire squadron to arrive at an updated situational assessment. One of the most difficult aspects of this level of autonomy is ensuring that all elements remain synchronized. Verifying that all messages are received, all vehicles have correctly interpreted the messages and the entire squadron has a single set of mission plans to execute will be a key accomplishment. The UCAV system will still have all of the subsystem management and contingency management autonomous attributes as the previous generation of UAV systems. Both Air Force and Navy UCAV are to demonstrate at least Level 6 autonomy.

The DARPA/Army Unmanned Combat Armed Rotorcraft program is advancing the state of the art in autonomous and collaborative behaviors over and above what the UCAV program is demonstrating. UCAR will develop the capability for collaboration between UCARs, collaboration with other air and ground-based unmanned systems, and collaboration with manned platforms. This collaboration will go beyond the sharing of information to enable collaborative search, target identification, target prosecution, and BDA. UCAR will also develop the capability for the interpretation of high-level mission tasking. What is envisioned is a system that can parse general mission objectives into specific mission objectives, which can then be used as inputs to a sophisticated mission planner. The UCAR systems will build upon the subsystem management and contingency management autonomous attributes developed in the previous generation of UAV systems. With of all of this activity, UCAR is headed for Level 8-9 autonomy.

The DARPA Software Enabled Control program improves the capabilities of control systems for advanced unmanned aircraft, both fixed- and rotary-winged. These control systems enhance the autonomy and reliability of both fixed- and rotary-winged unmanned aerial vehicles, and improve the performance of manned vehicles. The approach taken is to mathematically model complex changes in flight conditions and vehicle status, to design fast digital control systems to automate maneuvers, and to automatically detect and recover from faults or damage. These techniques will be implemented on a common, open computing platform (the OCP, Open Control Platform) using a flexible programmer's interface that facilitates re-use of real-time controllers across multiple vehicles. Advanced control system development exploits recent successes in hybrid systems research, which combines continuous-time systems with randomly occurring discrete events. Hybrid systems can then adapt to sudden changes such as aerodynamic disturbances, threat conditions, damage or failure, or limits in the flight envelope. The software to implement these controls manages these events and guarantees stable operation throughout the execution of the mission.

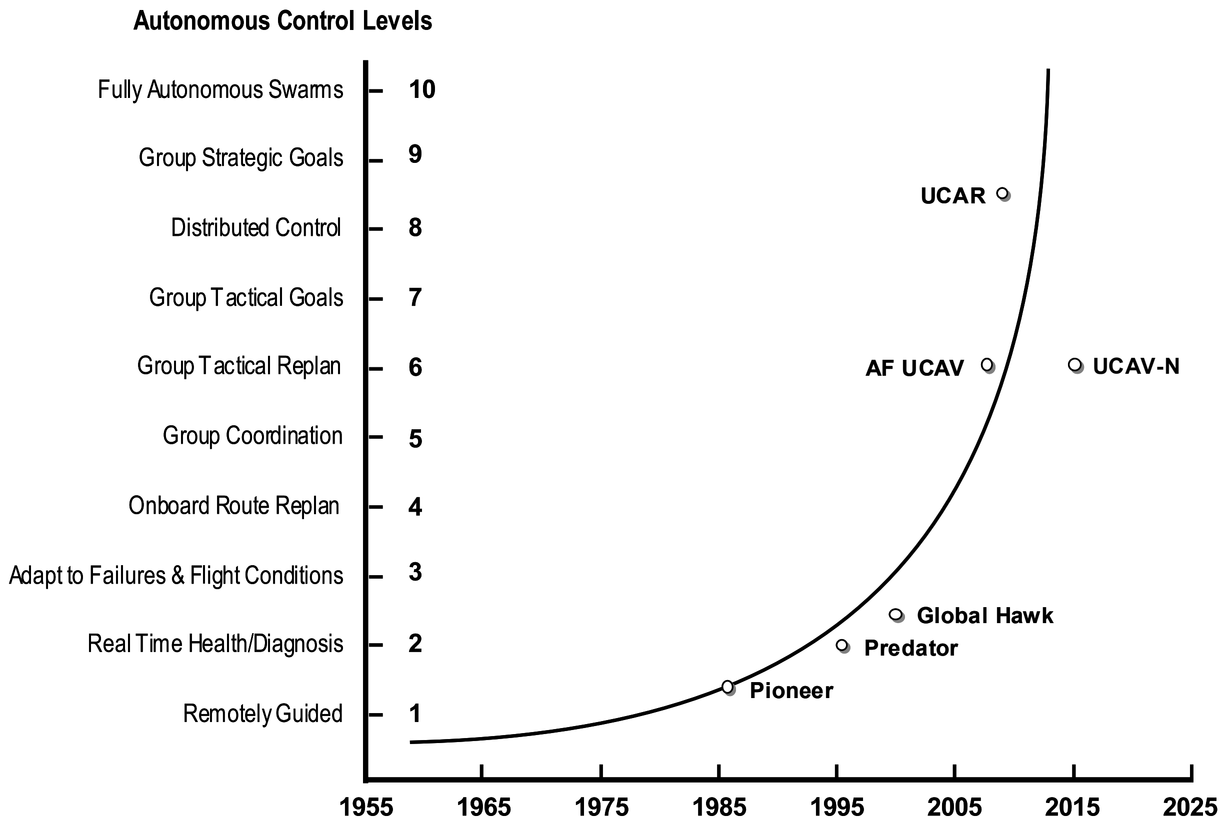


FIGURE A-5: AUTONOMOUS CAPABILITY LEVELS (ACLS).

b. Ground Station C3: As the capabilities of the air vehicles continue to improve; the capability of the command and control infrastructure needs to keep pace. There are several key aspects of the off-board C2 infrastructure that are being addressed: a) man-machine interfaces, b) multi-vehicle C3, c) target identification, weapons allocation and weapons release. The location of the C3 system can be on the ground, aboard ship or airborne. The functions to be accomplished are independent of the location.

UAVs hold the promise of reduced O&S costs compared to manned aircraft. There are no savings by simply moving the man from the cockpit to the offboard C3 station. There needs to be some leverage. This is an oversimplification of the total C3 crew required. This crew also needs to account for the sensor system operator/weapons release authority, often a communications officer and sometimes a mission commander. The reduction to practice of performing multi-vehicle operations is in its infancy. The increased capabilities of the air vehicles may finally enable routine operations. One of the difficult issues being addressed is how the operator interacts with the air vehicle(s): what information is presented to him during normal operations and what additional information is presented if an emergency occurs. Advanced interfaces are being explored in the DARPA UCAV programs. To date, the C3 stations being developed are aimed more at the test environment than the operational environment. The advanced interfaces take advantage of force feedback and aural cues to provide additional situational awareness to the system operators.

OSD platform goals

- **Development of a robust combustion HFE program targeting performance for tactical/theater UAVs.**
- Reduce wing and fuselage costs through incorporation of state of the art commercial composite molding technology.
- Develop technology solutions for high speed, anti-access UAV systems.
- **Develop and field a low cost tactical unmanned strike/SEAD platform by the end of the decade.**
- **Develop and field a low cost tactical unmanned airborne electronic attack platform by FY08.**

Appendix B: Sensors

Overview

Sensors are increasingly becoming the pacing item for the cost of unmanned vehicles dedicated to ISR. As sensors grow more complex, sophisticated, and specialized, it becomes critically important to take steps to control cost growth as well as to efficiently plan future sensor payloads that take advantage of commonality wherever possible.

Commonality at the high valued subcomponent level, such as focal arrays or receive/transmit elements for radar systems, can help to reduce overall sensor costs by increasing the quantity buys of these critical, often high cost items. Where actual sensors cannot be made common, data format standards can minimize the redundancy of ground stations and data exploitations workstations. OSD is keenly interested that the services take steps to maximize the return on investment that new generation sensors represent.

At the same time, new and in some cases mature technology offer the opportunity to simplify the task of gathering intelligence while improving throughput. The current ISR ground infrastructure copes well with day-to-day tasking but would be severely strained to support multiple simultaneous global conflicts. Innovative sensors and software offer ways of multiplying the capabilities of the current exploitation architecture and manpower while enabling collection that is not possible today – through forest canopies and visual obscuration, for instance. It is the intent of OSD to work with the Services to introduce this new technology as it matures while keeping sensor costs in check through coordinated development and acquisition plus adherence to common standards.

This appendix considers sensor technologies that will mature over the next 25 years and will offer promise for UAV applications. In the near term, many of these sensors may also find use on manned platforms – the most highly capable imaging and signals sensors in use on aircraft today are all on manned platforms. In most cases, though, there is nothing unique to the sensor that limits its use to either manned or unmanned aircraft. This appendix also accounts for enabling technologies that will allow UAVs to fully exploit current and emerging sensor capabilities. Finally, this appendix will set out OSD goals for the sensor area.

Mission Areas

Broad Area Reconnaissance. This refers both to imaging broad areas, as reflected in the HAE UAV goal of imaging 40,000 NM^2, as well as the ability to range over a large area on a single mission, while imaging only selected targets. A subset of this mission area is the need for synoptic coverage, instantaneous imaging of a broad area at the same time.

Denied Area Reconnaissance. Information collection in areas where permission to overfly would be denied.

Tactical Surveillance/Reconnaissance. Persistent coverage of a specific target of interest, or the need to find out what is just over the next hill.

Moving Target Indicators for Surveillance/Battle Management. Air, ground, and maritime MTI are growing in importance as a battle management tool as well as a cueing system for high-resolution imagery.

Intel Prep of the Battlefield. Pre-hostility information collection of an area where combat may occur. This is a "traditional" intelligence function involving collection of intelligence for a number of end purposes: targeting, force protection, troop training/mission planning, assessment of enemy center of gravity, and many others.

Precision Guided Munitions Targeting. Specific sensor requirements for pointing and imaging accuracy to provide precise geocoordinates.

Urban Surveillance/Reconnaissance. Observation of targets in an urban environment. Sensors designed for micro-UAVs are largely geared toward this mission; other technologies, such as multiple-look Light Detection and Ranging (LIDAR), show promise.

Force Protection. Tasks include perimeter surveillance/defense, chem/bio agent detection, and target identification. Hyperspectral imaging and broad field of view video on long dwell aerial vehicles are potential sensor contributors.

Chemical/Biological Agent Detection and Identification. One of the most promising potential missions for specialized HSI sensors, either in passive mode or in conjunction with a laser. Also a possible use for a disposable UAV with on-board detection sensors. This mission is tailored to the advantages of a UAV over a manned aircraft.

Battle Damage Assessment. Requires high resolution imagery, preferably near-real-time, in a hostile environment.

Homeland Defense. An emerging mission area requiring broad area, long dwell surveillance, and specialized sensors aimed at detection weapons of mass destruction.

Battlefield Simulation/Rehearsal. Specialized task requiring highly accurate digital terrain mapping. Challenges include not only accurate measurement but short time span between tasking and production. Digital maps of sufficient fidelity for mission rehearsals are highly perishable and must be updated immediately prior to use.

Existing Sensors

Most current sensor programs are either flying on manned platforms, or are on a mix of manned and unmanned vehicles. Since there is very little that makes a sensor inherently "manned" or "unmanned", this section contains both types. Very large, complex sensors flying on dedicated multiengine aircraft are not considered.

Video/Electro-Optic/Infrared (EO/IR) Sensors:

- Video: AF Predator and Army Hunter use real-time video systems mounted in turrets, derivatives of commercial products. The Air Force is integrating laser target designators/illuminators into Predator video systems, as the Army is planning to do with TUAV. Current Predator video (Wescam) typically provides NIIRS 5-6 in visual and NIIRS 4-5 in IR at close range .
- Global Hawk Integrated Sensor Suite (ISS) electro-optic sensor: The ISS consists of a SAR imaging radar and an EO/IR sensor, both produced by Raytheon

Electro-Optic Systems. The narrow-FOV camera produces an image by stitching together many small frames (“chips”). The EO/IR sensor is capable of NIIRS 6.5 at nadir.

- Senior Year Electro-optical Reconnaissance System (SYERS 2), formerly SYERS P3I: The electro-optic sensor carried by the U-2. A high resolution line scanning camera with a 7-band multispectral capability is in production and is projected to become operational in late FY02.
- Advanced EO/IR UAV Sensor: A high resolution, highly stabilized EO/IR sensor being developed for Army UAVs by the Army’s Night Vision Electronic Sensors Directorate. It consists of a multi field-of-view sensor that will provide greater standoff ranges and a highly stabilized gimbal that allows for an increase in the area of coverage. Its all digital output is JTA compliant and allows for ground processing tools, such as Airborne Video Surveillance. It is being evaluated for incorporation into the Army’s UAV program.

Synthetic Aperture Radar (SAR):

- Advanced Synthetic Aperture Radar System (ASARS 2A): Dedicated U-2 imaging SAR radar, capable of 1 foot resolution.
- Global Hawk ISS radar: A partially common system with ASARS 2A, tailored for use on Global Hawk. Capable of spot, search, and Ground Moving Target Indicator (GMTI) modes; resolution to 1 foot.
- Lynx: A tactical radar, with a limited deployment on manned aircraft, is to be evaluated on the Predator B. The Lynx radar has a resolution of 4 inches in the spotlight mode, and provides GMTI and coherent change detection capabilities.
- TESAR: Tactical Endurance Synthetic Aperture Radar (TESAR) is a strip mapping SAR providing continuous 1 foot resolution imagery. TESAR is flown on Predator. A total of 66 radar systems have been produced and delivered.
- Tactical UAV Radar (TUAVR): A 63 pound Tactical SAR/MTI radar for use on Army’s UAVs. Provides 1 foot resolution imagery in strip and spotlight modes and an integrated MTI capability with minimum discernable velocities of greater than 2 meters per second. The radar has been demonstrated on Hunter UAV.

Signals Intelligence (SIGINT):

The High Band Subsystem (HBSS) is designed as the high band portion of the Joint SIGINT Avionics Family (JSAF). HBSS was successful where the low band subsystem was terminated in development. HBSS is not operational but will form part of future high altitude SIGINT systems.

Wet Film:

The U-2 maintains a medium resolution wet film capability with the Optical Bar Camera. Advantages of wet film include very high information density and releasibility to non-DoD users. Broad area synoptic coverage is still the exclusive purview of wet film systems; without efficient digital mass storage devices, electronic sensors do not have the ability to capture imagery of broad areas nearly instantaneously, as wet film can. Primary drawbacks to wet film are the lack of a near-real-time capability and the extensive processing facility needs. Improvements to film processing recently have drastically reduced the requirements for purified water, and the post-processing hazardous material disposal problem, but it still poses a requirement for specialized ground handling equipment.

Emerging Technologies

Multispectral/Hyperspectral Imagery (MSI/HSI). Multispectral (tens of bands) and hyperspectral (hundreds of bands) imagery combine the attributes of panchromatic sensors to form a literal image of a target with the ability to extract more subtle information. Commercial satellite products (such as Land Remote-Sensing Satellite (LANDSAT) or Systeme pour l'Observation de La Terre (SPOT)) have made multispectral data a mainstay of civil applications, with resolution on the order of meters or tens of meters. Systems designed for military applications are beginning to be tested and in some cases fielded. Military applications of HSI technology provide the promise for an ability to detect and identify particulates of chemical or biological agents. Passive HSI imaging of aerosol clouds could provide advance warning of an unconventional attack. The obvious application for this technology is in the area of battlefield reconnaissance as well as homeland defense. Though this technology is less mature than HSI as an imaging system, it should none the less be pursued as a solution to an urgent national requirement. HSI also provides an excellent counter to common camouflage, concealment, and denial (CCD) tactics used by adversaries.

Presently, the U-2's SYERS 2 is the only operational airborne military multispectral sensor, providing 7 bands of visual and infrared imagery at high resolution. A prototype hyperspectral imager, the Spectral Infrared Remote Imaging Transition Testbed (SPIRITT), is in work at the Air Force Research Laboratory. This sensor is intended for testing on larger high altitude platforms such as Global Hawk, but could also be carried on Predator B.

The Army's Night Vision and Electronic Sensors Directorate (NVESD) is preparing to demonstrate a TUAV-class EO/IR sensor with minor modifications to give it multispectral capability. In addition, NVESD is developing the daytime Compact Army Spectral Sensor (COMPASS) and the day/night Hyperspectral Longewave Imager for the Tactical Environment (HyLITE) specifically for UAV platforms at the brigade and division level.

The Naval Research Laboratory (NRL) had developed the WAR HORSE visible/near-infrared hyperspectral sensor system, which has been demonstrated on the Predator UAV. More recently NRL had developed a complementary short-wave-infrared hyperspectral sensor and has demonstrated the sensor on a UAV surrogate platform (Twin Otter). Other short- and long-wave infrared hyperspectral sensors are currently under development to provide a high-altitude stand-off capability for larger manned and unmanned platforms. The Department believes that hyperspectral imagery offer enormous promise and follows these programs with great interest.

HSI Phenomenology/Ground Truth. Civil and commercial work with multi- and hyperspectral imagery has built a phenomenology library that will greatly simplify introduction of these sensors onto manned and unmanned aircraft. Some data already exists in open or commercial venues to build characterization databases in anticipation of the sensors coming online over the next decade. Using products available now and in the near future, the department encourages the services to characterize areas of interest with a view toward optimizing spectral band selection of dedicated military sensors. This intelligence product represents an area in which characterization of the data will be significantly more challenging that just building and operating the sensor.

SAR Enhancements. SAR improvements are changing the nature of the product from simply an image or an MTI map to more detailed information on a target vehicle or battlefield. Current SAR systems can perform limited coherent change detection, showing precise changes in a terrain scene between images. Use of phase data can improve resolution without requiring upgrades to the SAR transmitter or antenna, through data manipulation with advanced algorithms. These and other advanced SAR techniques require access to the full video phase history data stream. To take full advantage of them, UAVs must plan on either wide-band real time data links allowing ground processing of the signal, or extensive on-board processing capability. Size and weight constraints mitigate toward increasing processing power on the ground and moving data off the vehicle at the high rates necessary (on the order of 274Mbps). While modern intelligence collection places a premium on real-time data availability, on-board mass storage of data could at least allow post-mission application of advanced data handling procedures requiring full phase history information.

The Multi-Platform Radar Technology Insertion Program (MP-RTIP) should result in more capable SAR Active Electronically Steered Antenna (AESA) within this decade. Larger UAVs, such as Global Hawk for the Air Force and potentially for the Navy's Broad Area Maritime Surveillance role, are one intended recipient of this technology. AESA permits mission expansion into an air surveillance role, as air-to-air operations is easily accomplished using AESA technology. Combined with conformal antennas, large AESA-based SAR systems may be able to achieve greater imaging and MTI capabilities as well as more specialized missions such as single pass interferometric SAR.

UHF/VHF Foliage Penetration (FOPEN). There are a number of technology efforts to solve the Targets-Under-Trees (TUT) problem. One approach is dual-band radar, using VHF wavelengths to cue a UHF radar for more precise target identification. DARPA, since 1997, has sponsored an advanced, dual-band FOPEN SAR development. DARPA and MIT/Lincoln Labs have participated in joint evaluations of this radar system. After FY02, which is the last funded year of DARPA development, the AFRL's TUT program takes over the dual-band effort and will work to further mature this technology.

Light Detection And Ranging (LIDAR). Use of LIDAR is another method that offers the possibility of imaging through forest canopy. In current and projected tests, an imaging LIDAR sensor on an aircraft takes several fore-and-aft cuts at a given area of interest as the vehicle moves, allowing the sensor to "integrate" an image over time. Initial coverage rates are far less than typical SAR or EO capabilities, but planned systems at this point are for demonstration purposes only.

LIDAR Imaging. LIDAR may be used to image through an obscuration as well. By using a precision short laser pulse and capturing only the first photons to return, a LIDAR image can be formed despite the presence of light-to-moderate cloud cover, dust, or haze. Imaging through moderate or greater obscuration (clouds greater than 200 feet thick) attenuates the outgoing laser pulse by a factor of about 10^{-4}. LIDAR can be used to simultaneously image through cloud and foliage, with greater attenuation (equating to even lower coverage rates). Currently in demonstration, this appears promising at least for specialized reconnaissance tasking.

LIDAR Aerosol Illumination. The task of detecting and identifying chemical or biological agents can be aided with active LIDAR illumination of the target area. Exciting a particulate or gas cloud with a laser simplifies the "fingerprinting" necessary to identify the specific substance. Used in conjunction with a hyperspectral imager, LIDAR can provide faster and more precise identification.

SIGINT Way Ahead. With the failure of the Joint SIGINT Avionics Family program to produce a low band subsystem, a future SIGINT architecture is in doubt. The high band subsystem is producible and effective, and will form the backbone of near term electronic intelligence systems. Efforts to consolidate low band system development are underway and should result in airborne platforms sharing data via standard data formats, using equipment tailored to the specific platform's capabilities and mission needs. In the near term, federated systems, developed to add specific capabilities to manned aircraft, will be used to provide an initial SIGINT capability on UAVs such as Global Hawk. These "clip-in" systems, primarily developed by/for NSA, have been successfully employed on platforms such as the U-2 and RC-135 Rivet Joint. A loose federation of these "clip-ins" coupled with an ESM suite such as the LR-100, demonstrated on Global Hawk as part of the Australian TANDEM THRUST exercise, can provide the basis of an interim capability until a low band alternative is developed. A primary task for SIGINT on UAVs such as Global Hawk will be cross cueing the on-board imagery sensors.

The Army is presently developing the Division TUAV SIGINT Payload (DTSP), a payload for inclusion on the Extended Range/Multi-Purpose (ER/MP) UAV. The ER/MP will be capable of carrying a payload of 200-300lbs and have the ability to stay airborne for 10 hours. The primary mission of DTSP will be to rapidly map radio frequency (RF) emitters on the battlefield to increase the commander's situational awareness. These emitter locations will then be used to cue other ISR sensors in order to reduce their search times. The DTSP could provide a QRC capability on a surrogate Hunter UAV in FY04 to support a Brigade Combat team.

In the longer term, the Army is developing tactical SIGINT payloads that will give the TUAV and smaller vehicles capability against specific targets. Rather than an all-encompassing system that weighs hundreds of pounds and requires electrical power far beyond the ability of a small vehicle to provide, the TUAV packages will be optimized for specific emitters or roles such as direction-finding. Cost, complexity, and most of all requirements growth on past SIGINT programs have posed major obstacles for new SIGINT sensor development as well as major upgrades to legacy systems over the past decade. The Army's efforts to carefully limit the scope of systems designed for smaller UAVs represent the right approach to making SIGINT a key part of the UAV mission area.

Nuclear Detection Systems. Use of endurance UAVs outfitted with nuclear material detectors could play a key role in homeland defense over the next 25 years. Depending on the characteristics of the detection systems, either an aerostat or a Global Hawk-like long dwell aircraft could be the host platform. The department strongly supports work to develop and refine these detectors, with an emphasis on increased sensitivity and long-range effectiveness.

Enabling Technologies

HDTV Video Format. High definition television (HDTV) is becoming the industry standard format for video systems of the type flown on Department of Defense tactical and medium altitude endurance UAVs. The Joint Technical Architecture (JTA) specifies that motion video systems should be based upon digital standards, to date, no fielded system complies. HDTV standards represent a fundamental shift in video technology – from an interlaced image, where a scene is scanned in two, temporally separate steps and recombined to form a full image, to a progressive scanning and display process, where an entire scene is scanned and reproduced in one step. Progressive scanning eliminates temporal skewing and is the underpinning to advanced video processing techniques. Initial analysis indicates that moving to the HDTV specified formats and compression methods will result in an increase of about 2 NIIRS in image quality as compared to the current Predator A sensor, for example, when displayed to the video analyst. SHADOW is projected to field with a JTA compliant sensor. While digital sensors have historically been large and expensive, technology has significantly improved options in both of these areas. For example, the Army Night Vision lab recently demonstrated a 480p focal array in an 11 inch turret, suitable for employment on a vehicle the size of the SHADOW 200. Establishment of a common format allows COTS interoperability and insures that ground terminals will be able to interpret video data regardless of the vehicle providing that data. Equally as important, using a digital format reduces the deleterious effects of repeated image conversion from analog to digital and back along the image exploitation chain, improving over all image quality at the receiving station. Currently, fielded video systems and data transfer protocols are not standardized; many are proprietary systems that are not interoperable. In addition, the increased amount of data generated by a digital video system may require additional bandwidth to move the data from the vehicle. Data compression and innovative data transmission techniques will need to be explored, and impacts to existing communications architectures and allocated spectrum and bandwidths will also need to be considered and addressed.

HDTV related sensors will significantly improve not only the timeliness of PGM-quality coordinate generation (GRIDLOCK (OSD)/RAINDROP (NIMA)) but the quality of the data as well. **OSD GOAL: Services will initiate (continue) digital video sensor demonstration efforts in FY05 with a goal of migrating this capability to the field by FY08. A limited operational capability is desired by the end of FY05.**

Focal Plane Array Technology. Small and micro UAVs place a premium on high performance components that make as little demand as possible on power, weight and volume. The commercial market for focal plane arrays in consumer goods has increased vastly over the last three years; the top-of-the-line digital cameras were only recently reaching the megapixel mark, and now routinely offer 5 megapixel devices as well as handheld digital video recorders.

While commercial products may emphasize only some of the spectral bands of interest for military applications, the trend toward more capable systems requiring less battery power and fitting into handheld cameras can only benefit the department. The services should expect vendors to capitalize on this trend and work to insure that military needs (such as infrared sensitivity, environmental tolerance, and ruggedness) are represented wherever possible.

Digitally based (single conversion on the array) technology significantly improves the quality of the information in the data chain, eliminating image degradation from repeated analog-digital-analog conversions. For this reason, multispectral versions of digital focal arrays are critical. Additionally, common focal arrays between sensors/platforms are desirable. **OSD GOAL: Services (labs) will initiate digital multispectral still/video focal array programs in FY04 with the goal of demonstrating a Predator class digital IR system within 3 years.**

Flexible Conformal Antennas. There are numerous commercial and government programs to develop affordable conformal SAR antennas for use on a variety of aircraft. Their eventual availability will allow UAVs to more effectively use onboard payload space; currently, a SAR antenna (Mechanically-Steered Antenna (MSA) or Electronically-Steered Antenna (ESA)) may be the core parameter around which the rest of the aircraft, manned or unmanned, is designed. Conformal antennas will allow larger apertures using the aircraft's skin. Agile antennas will be able to perform more than one function, so a single antenna (covering a large portion of the vehicle's exterior) can serve the datalink needs as well as acting as imaging radar. On larger vehicles like Global Hawk, conformal antennas mounted near the wingtips will enable single pass interferometric SAR data collection, leading to swift production of precise digital terrain maps.

Sensor Autonomy. One of the key attributes that some UAVs offer is very long endurance, much longer than is practical for manned aircraft. While it may be possible to maintain 24 hour battlefield surveillance with a single vehicle, the system will only reach its full potential when it is doing part of the work of the intelligence processing facility to alleviate manpower needs. A number of image/signal processing and network collaborative technology developments will facilitate the ability to automate sensor operation, at first partially and over time leading to nearly total sensor autonomy.

Current operations for large ISR platforms – Global Hawk and the U-2, for instance – focus on collection of a preplanned target deck, with the ability to retarget sensors in flight for ad hoc collection. This is suitable for today's architecture, but proliferation of UAVs with a range of different capabilities will stress the exploitation system beyond its limits. Long dwell platforms will allow users to image/target a collection deck initially and then loiter over the battlefield looking and listening for targets that meet a predetermined signature of interest. While automatic target recognition algorithms have not yet demonstrated sufficient robustness to supplant manned exploitation, automatic target cueing (ATC) has demonstrated great utility. OSD strongly encourages the Services to invest in operationalizing ATC in emerging UAV sensor tasking and exploitation. Sensor modes that search for targets autonomously that meet characteristics in a target library, or that have changed since the time of last observation, or that exhibit contrast with surroundings can be used to cue an operator for close examination. Advances in computer processing power and on-board memory have made and will continue to make greater autonomy possible. In a similar fashion, different sensor systems on board a single vehicle may also be linked, or fused, in order to assist in the target determination problem. Combing sensor products in novel ways using advanced processing systems on board the vehicle will help solve the sensor autonomy problem as well.

Smaller UAVs operating with minimal datalinks, or in swarms, need this ability even more. The ability to flood a battlespace with unmanned collection systems demands autonomous sensor operation to be feasible. While the carriage of multiple sensors on a single, small UAV is problematic, networks of independent sensors on separate platforms that can determine the most efficient allocation of targets need to be able to find, provisionally identify, and then collect definitive images to alert exploiters when a target has been found with minimal if any human initiative. The desired end state will be achieved when manned exploitation stations – whether a single special forces operator or a full Deployable Ground Station (DGS) – are first informed of a target of interest when a sensor web provides an image along with PGM quality coordinates. This technology is available currently, and needs to be applied to this particular task – which will involve a radical change in ground exploitation infrastructure and mindset, akin to the change in taking a man out of the cockpit.

Air Vehicle Autonomy. Along with sensor autonomy, swarming UAVs will require the ability to self-navigate and self-position to collect imagery and signals efficiently. While air vehicle autonomy is dealt with elsewhere in the Roadmap, it is identified here as critical to fully exploit sensor capabilities and keep costs and personnel requirements to a minimum.

Lightweight, Efficient Power Supplies. In the near term, UAVs will be more power limited than manned aircraft, particularly in the smaller size classes. Every component of the aircraft, sensor and data link strives for small size, weight, and power consumption. For micro-UAVs, batteries with high power/weight ratios are important to maximize sensor capability and endurance. Larger aircraft need to extract power from the engine to generate AC and DC power for sensor and data link operation. Industry is encouraged to refine methods of drawing power from the engine to reduce mechanical inefficiencies and losses with traditional airframe-mounted electrical and hydraulic drive systems. Services should consider power requirements, including prudent margin to allow future sensor and mission growth and total power generated as a fraction of system weight, when developing unmanned vehicles.

Lightweight Optics and Support Structures. In keeping with the need to reduce vehicle weight, lightweight optics and optical support structure will enable small vehicles to carry the best possible EO/IR sensors. The use of composite materials for optical enclosures results in very stiff but light sensor housings that are capable of maintaining tight tolerances over a range of temperatures and operating conditions. Optical elements themselves must also be designed for low weight. This becomes more important in larger sensors with multiple glass elements; even in medium to large UAVs such as Predator B and Global Hawk, EO/IR sensor characteristics can limit the ability to carry multiple payloads simultaneously. Contractors have put a great deal of work into reducing optical sensor weight; the Services should capitalize on this work by adapting existing sensors for new vehicle applications wherever possible, to avoid the costly solution of sensors designed for single vehicle applications.

Ultra lightweight materials are also becoming available that can be used on board UAVs to enhance sensor operation. In particular, aerogels for vibration isolation and damping offer a way to improve sensor resolution and range with very low weight penalty. The combination of stiff, lightweight structure with effective isolation from airframe vibration will give much greater capability to video and EO/IR sensors on small and medium platforms, which in turn will improve vehicle survivability by allowing greater standoff ranges.

Communication. Data links that are designed for small vehicle applications are already proliferating in US and foreign UAV systems. Israel in particular has long recognized the need for effective line-of-sight and beyond-line-of-sight real time links to make effective use of sensor data from UAVs. Data links are dealt with extensively elsewhere in the roadmap, but the importance of a family of small communications packages using the standard CDL interface must be emphasized specifically as a sensor enabler.

In addition to the need for smaller tactical data links, large vehicles carrying sophisticated sensors will need high capacity CDL standard links, particularly in over-the-horizon roles. Current data capacities of 274 Mbps are stressed when carrying multiple sensors simultaneously. Classes of sensors that particularly tax links are radar imagers when full phase history is sent to a ground station for post processing, and multispectral sensors with high resolution and wide fields of view. Hyperspectral data has the potential to vastly outstrip current data rates provided over existing links and most satellite and ground communication networks. If all (or many) bands of hyperspectral data must be downlinked, there will be no ability to operate any other sensors on the vehicle in near-real-time. Data rates in excess of 1 Gbps, using other than RF links (specifically laser communication), will be needed to exploit sensor capabilities, as well as to reduce RF spectrum saturation, in the near term.

Swarms of UAVs carry additional communications needs. Effective distributed operations require a battlefield network of sensor-to-sensor, sensor-to-shooter, and UAV-to-UAV communications to allocate sensor targets and priorities and to position vehicles where needed. While the constellation of sensors and vehicles needs to be visible to operators, human oversight of a large number of UAVs operating in combat must be reduced to the minimum necessary to prosecute the information war. Automated target search and recognition will transfer initiative to the air vehicles, and a robust, anti-jam communications network that protects against hostile reception of data is a crucial enabler of UAV swarming.

Mass Data Storage. Onboard storage of sensor data in the terabyte class should be a goal to exploit manned and unmanned sensor data. Storage of complex imagery or phase history of radar data onboard can substitute for the extremely wideband data links required for near-real-time relay. Similarly, storage of the full output of a hyperspectral sensor will allow transmission of selected bands during a mission and full exploitation of data post-mission. The stored data is crucial in building an HSI phenomenology database to select the right diagnostic bands in the first place.

The goal for onboard mass data storage should be to replicate the capability of wet film for broad area synoptic coverage. Current medium resolution film cameras operating at high altitude can image over 60,000 square kilometers in stereo on a single mission of a few hours, a capability unequalled by airborne digital sensors at this time. This storage capability should be possible in the mid to far term and would result in the elimination of wet film and its processing infrastructure.

Appendix C: Communication

Purpose

The purpose of this annex is to provide a broad outline of the required communications architectures necessary to support UAV operations in the near-term (FY10), and to lay the groundwork for the migration of these architectures to the Transformational Communications System after FY10. This appendix will also identify and describe actions needed to correct near-term (FYDP) shortfalls in satisfying the current communication requirements of the ISR family of UAVS -- tactical, medium, and high altitude -- as well as emerging UCAVs. Finally many of the aspects of UAV communications require protection at levels above this document. A classified Communications appendix is in work and is planned to be available at the beginning of FY04 providing additional detail.

Near-Term Architecture

The near-term communications architecture supporting DoD's UAV systems consists of 3 independent but mutually supporting capabilities.

1. Line-of-Sight (LOS) capabilities: All DoD UAV systems employ some form of LOS capabilities. Currently these exist in several different and non-interoperable frequencies and waveform standards. Data-rate range from a few Mb/s to greater than 250Mb/s. All DoD tactical and larger UAVs will migrate to the DoD Common Data Link (CDL) standard for LOS operations.

2. Narrow Band Beyond Line-of-Sight (NB-BLOS): Narrow-Band BLOS is defined as data-rates below 1 Mb/s and generally support platform and sensor C2. Various MILSATCOM and Commercial SATCOM systems and formats are currently in use. All DoD UAVs utilizing NB-BLOS will support voice and data DAMA capability.

3. Wide-Band Beyond Line-of-Sight (WB-BLOS): Defined as data-rates above 1 Mb/s. This capability is supported by both Government SATCOM and Commercial SATCOM. Commercial SATCOM are generally limited to data-rates less than 50 Mb/s.

    1. Systems requiring data-rates greater than 50 Mb/s will be required to interface with Government SATCOM capability.

    2. Systems requiring less than 50 Mb/s can be supported by either Commercial SATCOM or Government/MILSATCOM. It is envisions that most DoD UAV system will find it beneficial to use Government/MILSATCOM as the primary provider of service.

Future Direction

In order to achieve the Department's goal of decision dominance throughout the Joint Force, it must build an integrated network, populate the network with data, develop command and control to exploit the network, and protect the network. The roadmap provided herein emphasizes building wide bandwidth connectivity of UAVs to the network. This will support a Joint ISR "system-of-systems" by improving capabilities to provide information in near-real-time through the network to operational forces.

Transformation Communications System components including Lasercom satellites, when launched, must be able to support laser crosslinking within their own constellation and relay other sources generating high data rates. The long-term goal should be laser for all high data rate links (>50Mbs). A migration plan to move from RF to laser is required. Data that is exfiltrated from ISR sensors through a storage and Lasercom architecture will be routed on the backbone, brought to the ground and delivered to processing centers. The link to a theater for dissemination would be over terrestrial or laser backbone in an I/P format, based on user pull. Direct downlink (from the Lasercom relay satellites to Theater) of these extremely high data rates will not provide the primary data exfiltration path. Gateways from Laser to traditional RF transport need to be defined however, high altitude UAVs appear to be an ideal platform for this function. There may be a role for airborne nodes that concentrate communications from other sources for (laser) uplink to the Lasercom satellites**.** An ACN would generally remain far enough behind the front lines to avoid most direct attacks, high enough to provide information to the forward line of troops, and would be integrated into the Joint Tactical Radio System (JTRS), follow-on radio concepts and the Global Information Grid (GIG) as a whole.

Current Documented Communications Requirements

TABLE C-1: CURRENT DOCUMENTED SPACE AND AIRBORNE SYSTEMS AND THEIR DATA RATE REQUIREMENTS.

Collection System	Individual Data Rate (Mbps)
Global Hawk	548
U-2	548
Predator	44.7
Rivet Joint	10.7
Joint Stars	10.7
Combat Sent	10.7
SBR	10.7
Cobra Ball	10.7

TABLE C-2: THE TOTAL MILSATCOM (2010) DATA RATE CAPABILITY FOR BEYOND LINE OF SIGHT COMMUNICATIONS FROM WHICH UAVS WOULD COMPETE.

Estimated Throughput for MILSATCOM Systems (2010)		
SATCOM System	**Number of Satellite Operational**	**Max. System data rate (Mbps)**
DSCS/SLEP	4	800
WGS	6	15,000
AEHF	4	1,000
MUOS	6	0.039
Totals		~ 97,300

Tactical ISR UAVs

TUAV ORD, HQ DA (Nov 2001): The threshold DL shall be the Tactical Common Data Link (TCDL). BLOS and Non-Line-Of-Site (NLOS) Data Link will be air-to-air relay through one TUAV (Relay) to a second TUAV (Mission) and satellite communications to 200 km (Threshold), 300 km (Objective). The change to a SATCOM datalink for TUAV control will necessitate a change in the control station and data terminal.

The TUAV will be capable of relaying VHF and UHF radio voice/data communications from the control station via TCDL through the TUAV to ATC/ATS agencies, AWACS, ABCCC and other manned or unmanned aircraft.

Pioneer. The Pioneer UAV communications are currently supported by a duplex C-Band data link over the frequency range of 4,430 MHz to 4,940 MHz. The Pioneer Improvement Program (PIP) will migrate to a TCDL LOS data link for platform and sensor support.

Fire Scout. TCDL is to be used as the primary datalink between the control station and the air vehicle in the VTUAV communications suite. It is a Ku-band, full-duplex, digital RF datalink that's capable of downlinking 10.71 Mbps using the CDL legacy waveform as well as uplinking 200 kbps in spread-spectrum format.

UHF is to be used as the secondary datalink utilizing ARC-210 UHF/VHF radios. The secondary link operates between 225 to 399.975 MHz (FM).

Shadow. Shadow uses a C-band FM link for C2 and imagery downlink. This link will be replaced by a TCDL configuration, currently under development to support the challenging Shadow SWAP constraints, and support operation in the CDL Ku-band at the 200 Kbps command and 10.71 Mbps return link rates. To be compatible with other Tactical UAVs, the system threshold bandwidth for the data uplink (Ground Data Terminal to the air vehicle) shall be 50 KHz (the objective is 200 Khz). The downlink shall have a minimum bandwidth of 18 MHz (threshold).

Small Unmanned Aerial Vehicle. The threshold data link requirements are that it is non-secure, provides a line of site data link from the controlling location to the air vehicle and be capable of simultaneous transmission and reception of command uplink and sensor/air vehicle telemetry downlink using discrete, selectable frequencies.

Medium Altitude ISR UAV (Predator). Predator currently uses an analog C-Band LOS primary link at 20 MHz bandwidth for launch and recovery operations. Once airborne and established in normal flight operations, Predator switches to leased wideband commercial Ku-Band SATCOM for primary link BLOS operations. C2 data rates are 200 Kbps forward, and include voice channels for ATC coordination. Sensor data rates are normally 3.2 Mbps return.

The current Predator requirement listed in the Satellite Data Base (SDB) is 10.7 Mbps thru 2020. As sensor technology matures, Predator is expected to receive a hyper-spectral capability and the required data rate could grow to as much as 45 Mbps (a Tactical CDL – TCDL – data rate). Predator will migrate to TCDL primary LOS communications support by FY05.

High Altitude ISR UAVs.

Global Hawk. Currently there are 3 Global Hawk requirements listed in the Satellite Data Base. The current IMINT entry requires 274 Mbps from 2004-2014. The current SIGINT entry requires 45 Mbps from 2010-2014. The current Multi-INT entry requires 548 Mbps in 2015 and beyond. The Global Hawk program is undergoing an effort to re-baseline the program. This new baseline program will have a payload configuration that includes an IMINT (EO/IR and SAR) and SIGINT capability configuration and a second configuration that is an MP-RTIP-only sensor payload.

Global Hawk uses a UHF LOS 1-4.8 Kbps capability for launch and recovery operations. Normal C2 bandwidth is 200 Kbps and includes voice channels for ATC coordination. Once airborne and established in normal flight operations, Global Hawk can switch to SATCOM for BLOS C2. These C2 SATCOM options include UHF Military Satellite Communications (MILSATCOM), International Marine/Maritime Satellite (INMARSAT), or leased wideband commercial Ku-Band SATCOM. Global Hawk is currently not DAMA capable, and requires a complete 25 KHz UHF MILSATCOM channel. Global Hawk will receive a data only DAMA capability in 2004. Global Hawk will upgrade to DAMA voice capability by FY05.

Global Hawk currently transmits sensor data using either commercial Ku-band SATCOM for BLOS operations, or X-Band CDL for LOS operations. Commercial Ku-band SATCOM data rates are currently fixed and selectable at 1.5, 8.58, 20, 30, 40, 47.9 Mbps. Global Hawk will receive the ability to select any data rate (not just the above fixed data rate increments) later in 2003. Current X-band CDL data rates are selectable at 10.7, 137, or 274 Mbps.

Global Hawk will receive an Extended Tether Program (ETP) capability in 2003. While using ETP for sensor data, Global Hawk will still require SATCOM (UHF MILSATCOM or INMARSAT) for C2 of the air vehicle. Global Hawk will upgrade to full platform and sensor support with ETP by FY05.

A hyper-spectral payload capability is expected to be developed for Global Hawk that will drive the data rate requirement to 548 Mbps and beyond. The Transformation Communications System is planned to migrate Global Hawk to laser communications capability. It is expected that data rates above 1 Gbps will be possible.

Broad Area Maritime Surveillance (BAMS). Navy requirements for BAMS being reviewed and are expected to range between 274 and 548 Mbps for both LOS and BLOS applications.

Weaponized UAVs.

The estimated Air Force UCAV communications requirements are:

a. BLOS Communications:
   Near Term: Demand Assignment Multiple Access (DAMA) UHF Satellite Communication at 2-4 Kb/s.
   Mid Term: Once the airborne terminals are developed and available the UCAV system will use the MILSTAR Medium Data Rate (MDR) and High Data Rate (HDR) channels for transmitting SAR chips for targeting at 1 Mb/s.

Far Term: Once deployed the UCAV system will integrate with the Transfomational Communications System (TCS) for both Command and Control of the Air Vehicles and transmission of SAR data for targeting.

b. LOS Communications:
The primary link for LOS control of the UCAV is Link 16. The back-up link is ARC-210. Intervehicle LOS communication will be accomplished with Link 16 and in the future an Inter-Flight Data Link (IFDL) that supports stealthy platforms.

The Navy's UCAV-N potential requirements are:

a. BLOS communications: Small AEHF transceiver capable of supporting single and multi-channel (wideband – approx 10-12 mbps) operations, commercial Ka-band, CDL-N/TCDL (Ku band) for airborne relay, CAN – Adaptive Communications Node, MP-CDL (Multi-platform CDL) to support networked dissemination, Mil-Satellite DAMA UHF for back-up air vehicle C2, and VHF/UHF Voice Relay (for Air Traffic control).
b. LOS Communications: CDL-N/TCDL direct link, MP-CDL network operations, LINK 16 (back-up link to ship, possible intra-flight data link), LPD/LPI/AJ Ka/UHF intra flight data link, and VHF/UHF C2 and voice relay.

MQ-1B, the weaponized version of the current Predator RQ-1B, will employ TCDL capability as primary communication for LOS operations.

Communications Capabilities

For the purpose of planning, an acquisition strategy with linkage to the command and control required to operate a UAV in the broad categories of LOS and BLOS must be considered. BLOS communications for this roadmap shall be considered as being supplied through the use of satellite communications (SATCOM).

Line of sight communications systems

Narrowband Line of Sight. Current C-band LOS communications, used to launch and recover Predator, interferes with some foreign countries ground infrastructure communications networks due to differences in U.S. and foreign spectrum allocation and approval.

Wideband Line of Sight. CDL is the DoD mandated family of wide-band data links used for full duplex, jam-resistant and point-to-point transmission of SIGINT and IMINT data to ground processing centers. CDL systems, built to common waveform specifications, support high data rates and operate in the X and Ku-bands. Multi-Platform CDL (MP-CDL) is being developed for MP-RTIP applications which may include JSTARS, NATAR, Wide Area Surveillance (WAS), and Global Hawk, as well as Network-Centric Collaborative Targeting (NCCT) and other applications.

Data link interoperability is accomplished through the use of specifications and standards. CDL systems fall into seven groups of CDL systems: 10.71 Mb/s through 274 Mb/s and 2x and 4x CDL.

Support to Tactical UAVs. The Army's TUAV ORD requires TCDL, as do Fire Scout and the Pioneer Improvement Program. Both the Army and the CDL Program Office are pursuing miniaturization of the TCDL for TUAV applications.

Support to Medium Altitude UAVs. Predator has funded for integrating a TCDL capability for LOS use in lieu of the current C-band LOS communications. As previously mentioned, Current C-band LOS communications, used to launch and recover Predator, interferes with some foreign countries ground infrastructure communications networks. A TCDL capability for Predator LOS operations would resolve this conflict and provide Predator with additional communications options for operating in foreign countries.

Support to High Altitude UAVs. The current Global Hawk LOS capability is a 137 Mbps CDL. The program is migrating to full data rate, 274 Mbps, CDL at IOC.

BLOS SATCOM. Satellite communications supporting UAV operations are provided through commercial providers and as well through government resources. SATCOM is used for the command and control of the aircraft when operating beyond line of sight as well as for providing the path for sensor data to be taken from the onboard sensor and delivered directly to a user or to be delivered to a network for additional processing and routing. SATCOM is characteristically in short supply and the demand grows exponentially each year. Both narrowband and wideband systems occupy different segments in the radio frequency spectrum, each segment having it's own capability for transmitting data as well as having it own sensitivity to environmental factors. These factors must be considered when selecting which radio spectrum segment is to be used to operate UAVs.

Considerations for supply and demand are also important factors to consider in the UAV acquisition process. Commercial and MILSATCOM systems currently experience an enormous amount of pressure for more availability.

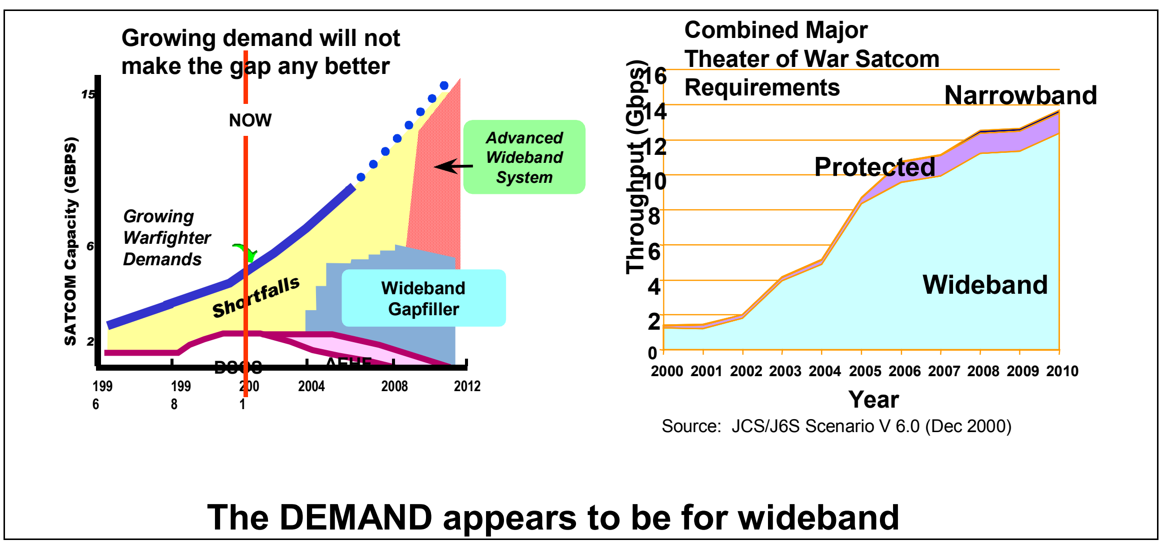


FIGURE C-1: SUPPLY & DEMAND.

Commercial SATCOM. Commercial SATCOM is in short supply and even that may not be available during contingencies because of competing users. Because of market factors, commercial SATCOM assets are much fewer than were expected several years ago plus bandwidth is limited on those assets that are available to DoD. Additionally, commercial Ku-band SATCOM coverage is not available over major portions of the planet (such as over the oceans, interior Africa, etc.). Since systems like Predator and Global Hawk can only operate BLOS where commercial Ku-band satellite coverage is available, this can be a limiting factor for operational employment. Although commercial coverage may exist over the specific area of interest, SATCOM transponders may already be leased and unavailable for DoD UAV use. The commercial SATCOM market place is competitive and currently there exists a spot and ad hoc market for the bandwidth commodity. The spot market for short-term bandwidth leasing is dynamic and therefore must be accounted for when choosing the type of SATCOM system a UAV must use. Furthermore, per international frequency allocation treaties, commercial Ku-band SATCOM is not approved for "mobile subscriber use" (i.e., use by aircraft or UAV's).

MILSATCOM. Although reliant on commercial SATCOM resources in the near term, the replacement of military SATCOM systems fielded during the 1980s and 1990s has already begun to provide additional capacity needed to support not only combat forces, but also the UAV community. It should be recognized however, that a large percentage of these satellites will be allocated to existing tactical missions. Available capacity to support ISR missions remains very low at least for the near term and is the reason the Air Force is pursuing the Advanced Wideband System (AWS) as the future generation of wideband SATCOM. The system has been proposed to include high capacity RF frequencies like V-band or laser communication. The first AWS satellite is scheduled for launch in FY10 and fielding of a constellation of five satellites is predicted to occur around FY12. On this schedule however, AWS will be fielded too late to satisfy the fielding dates for the collection platforms shown previously but will be expected to satisfy many of the connectivity requirements UAVs will present beyond 2010.

A bigger issue that needs to be addressed is the mismatch between the time it takes to deploy new MILSATCOM constellations with enhanced capabilities, and the time to conceive and develop new systems that generate the demand for these improvements. Because an increase in improved ISR systems are seen as key contributors to various operational needs (like rapid precision weapon delivery, for example), new initiatives (e.g., evolutionary improvements) in this area occur every one or two years. New SATCOM systems take five to seven years to reach the point of first launch of a new satellite. Consequently, at program initiation, the new SATCOM system might meet requirements as initially envisioned, but would fall short by the time it is ready to deploy.

There may be more utility in spacecraft that combine commercial C band and military X-band, or commercial and military Ka, than the current approach that combines X and Ka. The C/X and Ka/Ka both combine frequency bands that are adjacent and may offer an innovative opportunity for synergy with commercial. The assumption is Ka users' primary use at higher data rates is to receive the downlink (at the same 20 GHz as the planned AEHF) rather than to transmit (as the GBS is used today). The connection between other tactical capabilities and the rest of the world will be through Teleports.

SATCOM is becoming a limiting factor in meeting the data distribution needs of DoD's projected transformation systems, including ISR systems like Global Hawk. Currently, Global Hawk is limited to a maximum of 50 Mbps data rates over SATCOM, but is expected to require 274 Mbps links in the FY04 time frame and 548 Mbps in the FY 2010 timeframe. Today's SATCOM systems and the next generation WGS cannot meet the 274 and 548 Mbps data rates. WGS can support a single channel 137 Mbps and with modifications 274 Mbps (currently unfunded) to the airborne terminals using two WGS channels. However, use of WGS for UAV support would result in current subscriber losing access.

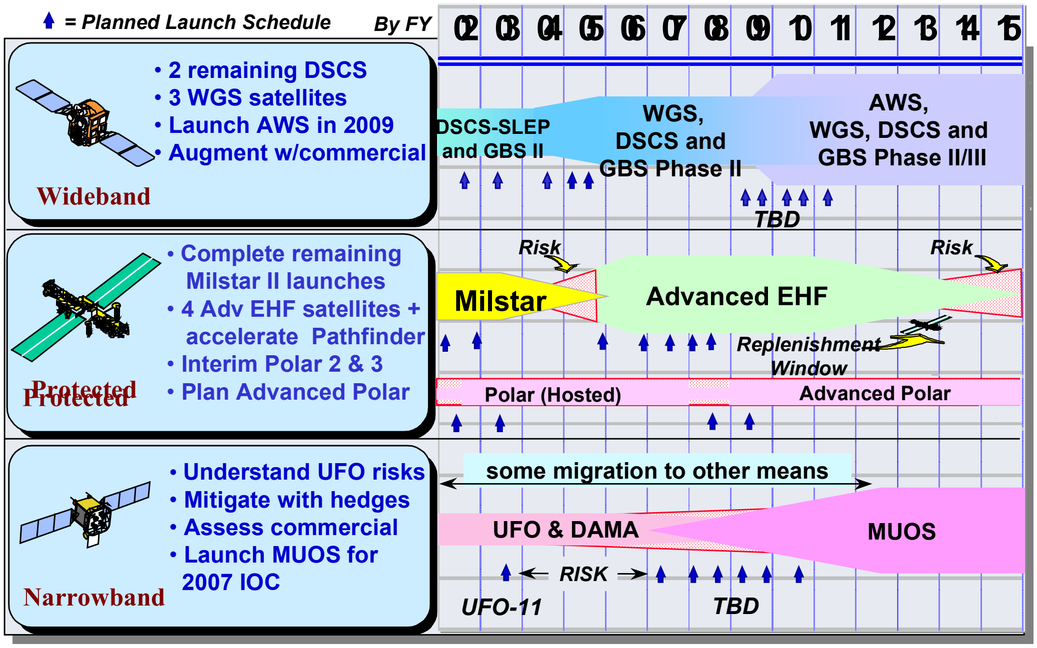


FIGURE C-2: MILITARY SATELLITE COMMUNICATIONS FUTURE DIRECTION.

<u>Defense Satellite Communication System (DSCS).</u> DSCS is the current operational wideband satellite communication system for DoD and other government users. Designed in the late 1970's, the DSCS III spacecraft was originally optimized for strategic and fixed, high data rate users. Fourteen spacecraft were acquired under a block buy contract to minimize acquisition costs; the first was launched in 1982, and two are still awaiting launch.

The strategic mission is to complete transition to Milstar in 2003, and since Desert Storm much more emphasis has been placed on tactical wideband communications. The last four spacecraft were modified to better support this mission, under the Service Life Enhancement Program (SLEP). Two of these have been launched.

<u>Wideband Gapfiller System (WGS).</u>

- WGS will consist of 3 or more satellites each offering high-capacity, DoD controlled, modestly-protected communications, system is planned to primarily replace the current (and outdated) DSCS system at X-band, but will also include mid-band Ka transponders that can be used for ISR applications.

  Although the WGS system will provide additional needed SATCOM capacity, its use contends with tactical needs and modifications are needed to enable 274 Mbps.

- Support to Medium Altitude UAVs: Predator does not currently have a Ka-band capability. Developing a Ka-band terminal for the Predator air vehicle would reduce its reliance on leased commercial Ku-band SATCOM, and provide improved coverage areas and provide a DoD owned and operated architecture. The Predator program office is studying the feasibility of developing and integrating a Ka terminal on the Predator for use with WGS.
- Support to High Altitude UAVs: Global Hawk does not currently have a Ka-band capability. Developing a Ka-band terminal for WGS on the Global Hawk air vehicle would provide an additional C2 capability, and also provide an additional capability to relay sensor data at data rates up to 137 Mbps. It would reduce Global Hawk's reliance on leased commercial Ku-band SATCOM. Currently, this capability is unfunded.

Advanced Wideband System (AWS). AWS will provide wideband MILSATCOM services to users starting in about FY09, using X-band and Ka-band frequencies, and possibly others. The emphasis will be on tactical users of all types, although the requirements are not completely defined. It is expected that UAV support will be provided.

AWS was intended to be the follow-on to DSCS III, but in 1996 the JROC directed that an interim system be built, which became the Wideband Gapfiller System. The AWS program funding profile is based on the concept that only three Gapfillers will be acquired. AWS and its associated requirements are to be fulfilled by the Transformational Communication System.

- Support to High Altitude UAVs: The WGS support to Global Hawk discussion, above, applies as well to the AWS.

Description of Actions Needed to Correct Shortfalls

The actions listed below include funded, partially funded, and unfunded activities. Some have been included in previous POMs, but have slipped.

1. Improved Network Communications -- Communications Transformation**.** Communications upgrades are a major portion of transformation efforts, and will enable robust network centric operations. The FY03 budget includes significant funds to sustain and improve our communications, including expansion of terrestrial and space-based communications by laying additional fiber optics and employing novel approaches like laser communications on satellites. Within these areas, we will invest $5.5B in a superior command, control, and communications infrastructure that moves a high volume of warfighting information, plus over $800M to develop a new survivable, secure communications system to support the warfighter.

   Examples of programs we are emphasizing in the FY03 budget that support transformation include:

   - Laser communications

- Expanded terrestrial communications fiber
- Mobile User Objective System
- Deployable Joint Command and Control system
- Joint Tactical Radio System
- LINK-16 Tactical Data Link

There is also substantial funding to protect and safeguard our networks to assure the security of information transmitted over them.

2. Improved UAV Communications:

   - Implement TCDL Ku-band in 2003 for Shadow.
   - Integrate a TCDL capability for LOS use for Predator in lieu of the current C-band LOS communications.
   - Study and, if feasible for Predator environment, integrate a Ka terminal on the Predator to allow WGS use in 2004.
   - Global Hawk will receive a data only DAMA capability in 2004. DAMA voice capability is required by FY05..
   - Global Hawk will receive an Extended Tether Program (ETP) capability in 2003. C2 over ETP is required, otherwise Global Hawk will still require SATCOM (UHF MILSATCOM or INMARSAT) for C2 of the air vehicle. Developing a Ka-band terminal for WGS on the Global Hawk air vehicle would provide an additional capability if ETP is unavailable until TCS implementation. It would reduce Global Hawk's reliance on leased commercial Ku-band SATCOM.
   - **Migrate all UAVs to CDL compatible data links for LOS and BLOS communication by FY06.**

3. NSSA is recommending the development of an Airborne Communications Network (ACN) to Augment Ground Infrastructure. Current terrestrial communications networks are not as mobile as their supported maneuver elements. The NSSA's vision for an ACN is a collection of UAV-mounted L- or S-band payloads that can provide multiple megabits per second of wideband data and narrowband voice and data, in the form of broadcast, multicast, and point-to-point communications.

4. Improved Extended Tether Program Ground Systems:

   - Improve existing ETP ground systems beginning in FY04.
   - Add to ETP ground structure to support the accelerated fielding of Global Hawk and advanced U-2 configurations.
   - Fully incorporate available satellite constellation

Conclusions

Global conflict and the War on Terrorism will continue to stress ISR communications at least through 2015. The existing commercial and military LOS and BLOS assets cannot accommodate the increasing demand resulting from additional platforms and improved sensors unless UAVs, data link and SATCOM systems are modified. Furthermore, such improvements are essential to achieve the Department's goal of decision dominance throughout the Joint Force. This UAV Communications roadmap supports a Joint ISR "system-of-systems" by improving capabilities to provide information in near-real-time through the network to operational forces.

Appendix D: Technology Migration

Overview

In response to this roadmap's data call, the services and other DoD agencies identified approximately 101[4] funded Research & Development (R&D) programs and initiatives developing technologies and capabilities either for specific UAVs (UAV "specific" programs) or broader programs pursuing technologies and capabilities applicable to manned as well as unmanned aviation (UAV "applicable"). The total research investment across the DoD was approximately $2,553M, of which approximately $1,216M (48%) was in UAV-specific programs , and $1,337M (52%) in UAV applicable programs. In the latter category, spending was primarily in the areas of platform, control and payload/sensors R&D, whereas the bulk of the spending in the former UAV specific category was in broad technology initiatives and weaponization. Weapons and targeting R&D constituted 61% of all UAV specific R&D program spending. Specific investment was broken out by broad technology areas as follows:

- 27 % ($692.46 M) was in platform-related enhancements,
  - of this, 5% was UAV specific and 95% was UAV applicable R&D

- 14 % ($353.63 M) in control technologies (to include autonomy),
  - 32% UAV specific, 68% UAV applicable R&D

- 19 % ($496.95 M) in sensors and other payloads,
  - 12% UAV specific, 88% UAV applicable R&D

- 29 % ($747.3 M) in the area of weapons & targeting,
  - 100% UAV specific R&D

- 10 % ($261.85 M) in broad R&D efforts.
  - 100% UAV specific R&D

Unlike last year, there were no specific R&D efforts in processing identified to the Task Force. Overall, the lack of specific investment in processing technologies is reflective of the dominance of commercial influence in new developments in the communications and information processing fields, clear examples of how the Department is benefiting from "spin-on" technology. These trends can be expected to continue and should continue to be leveraged as the Department considers its long-term R&D investment strategy.

Broad Area R&D

The following matrix shows the near term UAV specific and UAV applicable R&D programs currently identified by the services and agencies in this area. Broad area

[4] Note – figures and percentages used in this chapter's discussions are approximations due to incomplete data receipt.

programs are those that encompass a number of activities contained in at least two or more of the other technology categories in the roadmap. They are grouped together in this additional category because the level of detail of required to break out their funding into sub-categories was beyond the scope of the roadmap. This category includes programs such as the Unmanned Air Vehicle Defense Technology Objective and platform R&D programs that integrate multiple technologies, such as the Army/DARPA A-160, DARPA's Canard Rotor Wing and the USN/USMC Dragon Warrior. Total broad area R&D spending is $261.85 M, or approximately 10 % of total Department and Agency spending on UAV programs. 100% of this spending is on UAV specific programs.

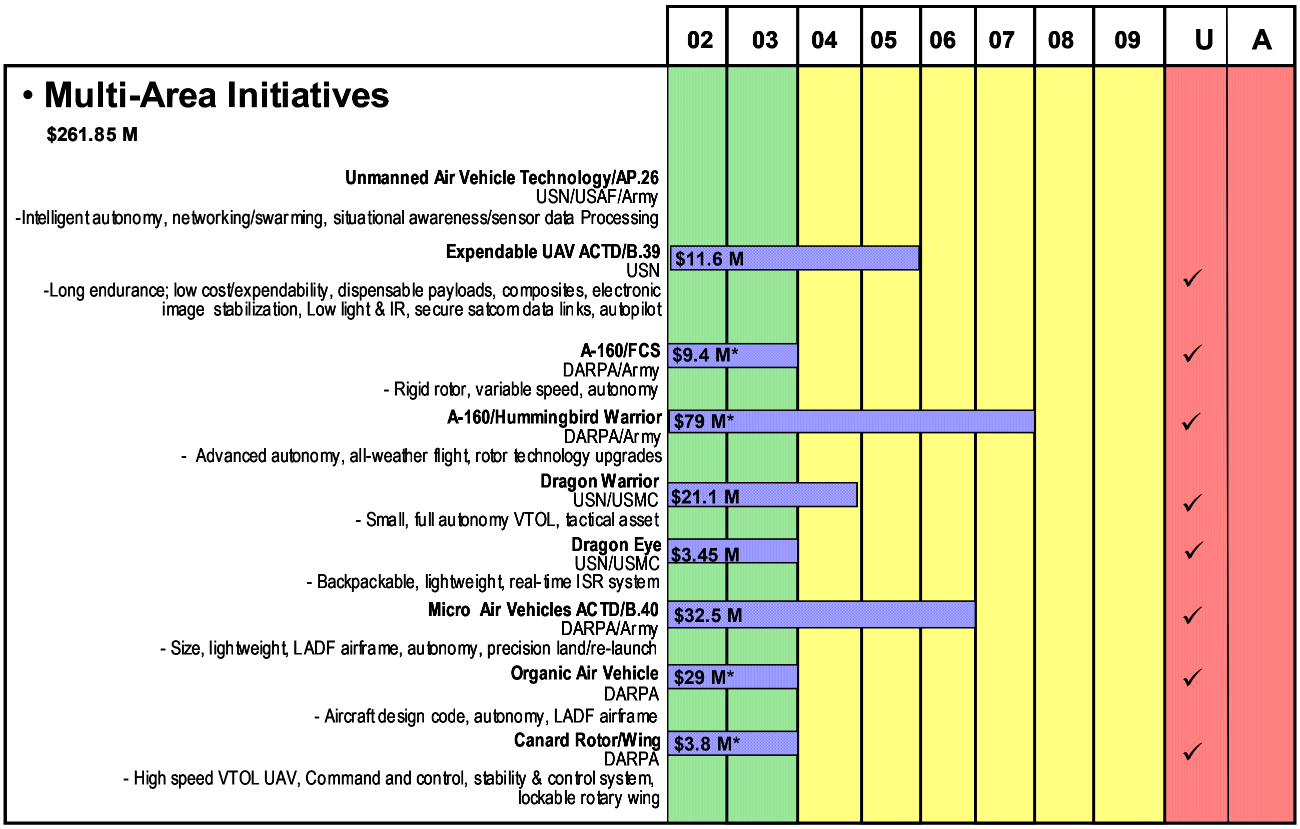


FIGURE D-1: MULTI-AREA INITIATIVES.

Platform Technology

Platform-related R&D has been further divided into the major R&D categories of Airframes & Aerodynamics, Materials, Propulsion & Power and Survivability. Each is dealt with separately below, however overall spending on platform related R&D totals $693.06M, or 27% of total spending. Of this, $33.7 M, or 5%, is spent on UAV specific R&D programs (this represents just over 1% of the total $2,552.79M spending on UAV R&D), and the remaining $659.36M, or 95%, is spent on UAV applicable R&D programs.

Airframes/Aerodynamics. The following matrix shows the near term UAV specific and UAV applicable R&D programs currently identified by the services and agencies. Total R&D spending on aerodynamics and airframes is $167 M, or approximately 6.5% of total UAV spending. Only $29.4 M, or 18%, of the $167 M total investment in Airframes and Aerodynamics is being spent on UAV specific programs (this represents just over 1% of the total $2552.79M spending on UAV R&D). The remaining $137.6M (82%) is being spent on UAV applicable technologies.

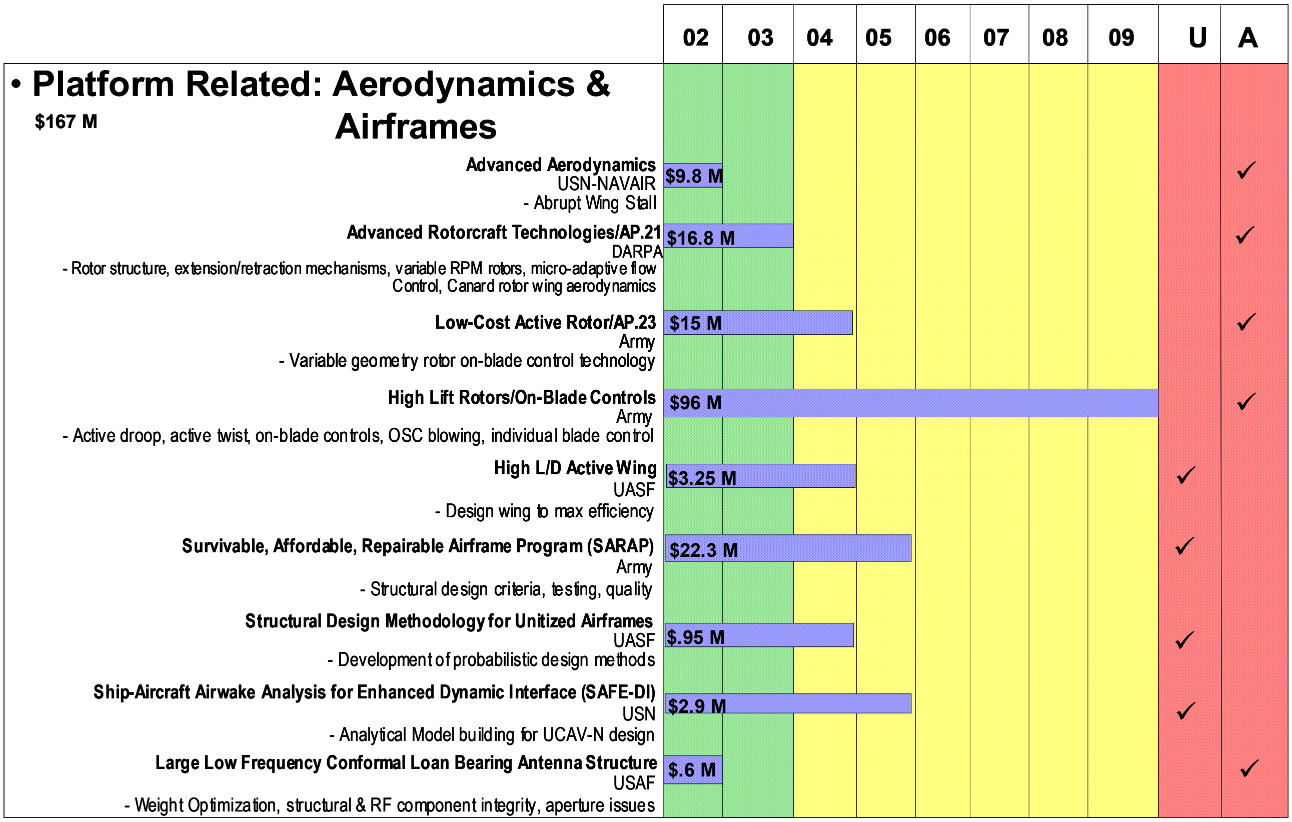


FIGURE D-2: PLATFORM RELATED: AERODYNAMICS & AIRFRAMES.

Materials. The following matrix shows the near term UAV specific and UAV applicable R&D programs currently identified by the services and agencies in this area. Total R&D spending on platform materials is $134.6 M, or approximately 5 % of total UAV spending. Of this $134.6 M, $3 M, or 2%, of the total investment in materials technologies is being spent on UAV specific programs (this represents just over 1 tenth of 1% of the total $2552.79M spending on UAV R&D). The remaining $133.6M (98%) is being spent on UAV applicable technologies.

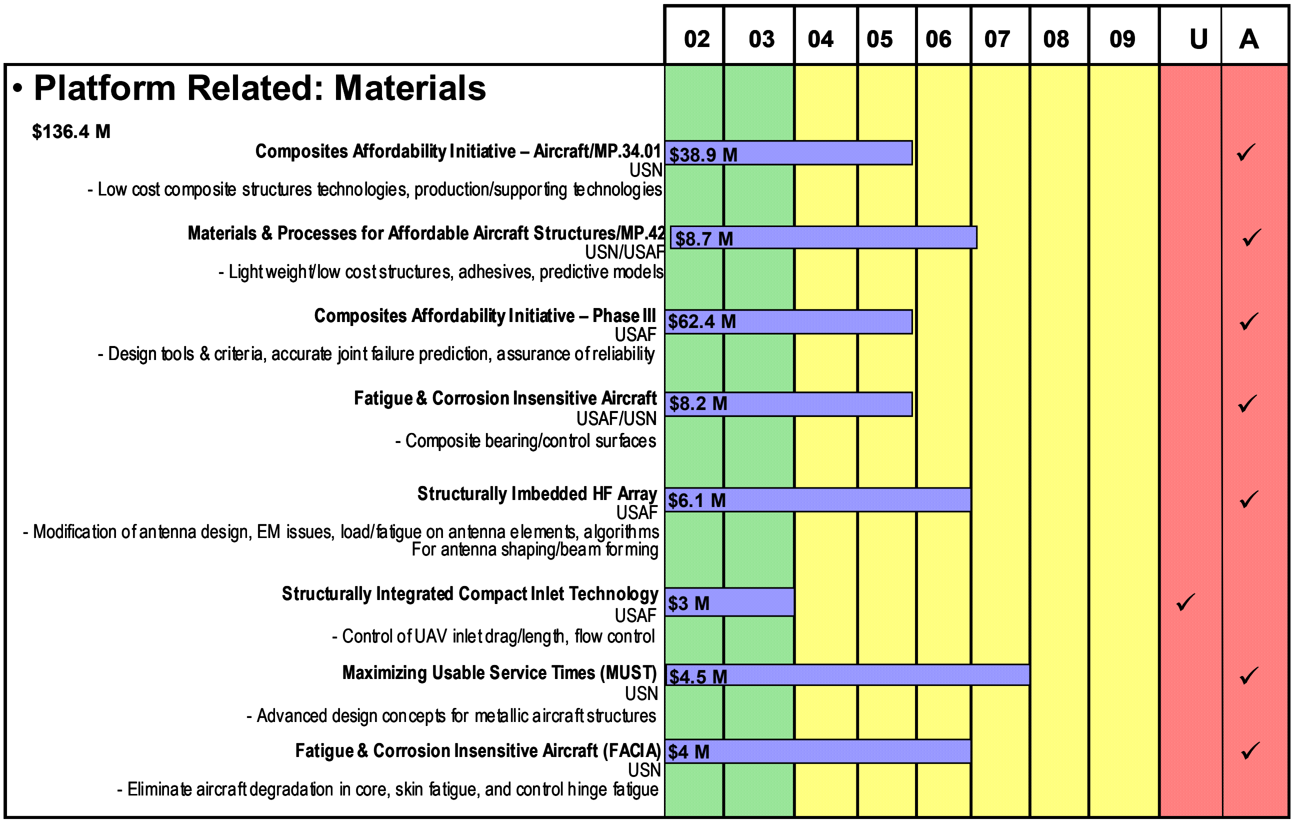


FIGURE D-3: PLATFORM RELATED: MATERIALS.

Propulsion & Power. The following matrix shows the near term UAV specific and UAV applicable R&D programs currently identified by the services and agencies in this area. Total R&D spending on propulsion and power R&D is $309.5 M, or approximately 12% of total Department and Agency spending on UAV programs. None of this spending is on UAV specific programs, all funded programs are UAV applicable.

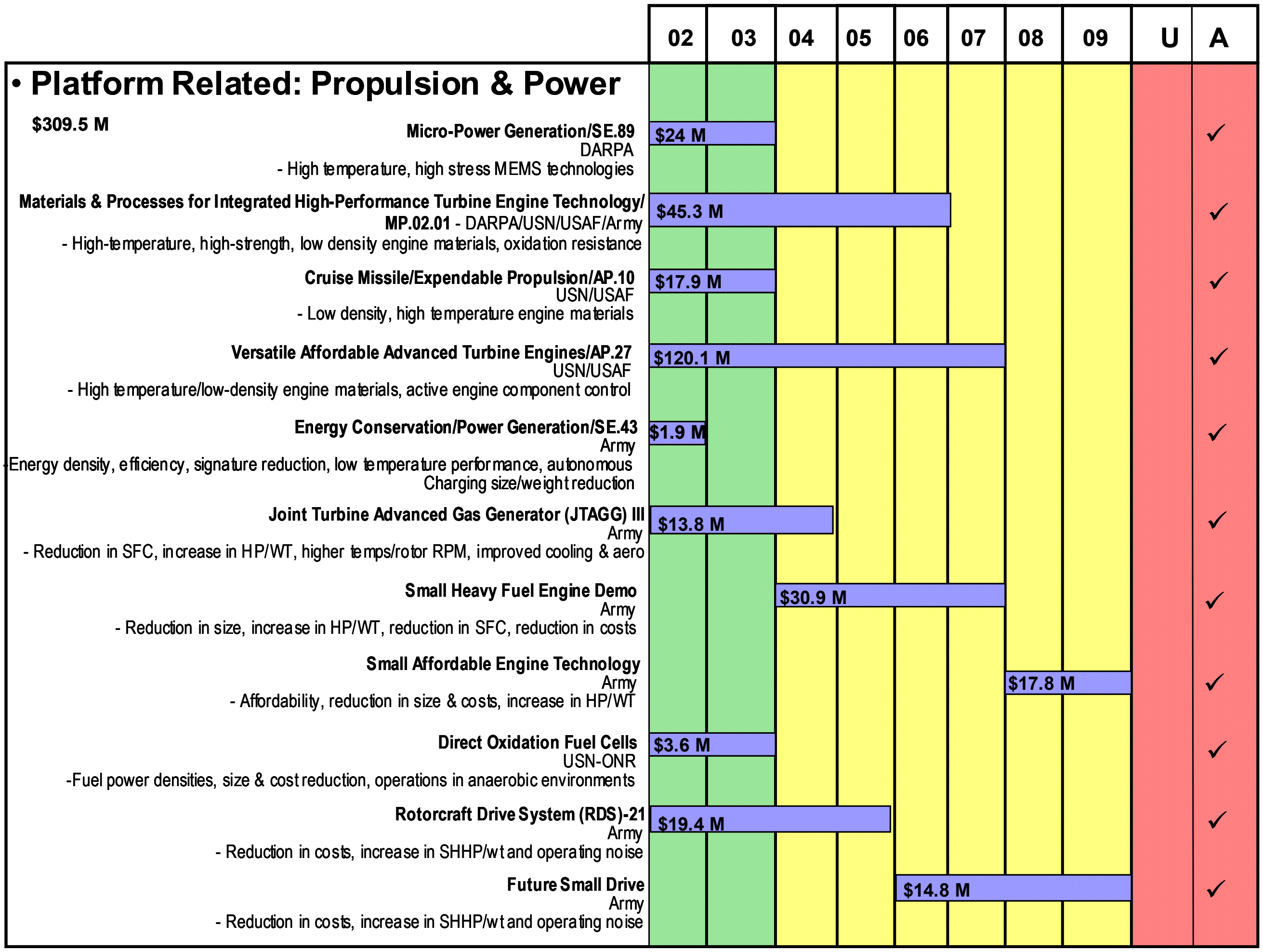


FIGURE D-4: PLATFORM RELATED: PROPULSION & POWER.

Survivability. The following matrix shows the near term UAV specific and UAV applicable R&D programs currently identified by the services and agencies in this area. Total R&D spending on survivability technologies is $79.56 M, or approximately 3 % of total Department and Agency spending on UAV programs. $1.3 M, or approximately 2%, of this spending is on UAV specific programs. The remaining $78.26 M (98%) is being spent on UAV applicable technologies.

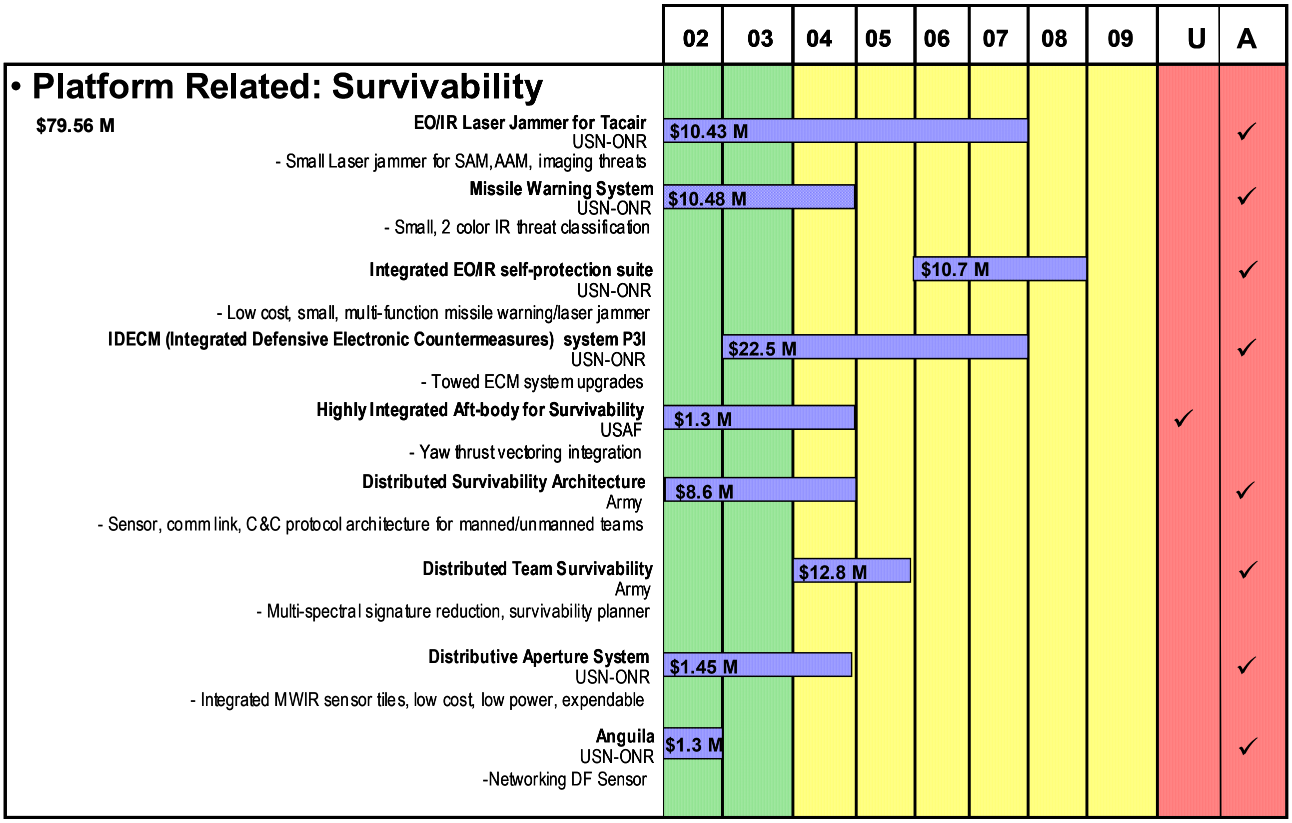


FIGURE D-5: PLATFORM RELATED:SURVIVABILITY.

Platform Trends & Future Initiatives.

Propulsion & Power. Significant advances in propulsion technology have been achieved over the past decade by the AFRL-led, joint Integrated High Performance Turbine Engine Technology (IHPTET) program. Since its inception in 1988, it has increased the thrust-to-weight (T/W) ratio of its baseline small turbine class (Honeywell F124) engines by 40 percent, reduced SFC by 20%, and lowered engine production and maintenance costs by 40 percent. IHPTET concludes in 2003, but its successor, the Versatile Affordable Advanced Turbine Engines (VAATE) program, aims to improve each of these three criteria half again by 2015. If these trends can be continued through 2025, T/W will improve by 250 percent, SFC by 40 percent, and costs will decline by 60 percent (see figure below). For UAV use, these goals may partially be met by deleting turbine blade containment rings and redundant controls, as well as reducing hot section lifetime from 2000 to 1000 hours or less. In combination, the T/W and SFC improvements provided by IHPTET should enable the number of endurance UAVs needed to provide 24-hour coverage of an area to be reduced by 60 percent, or conversely, the endurance of individual UAVs increased by 60 percent.

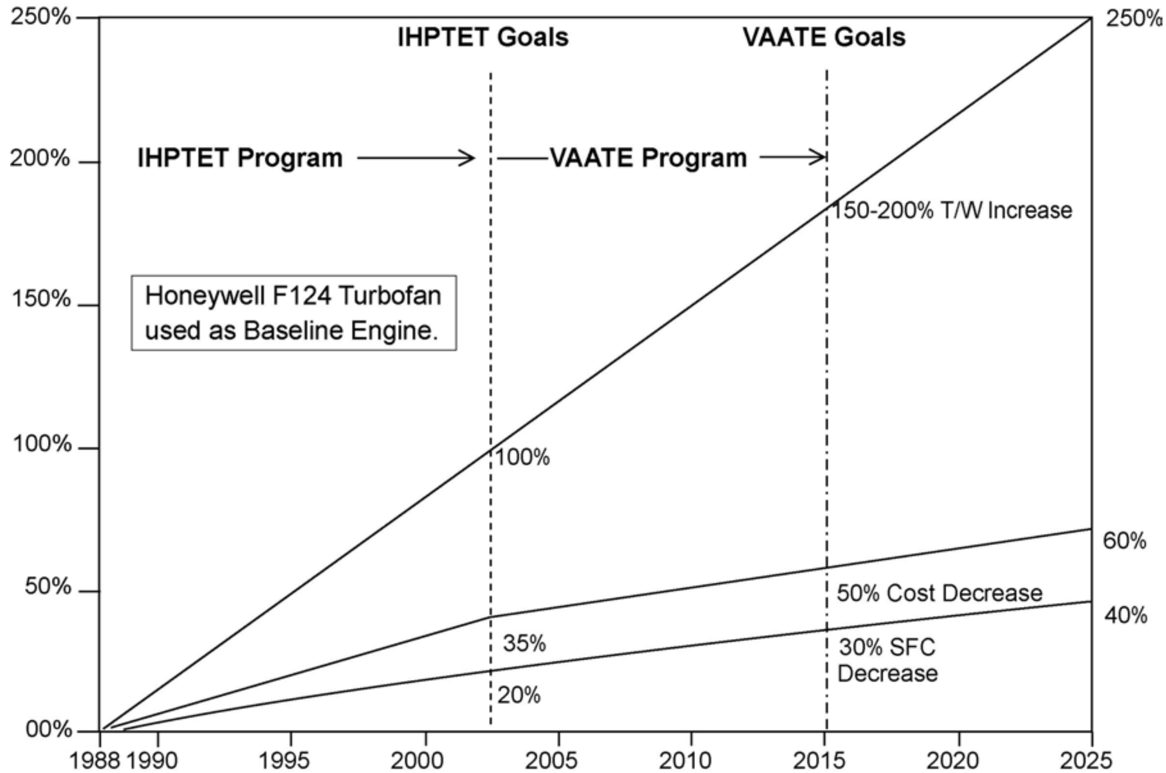


FIGURE D-6: IHPTET AND VAATE PROGRAM GOALS AND TRENDS.

Electrical Systems: Three types of electrical propulsion systems are available for UAVs: batteries, fuel cells, and solar cells. The energy storage capacity of batteries is measured in terms of specific energy, and usually expressed as watt-hours per kilogram (hp-hours per lb).[5] Higher specific energies lead to batteries with increased lifespan, which would lead to battery-powered aircraft with increased range and endurance, a major operational limitation of battery powered UAVs to date. Future growth in battery specific energy capability is expected with the introduction of the Lithium-polymer battery, which suffers from a rather short lifespan.[6]

The solid oxide fuel cell (SOFC), together with the multi-carbonate fuel cell (MCFC), represent the current state-of-the-art in fuel cell technology. A jump in specific energy capability is anticipated with the advent of the hydrogen-air, or proton exchange membrane (PEM), fuel cell, which is at least 5 years from production. Further advances in fuel cell technology could occur with hybrid cells, which use the waste heat from the cell to generate additional power via an attached turbine engine. By 2004, the MSP of fuel cell powered engines should equal or exceed that of noisy internal combustion engines.

Solar energy is a viable option for other types of UAVs, such as high-altitude, long endurance UAVs, for use as long-dwell reconnaissance or airborne communications relays. The NASA/AeroEnvironment Helios solar-powered UAV set the altitude record (96,863 ft) in 2001 for propeller-driven aircraft by using solar cells to drive 14 electric motors, which together generated roughly 28 horsepower. While a storage system for

[5] Specific energy is the amount of energy a battery or fuel cell stores per unit mass,
[6] The result of internal self-shorting when an electric current is passed over the metal in the polymer

solar energy for use during foul weather or night conditions is being developed, the added weight of these storage systems probably make them prohibitive for use on micro air vehicles and combat UAVs.

The above numbers can be compared to the energy content of the most popular energy source, gasoline. The specific energy of gasoline is about 12 hp-hr/lb. The best batteries listed above remain less than 2 percent of gasoline in terms of their specific energy. Fuel cells, while an improvement over batteries, have specific energy values roughly 4 percent that of gasoline. However, by 2015, this disparity between fuel cells and gasoline will likely be reduced by over half.

Emerging Propulsion Technologies

- Beaming energy to the aircraft for conversion to electricity using either microwaves or lasers eliminates the need to carry propellant onboard, but requires a tremendous transmit-to-receive power ratio (microwaves) or very precise pointing (lasers) and limits flight to within line-of-sight of the power source (both). Microwave beaming would take 100 kW (134 hp) of transmit power to run just a micro-UAV at a range of 0.6 miles, let alone a more substantially sized aircraft, whereas a laser would only require around 40 W (0.05 hp) of power. (is this worth even mentioning?)
- Reciprocating Chemical Muscles (RCMs) are regenerative devices that use a chemically actuated mechanical muscle (ionomers) to convert chemical energy into motion through a direct, noncombustive chemical reaction. Power generated via an RCM can be used for both propulsion (via wing flapping) and powering of on-board flight systems. RCM technology could power future generations of micro-UAVs, providing vertical take-off and landing as well as hover capabilities. (this assumes a flapping wing design – no longer being vigorously pursued)
- For dash or sustained high speed requirements, whether to enhance survivability or for access to space, propulsion options for future UAVs (and their level of maturity) include ramjets (mature), scramjets (developmental), integrated rocket-ramjet (developmental), air-turbo rocket (developmental), and pulse detonation engines (developmental), each with varying attributes depending on the mission.
- Nuclear fuel engines. Technologically feasible, nuclear fuel engine remain the most efficient means of power for long endurance (6+ month) flights. The implications for long-dwell ISR are obvious. Though there are technological obstacles to be overcome, the principal limitation on development of this technology will likely be the policy implications associated with operating a nuclear reactor in flight over foreign countries .

Weapons & Targeting Technology

Within the last year, the biggest change in UAV employment has been in their use as combat platforms, especially in a strike role. It has certainly generated significant press attention and also has arguably had the biggest impact on changing cultural perception of UAVs in the broader, non-UAV community. As a result of successes such as the Hellfire-equipped Predator, the thinking in the operational community about what an appropriate mission for a UAV is and what they are capable of doing has changed significantly.

The following matrix shows the near term UAV specific and UAV applicable R&D programs currently identified by the services and agencies in this area. Total R&D spending on Weapons and Targeting is $747.3 M, or approximately 29% of total Department spending on UAV programs – making it the largest category of spending. 100% of this spending is on UAV specific programs.

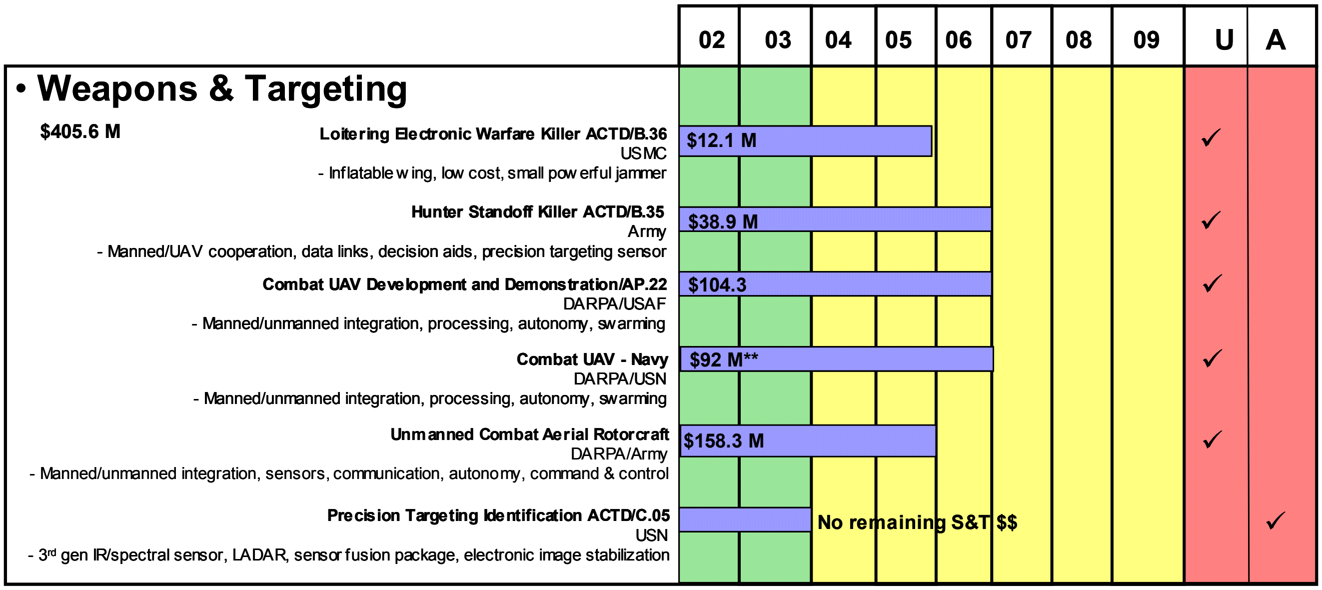


FIGURE D-7: WEAPONS & TARGETING.

General Trends & Future Initiatives. Short-term developments in this field will continue to focus on the fielding of strike UAVs by integrating existing technologies in response to short-term requirements. While almost all longer term – and big dollar - R&D is currently focused on the development of purpose-built Combat UAV systems (UCAV, UCAV-N, UCAR), the importance of the current short-term, operationally driven activities should not be overlooked. While it is imperative that long-term R&D into the purpose-built combat UAV continue in order to ensure that we are able to respond to the emerging realities of aerial combat in the 21st century, the additional operational utility driven by the "classroom of combat", along with attendant, required technological advancements, can be expected to identify or reinforce new applications of UAVs in combat roles. Whatever the motivation, it is clear that this technology category represents the area of maximum growth for UAV R&D.

Sensing Technology

Sensors & Other Payloads. The various payload capabilities being researched in this technology category can for the most part (currently and historically) be divided into two principal areas: intelligence collection sensors and communications relay payloads. In addition two these two areas, there are also a number or broad research programs in basic sensor technologies that can impact multiple programs. Finally, reflecting both the increased operational application of UAVs as well as advances in sensor technology, there are the two other areas of payload R&D worth noting; non-imaging radar programs, and multi-function RF payloads. This section will discuss each of these payload capabilities in turn; however it would be beneficial to recap some statistics first. Overall spending on sensor and payload R&D totals $496.95 M, or 19% of total UAV spending. Of this, 60.45 M, or 12%, is spent on UAV specific R&D programs (this represents just over 2% of the total $2552.79M spending on UAV R&D). The remaining $436.5M (88%) is being spent on UAV applicable technologies.

General Sensor Research. The following matrix shows the near term UAV specific and UAV applicable R&D programs currently identified by the services and agencies in this area. Total R&D spending on general sensor research is $128.9 M, or approximately 56% of total payload and sensor spending, and 5% of total UAV spending. None of this money is being spent on UAV specific programs, all is in UAV applicable programs. Programs in this category constitute R&D that has potential broad applicability across more than one payload category or intelligence discipline, and beyond UAVs in general.

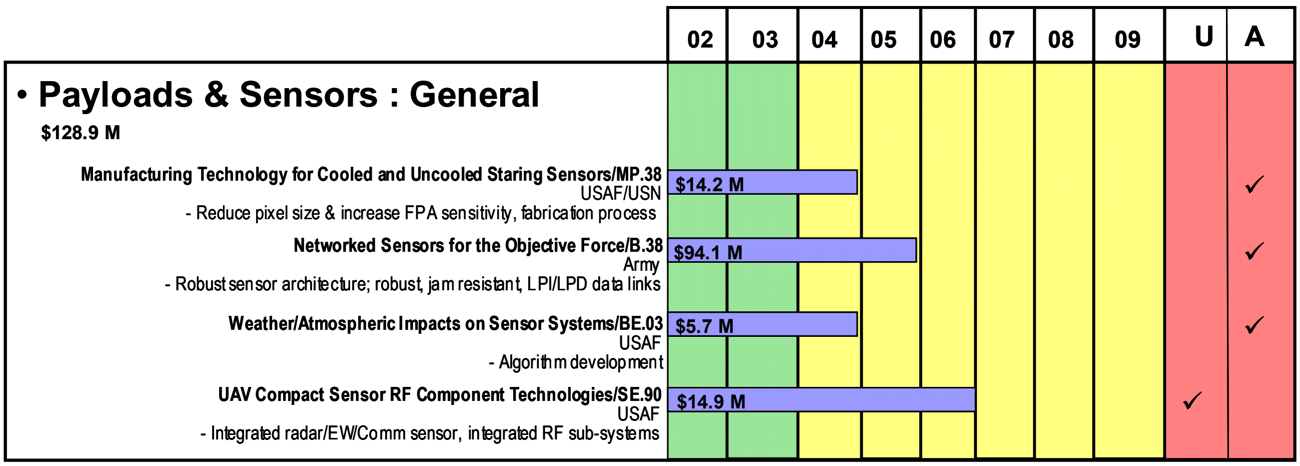


FIGURE D-8: PAYLOADS & SENSORS: GENERAL.

Intelligence. The ability to detect, recognize, classify, and identify targets is the key UAV payload requirement derived from the Combatant Commanders' IPLs. There are currently R&D programs for intelligence collection sensors in the disciplines of IMINT, MASINT, and SIGINT. Total spending on intelligence sensor R&D is $174.9 M – 35% of the sensors and payloads total, and 7% of overall spending on UAV R&D. Of this 174.9M, $28.2M, or 16%, is being spent on UAV specific programs.

Total R&D spending on UAV-related IMINT is $40.2 M, or approximately 23 % of total spending on intelligence sensor R&D and 8% of overall sensor & payload R&D spending. None of this spending is on UAV specific programs, all is in efforts applicable to UAVs.

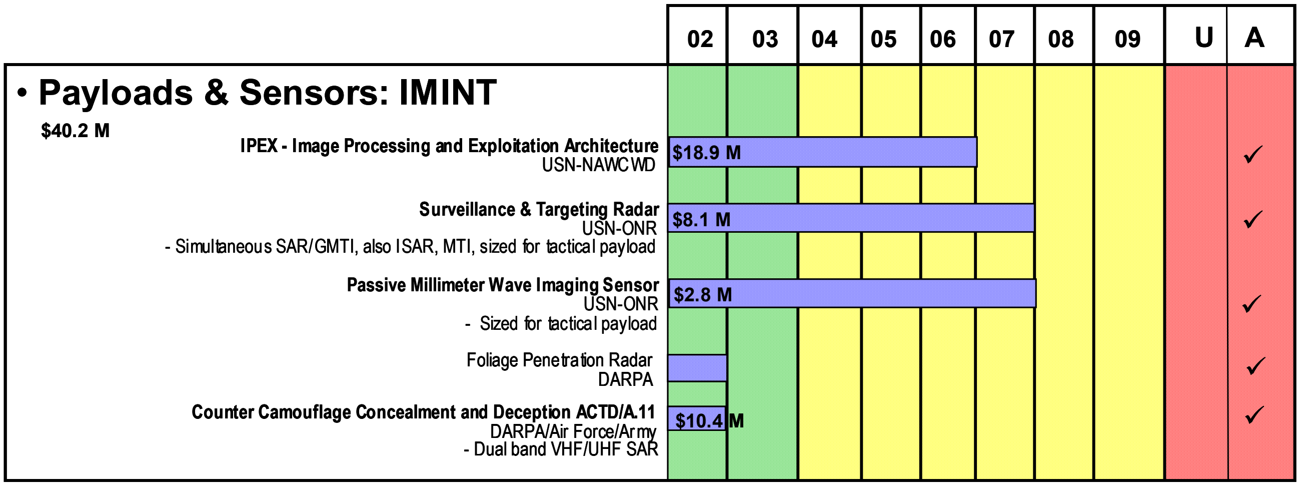


FIGURE D-9: PAYLOADS & SENSORS: IMINT.

MASINT. Increases in resolution for imaging sensors (passive and active) are nearing a leveling point where new technologies will not produce leaps in resolution. Therefore, near and mid-term increases in the operational capability to detect, identify, and recognize targets will be based on increased target signature information, not just pixel resolution. A target may hide in a few dimensions but not in all, and once it is detected in one dimension, additional resources can be focused for recognition and identification. For example, normal two-dimensional spatial imaging of an obscure object of interest may be insufficient for detection unless and until it is combined with vibration or polarization data on the same object. The capability to increase target information content is enabled by this emerging multi-dimensional sensing technology. The following matrix shows the near term UAV specific and UAV applicable R&D programs currently identified by the services and agencies in this area. Total R&D spending on MASINT is $97.7 M, or approximately 56% of total spending on intelligence sensor R&D and 20% of overall payload and sensor R&D spending. Of this 97.7 M, 28.2 M, or 29%, is on UAV specific sensors, while the remaining $69.5 M is on efforts applicable to UAVs.

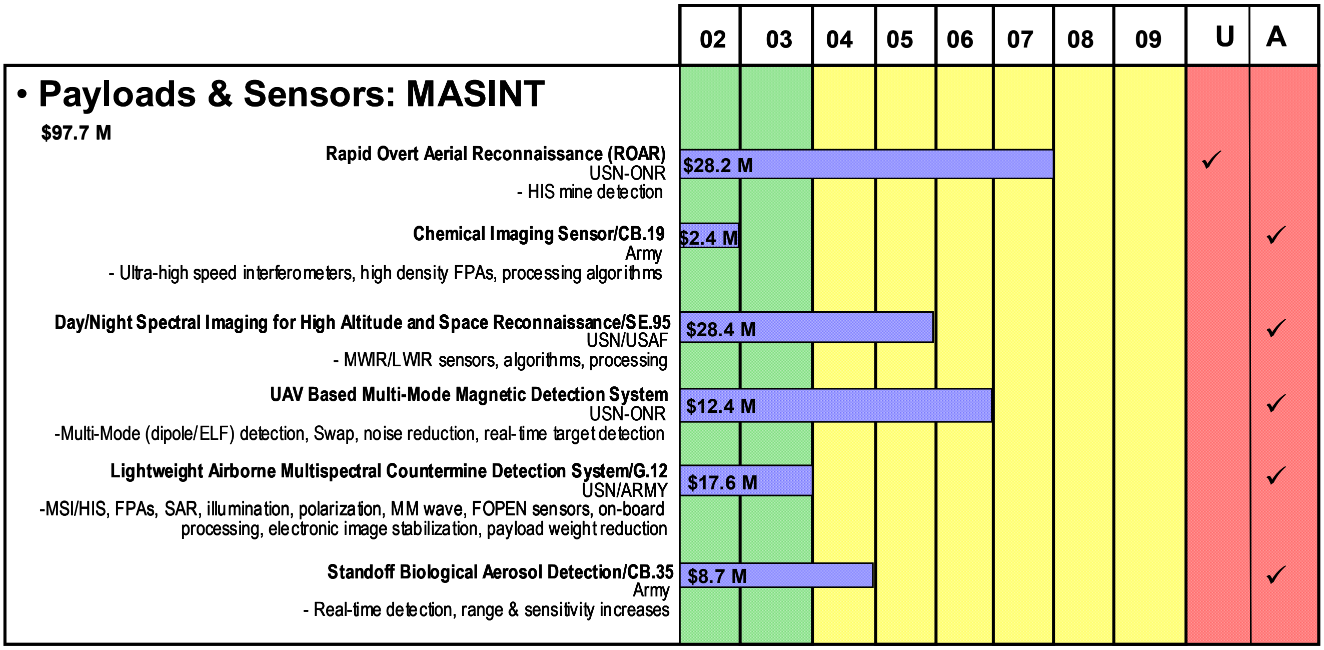


FIGURE D-10: PAYLOADS & SENSORS: MASINT.

SIGINT. A SIGINT system is expected to perform three functions: emitter mapping (geolocation of emitters), exploitation (signal content), and technical analysis of new signals. The following matrix shows the near term UAV specific and UAV applicable R&D programs currently identified by the services and agencies in this area. Total R&D spending on SIGINT is $37 M, or approximately 21% of total spending on intelligence sensor R&D and 7% of overall payload and sensor R&D spending. None of this spending is on UAV specific programs, all is in UAV applicable programs.

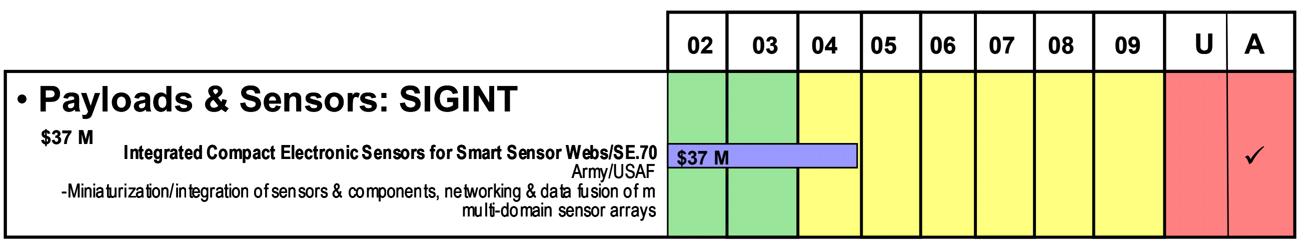


FIGURE D-11: PAYLOADS & SENSORS: SIGINT.

Communication Payloads. The following matrix shows the near term UAV specific and UAV applicable R&D programs currently identified by the services and agencies in this area. Total spending on communications payload R&D is only $10.7 M – 2% of the sensors and payloads total, and only 4 tenths of 1% of overall spending on UAV R&D. All of this spending is on UAV specific programs.

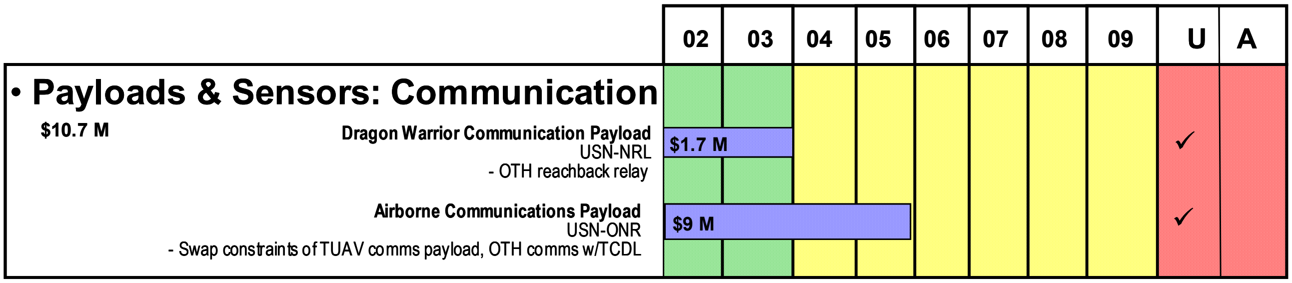


FIGURE D-12: PAYLOADS & SENSORS: COMMUNICATION.

Multi-Function RF Payloads. These payloads bridge the world of communication relay and intelligence sensor. Though optimized for neither mission, they have still demonstrated significant flexibility and utility. Though they are not intended to replace a high power, high fidelity collection or relay system, they will provide significant operational flexibility to a commander – especially in the early hours of a situation when force levels are low – through their ability to "morph" between missions. Additionally, they will provide ubiquitous, supporting collection capability as well as significant communications relay capability. The following matrix shows the near term UAV specific and UAV applicable R&D programs currently identified by the services and agencies in this area. Total spending on multi-function RF payload R&D is $175.8 M – 35% of the sensors and payloads total, and 7% of overall spending on UAV R&D. None of this spending is on UAV specific programs, all is in UAV applicable programs.

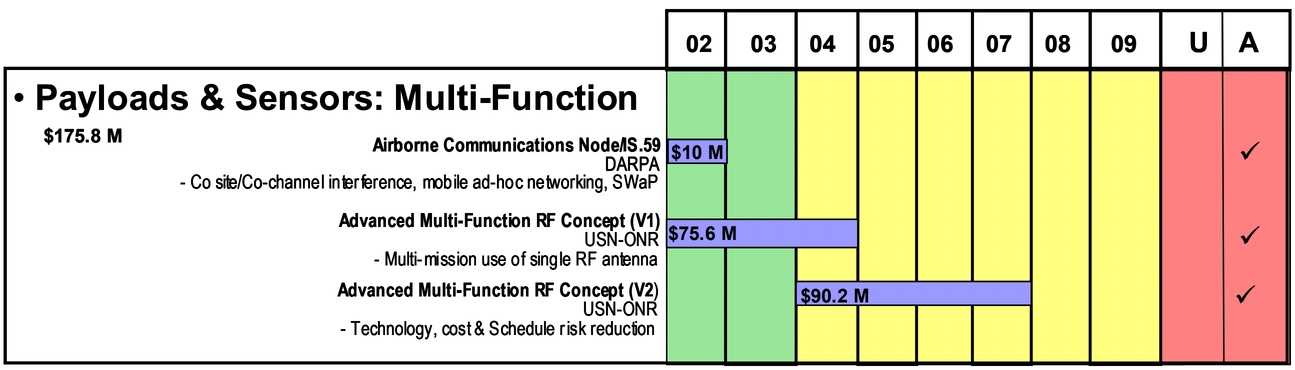


FIGURE D-13: PAYLOADS & SENSORS: MULIT-FUNCTION.

Non-Imaging Radar Payloads. This single program constitutes the final distinct category of payload and sensor R&D. The $6.65 M in total spending on the program is only 1% of the sensors and payloads total and 2 tenths of 1% of overall spending on UAV R&D. It is a UAV specific program.

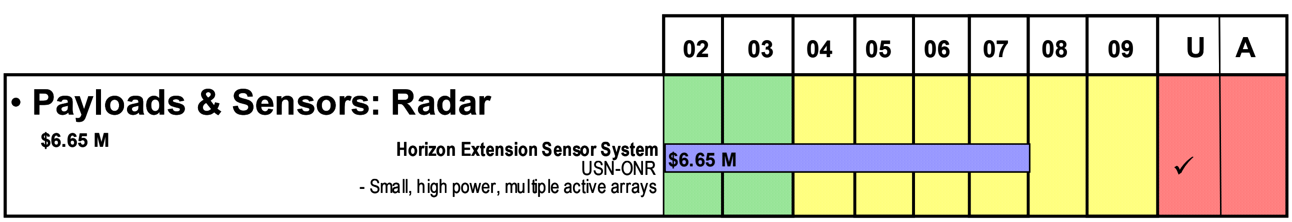


FIGURE D-14: PAYLOADS & SENSORS: RADAR.

Control Technology

Control-related R&D has been broken down into the major categories of General R&D, Health Management, Mixed-Initiative Control, Planning & Support, and Autonomy. Each is dealt with separately below, however overall spending on control related R&D totals $353.63 M, or 14% of total spending. Of this, $113.03 M, or 32%, is spent on UAV specific R&D programs, and the remaining 240.6 M, or 68%, is spent on UAV applicable R&D programs. Most R&D in air vehicle control technologies is either in the category of general R&D, or in the area of autonomy. General Control R&D spending amounts to $89.95 M, or 25% of the overall spending in this technology category. Of this, 34.15 M, or 38%, is on UAV specific programs, and $55.8 M, or 62% is on programs applicable to UAVs. Health Management spending is $4.1M, or 1% of the overall control technology spending. None of the money is being spent on UAV specific R&D. Spending on Mixed Initiative Control R&D amounts to 10.6 M, or 3% of overall control spending. 100% is being spent on UAV specific programs. 5.3M, or 1% of control spending is committed to Planning and Support R&D programs. None of it is for UAV specific programs. Finally, R&D into vehicle autonomy accounts for 69% of all spending in the category of control - $243.68 M, $68.28 M, or 28%, is for UAV specific R&D and the remaining $175.4 M, or 72%, is in programs with applicability to UAVs.

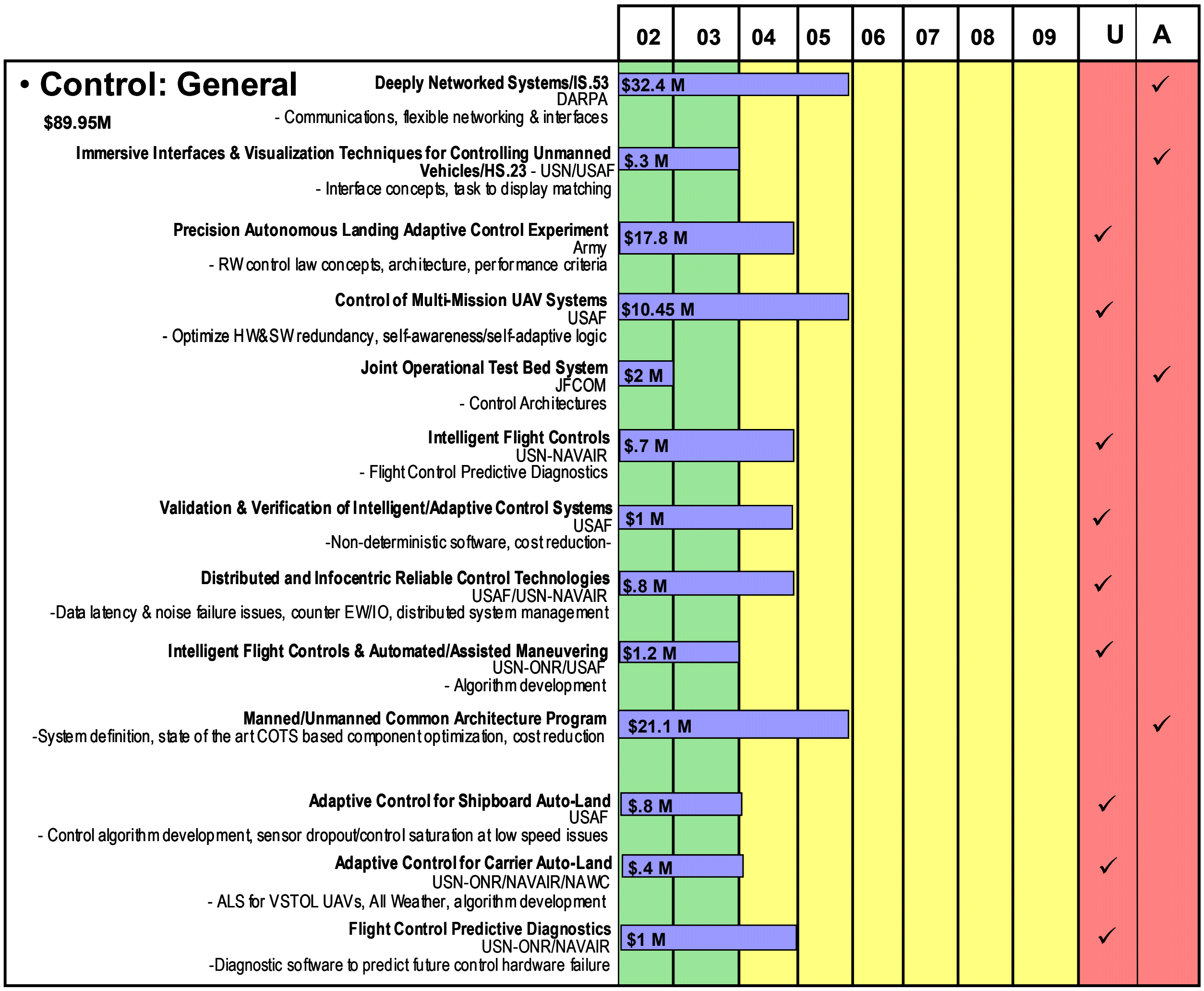


FIGURE D-15: CONTROL: GENERAL.

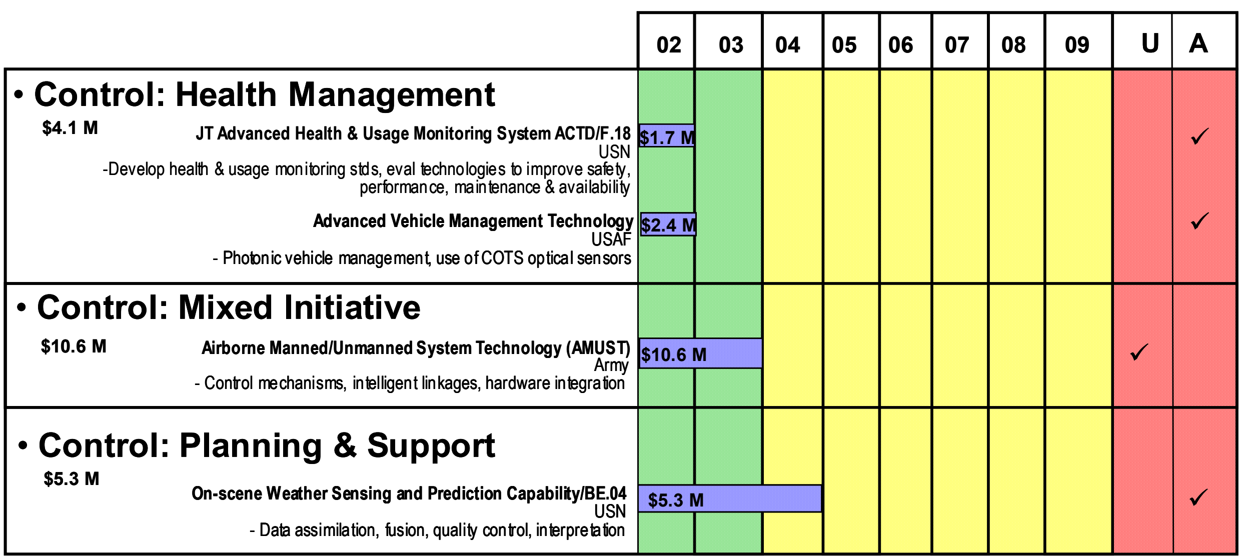


FIGURE D-16: CONTROL: HEALTH MANAGEMENT/MIXED INITIATIVE/PLANNING & SUPPORT.

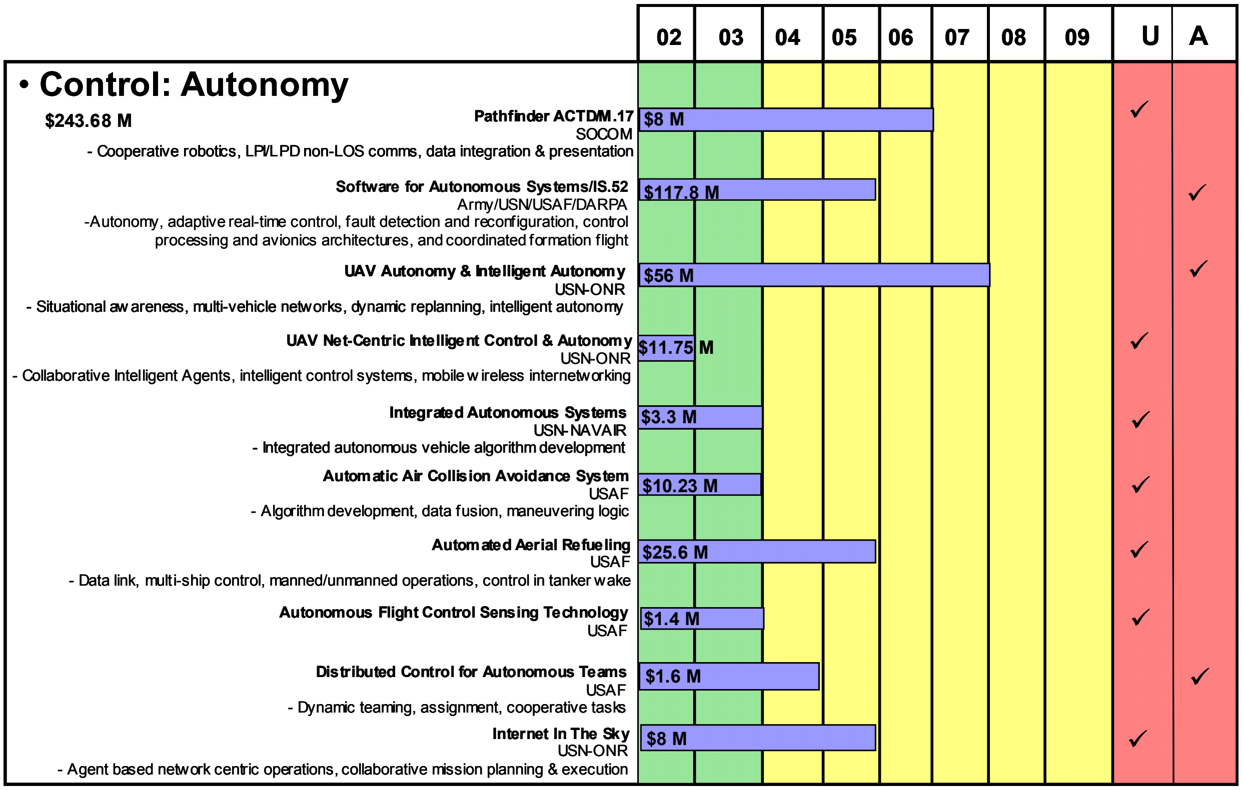


FIGURE D-17: CONTROL: AUTONOMY.

Appendix E: Small UAVs

Introduction

The subject of "small" UAVs is one guaranteed to raise controversy in any discussion of UAVs. Though there will likely be as many opinions as participants in the discussion, the central points of contention will likely revolve around the issues of whether small UAVs should be treated as a separate class, and "how small is small", i.e. what exactly constitutes a "small" UAV ad where is the dividing line between this class and the next one up? Both questions relate to the fundamental issue of how UAV's are differentiated by class - by mission, size, support requirements, etc.? As with the world of manned aircraft, class differentiation in UAVs has historically been made along mission lines rather than platform size; fighters, bombers, reconnaissance, etc for manned aircraft, and long range/endurance, short range, close range, etc. for UAVs. The question of size as a class arose only recently with the advances in technology that allowed small aircraft to accomplish militarily relevant missions. For the purpose of this document, a small UAV is defined as follows:[7]

a. For UAVs designed to be employed by themselves - any UAV system where all system components (i.e. – air vehicles, ground control/user interface element, and communication equipment) are fully transportable by foot-mobile troops
b. For UAVs designed to be employed from larger aircraft (manned or unmanned) – any UAV system where the air vehicle can be loaded on the larger aircraft without the use of mechanical loaders (i.e. – 2 man lift, etc)

Between 1996 and 2000, DARPA focused attention on this new area of UAV growth with its Micro Air Vehicle program. In this program, DARPA established what can be considered the present lower end of the UAV size spectrum by describing a micro air vehicle as one six inches or smaller - the first definition of a UAV class based solely on size.[8] Between the micro and what was commonly called the tactical class of UAVs there remained a large undefined, unclassified area. As the DARPA program began to demonstrate that very small vehicles were indeed capable of executing militarily relevant missions, less ambitious developmental efforts began to field candidate UAV systems defined by size that fell into this "no mans land" and the debate was on, using terms like small, squad, man portable, backpackable, etc in an attempt to put a label on their piece of "small". For good or ill, the size of the air vehicle had become an alternative standard to mission in defining the relevance of a UAV system.

The fundamental relevance of small UAVs – and the reason for their being addressed as a separate "class" of vehicle – *is*, indeed, a function of their size. However,

[7] This definition is not intended to preclude the individual services from developing a more nuanced definition that is more reflective of the limitations and demands of their operational environments.
[8] This decision on size was primarily a programmatic one based on the need to define the objective of the program with a goal that was suitably hard enough to justify DARPA involvement. Although it has become the de facto 'industry standard' to define micro, it is not doctrinally or technically based and is not immutable Rather, it has served to date as a convenient benchmark primarily because no other government agency has provided an alternative definition.

the relevance is not, as many have attempted to argue, that their small size imparts some unique function or mission relevance to them that is missing in larger vehicles. Additional confusion has been imparted by economics, since small UAVs have tended to be technologically unsophisticated and hence cheap in comparison with their larger brothers (Pioneer, Hunter, Predator, etc). This relative low cost has resulted in their attractiveness as expendable systems, to the degree that many portray and perceive this feature as a unique capability of this "class" of UAVs. The relevance of small UAVs is routed in neither unique missions nor economy, but rather in the operational impact of simple logistics. By virtue of their size, "small" UAVs offer flexibility in operational employment that larger, more logistically complex and intense UAVs do not.

In the case of ground force employment, this smaller size imparts a concomitant mobility that allows small UAVs to provide an immediate tactical responsiveness to the supported unit that larger UAVs can not because of their more extensive logistical support requirements. This is because prior to the paradigm shift that "small" UAVs enable, it was a given that aircraft - whether manned or unmanned – were relatively large. The tactical impact of this was that aviation support functions had to be based in the operational depth of the battle space, imparting a time distance factor to tactical requests for aviation support. Small UAVs eliminate that time delay in ground combat. They provide the commander with the ability to gather real-time information of the battlefield immediately to his front – over the next hill or behind the next building; they have the ability to provide the commander with combat information, immediately, as opposed to combat intelligence at some point in the future. Unlike their larger, more costly, more complex and logistically intense brothers, manned and unmanned, small UAVs currently under development will be able to be deployed literally at the front lines, at the company or platoon level, and will provide the commander with what amounts to a pair of flying binoculars.

Other such missions not directly related to ground combatant forces would include local security for airfields and port complexes; perimeter security for single naval vessels in foreign ports, support to Special Forces operations, and local security for national building operations. The list is as extensive as the need for local security. This imparts a second defining characteristic to this "class" of UAV – the fact that it is providing raw data directly to the commander in the same manner that other local security assets (observation posts, scouts, patrols, etc) would. The systems are not designed to primarily be Reconnaissance & Surveillance assets feeding a higher echelon. In an operational sense, they are direct support assets for the unit employing them.

In the case of air and naval force employment, their smaller size enables them to be employed as force multipliers with larger, more capable systems – such as the use of Predator A-employed FINDER UAVs in the Counter Proliferation II ACTD, the addition of UAVs to AC-130 gunships, the employment of UAVs such as LEWK or 2.75 Inch rocket from aircraft, the capabilities imparted by UAVs such as WASP employed from a surface combatant's naval cannon, or those deployed from submarines. In addition to these existing systems, this method of symbiotic employment lends itself to concepts such as a system of ground sensors based on small UAVs that would be delivered to the battlefield by a larger, loitering UAV – possibly with stealth characteristics or a high altitude airship. These sensors would be capable of self employment as well as autonomous adjustment based on operational requirements. In all these scenarios –

existent and conceptual – the use of small UAVs in conjunction with larger vehicles reinforces the strengths of both systems and yields a true force multiplier effect. Although the principal focus of "small" UAV systems to date has been the ground force, small unit support mission, it is likely that the real applicability of these systems in the future will be not as independent systems but as adjuncts to other, more capable UAVs.

"Small" UAVs are attempting to answer long standing and well documented service requirements, at least for the ground forces. After the Gulf War, for example, the Marine Corps codified its requirement to see "over the hill" in the Close Range UAV ORD based on Gulf War lessons learned. To date, however, little effort and money has been expended in comparison to larger UAV programs such as Global Hawk and Predator, however recent service emphasis in this area is seen in such programs as the Marine Corps Warfighting Lab's Dragon Eye and Dragon Warrior programs, the Navy XUAV ACTD, and the DARPA/Army MAV ACTD and OAV program. Although a significant dearth of capability remains in this area (see Figure E-1), given the growth potential and current commercial effort expended in the last few years in this sector of the UAV market (encouraged by DoD interest as evidenced by current procurement and developmental platforms listed), it is expected that significant numbers of "small" UAV systems will be developed and fielded in the period covered by this roadmap. The lack of articulated requirements by naval and air forces should not be interpreted as a applicability or need, but rather the reality that requirements generation cycle has not yet caught up with this transformational capabilities imparted by this rapidly evolving technology.

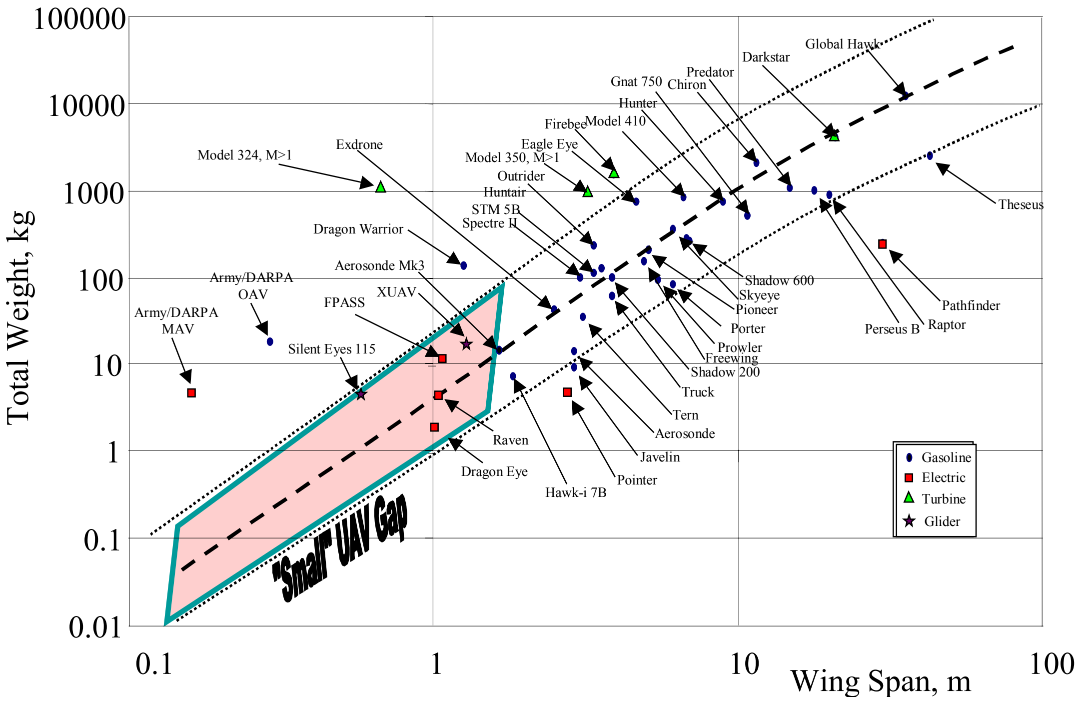


FIGURE E-1: UAV WINGSPAN VS. WEIGHT.

In this respect, "small" UAVs represent a class of systems with much greater opportunity for competition due to their simplicity and use of COTS technology. This implies at least low cost, large numbers and probably a wide range of capabilities. These attributes also imply a rapid evolution, or spiral development process as capabilities and missions expand – somewhat similar to the evolution of personal computing devices. These factors present both great opportunities and significant challenges to the management of the "small" UAVs within DoD.

Missions

Currently, there are no missions unique to small UAVs, however technology limitations do impact the payloads that they can realistically carry and hence impose defacto mission limitations on these systems. Current UAV mission capabilities are a function of multiple factors, including payload, range, volume of data collected, processing requirements, etc. As air vehicle size is decreased to allow employment by logistically austere organizations SWaP thresholds are crossed which eliminate the possibility or employing certain sensor payloads and hence potential missions. For example, at the current and foreseeable state of the art, data and power intensive payloads such as conventional SAR and HSI are not supportable in small UAVs. Conversely, there are a number of mission that small UAVs are particularly well suited for. Further, these missions require basic, existing payloads. The most prominent and pressing of these missions is the critical need for force protection, especially small unit situational awareness: local security, reconnaissance and surveillance and target acquisition – the need to see literally over the next hill, across the clearing and behind the building to find enemy soldiers – missions current tactical UAV systems can not conduct in a timely manner. Other potential missions could include biological and chemical agent detection and communications relay, critical resupply, precise bomb damage assessment, or even the possibility of future small UAVs having a lethal capability.

Although technology limits current missions, it conversely appears poised to reverse this situation in the near future. Current technology initiatives – if they realize their potential - have the potential to impart a unique mission niche to this class of UAVs. R&D in small VTOL UAVs has been a significant outgrowth of the DARPA MAV program. Commercial and government efforts, most notably the current DARPA/Army OAV program and MAV ACTD, are working to develop a class of vehicles capable of autonomous flight, precision landing and independent re-launch. While current VTOL UAV systems have this ability, when it is incorporated into a small air vehicle the operational significance it imparts increases markedly. Small size reduces the likelihood of detection; hence a class of small VTOL UAVs would be capable of missions such as precision delivery of unattended ground sensors (UGS) - or other sensors – perhaps even function as re-locatable UGS themselves. In this latter category, a small UAV with precision landing capabilities enables a "perch & stare" mission that allows for long-term surveillance of a high interest area for periods up to weeks at a time. In short, if any area of UAV technology can encourage "out of the box" thinking, it is the developmental technology associated with small UAVs.

Critical Technology Areas for Direct Support UAV Evolution

The DARPA MAV program did good work in establishing the technical foundations for work with very small air vehicles by identifying and pursuing critical technology areas and unique problems associated with very small vehicle flight.

Although all small UAVs will not operate in this extreme of the flight envelope, there are a number of critical technologies that are common to Small UAVs given the smaller physical size of the air vehicles. Among these are continuing advances in miniaturization – especially of processors – which will play a key role in advances in small UAV capability. The operational and tactical relevance imparted by the smaller air vehicle size of small UAVs demands that design size and weight be limited. Rapidly emerging electronic miniaturization technology will facilitate the development of a lightweight air vehicle and control system that will ultimately be transported by a single soldier.

Command & Control. To achieve their full operational potential, small UAVs must be built with the expectation that they will be employed by non-specialist operators whose primary job is something other than operating the UAV. This demands both a highly simple and intuitive control interface (a good GUI-Graphic User Interface) and the capability for autonomous vehicle operation by one or more vehicles being controlled by a single operator. At the same time, operational responsibility for tasks must migrate from the ground station to the air vehicles, the air vehicles gaining greater autonomy and authority, the humans moving from operators to supervisors, increasing their span of control while decreasing the manpower requirements to operate the UAVs. To make this so, critical technologies need working, both in the air vehicle and command elements of the UAV systems.

<u>Air Vehicle Element.</u> Today small UAVs are mostly remotely piloted, but in recent years autonomy has been introduced to reduce required operator training, as well as accidents. This needs to continue to free up the human for other duties. Currently, small UAVs demonstrate an autonomous control level (ACL) level of 2. ACLs of 4 to 6 would allow the human operator(s) to accomplish other duties as well as UAV operation. Control technology areas which need continued support and growth to enable the full potential of small UAVs are:

- Onboard Intelligence – The more intelligence we can 'pack" into the UAV, the more complicated task we can assign it to, and the less oversight required by human operators. We must continue efforts to increase intelligence of these vehicles, which means the services must not only look at their intelligent systems investment portfolios, but they must also assess the best way to package this intelligence into small packages.
- Teaming/Swarming – Getting groups of small UAVs to team (or swarm) in order to accomplish an objective will require significant investments in distributed control technologies which allow swarming, but do not require huge computational overhead or large communications bandwidth. Technology areas, such as bio-inspired control, offer paths to do such distributed control, but are now just coming out of the 6.1 world into 6.2. More work needs to be completed toward maturing these technologies via demos in the near term to show utility to the warfighter. Again, this takes the vehicles from an ACL of 2 to 6.
- Health Management – small UAVs are looked at as expendable; however, they must still be able to fulfill a mission. Health management technologies need to be integrated to ensure that they are ready to go for the next mission, as well as to let the operator know that they will not be able to complete the current mission so that

other assets can be tasked. These technologies are available; they just need to be modified to operate in the small UAV system environment.

- Collision avoidance – Small UAVs will either be launched from or working in close proximity to manned and other unmanned systems. These small UAVs, while not extremely massive, contain enough mass, fuel, and rotating machinery to damage machines and harm humans. Methods in keeping with the overall affordability of the vehicles must be developed. Collision avoidance technology currently in development for large UAVs (such as AFRL's Auto-Aircraft Collision Avoidance System (ACAS) system) is not well suited for direct application to small UAVs. Research is required into sensors and algorithms to ensure safe small UAV operation in a combined arms task force.
- Affordability – This cannot be ignored for as technology might determine whether a system is practical or not, the affordability determines whether it is actually purchased. Small UAVs are being designed to be put in harms way – we will loose them. We must ensure that keeping them in the supply chain will not harm pocketbooks. We must reduce system complexity and software lines of code where possible. Again, bio-inspired control techniques offer reduced software costs. More research into their application needs to be accomplished to bring them through 6.3 to enter product spiral development.
- Sensing - Sensing isn't only required for ISR and ATR applications, the autonomous small UAV must be able to "see" where it's going. The small UAV will have to develop, and maintain, some semblance of situational awareness, and this will come from on-board sensing. These must be small, and they must be affordable. Currently situational awareness sensors are being developed for small UAVs; continued emphasis on their development should insure their availability for small UAV use.

<u>Command Element.</u> The ground element is the portal that the human has to the UAV. As the UAV is given more autonomy, the role of the human using it will evolve from pilot, to operator, to supervisor, with the level of interaction with the UAV(s) moving to higher levels. Some of the critical technologies include:

- Lightweight – whether installed in an aircraft, truck, ship, or slung on a soldier's back, the weight and size of the command element must be minimized. Current efforts are looking at using PDA sized command consoles should continue for the man-portable systems.
- Assured Communication – Small UAVs are only as good as the links that bind them to the human operators. Current man-portable links have limited range. We also have to worry about information assuredness. Standardization Agreements, such as NATO Standardization Agreement (STANAG) 4586, make it easier for interoperability, but they also make available a portal from which enemies could hack into our systems. UAVs are info centric, and we must ensure we provide protection from cyber warfare.
- Displays – as the human interfaces with the UAVs at higher levels, the human must trust the UAV to do more. To develop and keep that trust the human must be able to delve intent of the UAV. Displays that show intent, as well as the algorithms

which develop the intent, must be matured. Currently ground-breaking work in this area is being undertaken by Air Force UCAV; work needs to be accomplished to migrate this technology to smaller and less expensive systems. These displays must also show the operator what is going on at a glance, and must fit into the lightweight system requirements as outlined above.

- Voice Control – One area that might not be receiving the attention it deserves is the capability to voice command the UAVs. Voice recognition technology has been around for years, but only recently has algorithm and hardware advances made it practical for small and critical applications. DoD S&T organizations continue to research and develop this technology. Now is the time to harvest that research and ally it to reducing the complexity of command and control interfaces to small UAVs.

Propulsion. Small UAVs, especially at the individual, squad company scale, have a different set of requirements than larger vehicles because propulsion systems don't scale uniformly (i.e. as size changes the percent of the total weight of various components changes.) Smaller engines have higher rpm but the weight of gears to reduce the rpm of the fan/propeller is more of a burden on the smaller systems (transmissions don't scale down well.) For example a large (20,000 pounds of thrust) gas turbine has the low turbine running at a max speed of less than 10,000 rpm while a small (10 pound) gas turbine runs at 150,000 rpm and a micro (1 pound thrust) gas turbine runs at over 500,000 rpm. While the small propellers can run at higher rpm, due to smaller diameter the tip speed will produce additional noise if it is to high. Developing small engines to run on JP-8 is another area of research. There are several activities that have shown promise in addressing this issue, including a DARPA program that is building a small engine that runs on pure JP-8, without additives.

Hovering. DARPA currently has two programs (OAV & MAV ACTD) are pursuing ducted fan air vehicles with the ability to hover and fly in forward flight efficiently. A goal of these programs is to field a vehicle with the ability to "Perch & Stare". Conceptually, this would enable the UAV to land in a place that it can observe the scene where enemy activity is a concern. When the SUAV observes movement it notifies the human by sending a picture of the object that has moved. This reduces the fuel required to operate and increases the time on station significantly and eliminates the users need to "watch" the video screen. The SUAV does not send pictures unless requested or movement is detected further reducing the power required.

Appendix F: Standards

Introduction

Interoperability among UAV systems is critical in order to reduce acquisition costs, share sensor data among disparate users, ease issues of operational and tactical control (OPCON and TACCON), allow common operational procedures and reduce training requirements. Interoperability, in this context, includes establishing appropriate technical architectures, interface standards and standard operational procedures. Hardware commonality, while desirable when practical so as to reduce acquisition and support costs, is not required to achieve interoperability under this definition. UAV interoperability requirements exist within the framework of existing manned aviation, ISR system, and Strike system interoperability architectures and are not unique requirements. The overarching goal intends that UAV systems contribute effective support to commanders through interoperability, not only with manned aviation, but with the entire spectrum of forces where they are operating. For near-term UAVs, the arena is predominately ISR with evolving capability in combat and combat support mission areas.

The UAV roadmap will, where practical, specify those specific standards which OSD expects to be implemented and which OSD will monitor during program and funding reviews.

The roadmap will discuss the preferred framework and methodology for establishment of interoperability within the UAV domain. Generically, this involves establishment of a UAV operational architecture, synchronization of applicable system architectures and refinement of the appropriate technical architecture. Historically, attempts at UAV interoperability originated primarily in the Intelligence, Surveillance and Reconnaissance domain through establishment of standards. Thus the elements of the technical architecture were developed in the absence of an operational architecture. The proposed methodologies for control of these architectures, once they are developed, will also be discussed.

The final objective of the roadmap will be to identify the "way ahead" for UAV interoperability. Development of the roadmap has led to identification of roadblocks or impediments to implementation of the current philosophy of UAV interoperability. Future actions will be recommended in order to address these impediments, allowing the continued evolution of interoperability among UAVs and improving the interoperability between UAVs and the broader Warfighter community.

Overview and Objectives of Current Standardization Efforts

This section of the UAV roadmap will cover current and emerging standardization efforts and will identify those portions of the Joint Technical Architecture (JTA) mandated for UAVs. Future efforts required to resolve contentious issues and to extend and improve interoperability through standardization will also be identified.

The DoD Acquisition Deskbook (http://web1.deskbook.osd.mil/default.asp) states that architecture views, as graphic representations of data, are very important to the C4I Support Plan review process. The Deskbook defines three types of Architecture Views – the Operational View (OV), the Systems View (SV), and the Technical View (TV). The systematic development of these architectures is essential to the development of interoperable C4ISR/DoD Architecture Framework-compliant systems. This is a process that shall be put into place for the UAV effort through development of UAV OV, SV, and TV.

DoD is developing a Joint Warfighter domain consisting of a Joint Operational Architecture (JOA), Joint Systems Architecture (JSA), and Joint Technical Architecture (JTA). The JTA is the only portion of the DoD joint architecture that is fully developed. The JTA is the DoD-level technical architecture and is mandated for all C4I applications including UAV. It provides the "building codes" (i.e., standards) for a seamless flow of information to support the Warfighter. The current JTA focuses on Information Technology (IT) (i.e., the transfer, processing, and protection of information). The JTA 4.0 also contains a Aviation Annex, Weapon System Annex, C4ISR Domain Annex and a Crypto logic Sub-domain Annex, both of which are applicable to UAV. If no overarching TV is developed for aircraft, it is envisioned that a UAV Technical View will be developed to augment the JTA information technology standards to meet the needs of the UAV community and to expand the scope beyond the information technology focus.

The top-level UAV functional architecture is divided into several key regimes. These include tasking, collection, processing, exploitation and dissemination. Standardization of the entire process is beyond the scope of the UAV roadmap. To achieve UAV interoperability, standardization is required in the regimes of situational awareness, control, tasking, collection, processing and dissemination. The portions of the cycle from control until the product is exploited or posted or the target is destroyed, are pertinent to the UAV roadmap in order to ensure platform, sensor and weapons interoperability while providing data to users in standard formats.

Situational awareness deals with basic UAV data to allow for an understanding of the location, type, and route of the UAV. This data is necessary for airspace integration in military or civil application. It is the basic data set virtually all UAVs should provide and will become another level in the defined levels of interoperability.

The intent of the standards section of the roadmap is to identify current and emerging standards that are the basis of UAV interoperability.

Joint Technical Architecture

Joint Technical Architecture (JTA) 3.1 and 4.0 provide flexibility for standards selection as they cover the full spectrum of interoperability throughout a broad range of applications.

At times, this will involve down selecting from several potentially applicable standards within the JTA. It may also involve supplementing the current JTA with additional interoperability guidance. The roadmap will identify, where practical, emerging standards that may be mandated in the future. The roadmap will also identify areas where standards development is required, but where the standards and systems maturity is not such that usage of those standards is anticipated within the short-term. Note that UAV interoperability must be achieved within the context DoD ISR and of manned aircraft, space, command and control, combat arms and other domains that interact with the UAV domain. UAV interoperability must be worked within the broader

DoD architecture in order to maximize the value of interoperability to DoD as a whole. *The clear intent is to develop only those standards, which do not currently exist or to modify existing standards where practical.*

NATO Standardization Agreements

Standardization Agreements (STANAGS) either contained in the JTA or to be placed in the JTA, are the preeminent interoperability standards. Within NATO, Air Group IV (AG IV) has developed the NATO ISR Interoperability Architecture (NIIA) (AEDP-2) that defines the technical view of architecture for national and NATO-owned ISR systems. (The systems view and operational view are being developed in coordination by operational elements of SHAPE.) This architecture is based on critical interfaces, thereby allowing each nation to develop systems that meet national needs, while still maintaining interoperability with systems of other nations. Most nations in NATO have adopted the NIIA for internal use to provide interoperability between the nation's systems (including joint operations between services). The key standardization agreements (STANAGs) are defined in Table 1, below.

TABLE F-1: APPLICABLE NATO STANAGS

STANAG 3377	Air Reconnaissance Intelligence Report Forms
STANAG 3809	Digital Terrain Elevation Data (DTED) Geographic Information Exchange Standard
STANAG 4250	NATO Reference Module for Open Systems Interconnection
STANAG 4545	NATO Secondary Imagery Format (NSIF)
STANAG 4559	NATO Standard Imagery Library Interface (NSILI)
STANAG 4575	NATO Advanced Data Storage Interface (NADSI)
STANAG 4586	Unmanned Control System (UCS) Architecture
STANAG 4607	NATO Ground Moving Target Indication (GMTI) Data Format
STANAG 4609	NATO Digital Motion Imagery Standard
STANAG 5500	NATO Message Text Formatting System (FORMETS) - ADatP-3
STANAG 7023	NATO Primary Imagery Format (NPIF)
STANAG 7024	Air Reconnaissance Tape Recorder Interface
STANAG 7074	Digital Geographic Information Exchange Standard (DIGEST Version 1.2a)
STANAG 7085	Interoperable Data Links for Imaging Systems

International Standardization Organization

The International Standardization Organization (ISO) has become the focus of commercial international standardization. Other organizations develop standards for specific technologies, but ISO has the broadest base of technical C4I standards. NATO is working with ISO to define profiles of some of the ISO standards to replace current STANAG requirements. With the profiles, the STANAG will reference the profile as the requirement.

Characterization of Standards

UAVs today are, for the most part, extensions of existing ISR sensors and platforms. As such, the ISR standards that are in place and being developed for the existing manned ISR systems apply to UAVs. These are covered within Data, Control, Interface, and Flight Operations Standards. The ISR interface standards address interfaces among the various horizontal and vertical architectures of ISR, and include interfaces that use both physical (e.g. wired, tape, etc.) and electromagnetic links. Note that the Joint Technical Architecture currently mandates, or will mandate in the next version, all the standards mentioned below.

Data Standards

Data standards are intended to ensure that data from on-board sensors and payloads can be processed and interpreted by any user. Some of the categories of data standards include still imagery, motion imagery, signals, radar complex or video phase history data, hyper spectral imagery data, acoustic, chemical detection, biological detection, and nuclear detection weapons data. As on-board processing continues to make advances, distinctions between data and product standards are beginning to blur. For the purposes of the UAV roadmap, data standards should be interpreted to include both raw data and product when the product is produced on-board the platform Interface Standards.

Control Standards

Control Standards deal with the control of UAV operations, including mission planning and sensor control. This regime includes appropriate standardization efforts for mission planning and air vehicle/sensor control. Procedural, doctrinal and other guidance is required for true interoperability as critical processes (such as mission planning) are otherwise not appropriate for inclusion in a technical architecture description. One of the key issues facing UAV interoperability and standardization is the degree to which the collection regime can be made common between differing types of UAVs, particularly as regards mission planning and system control functions. UAVs range in continuum from small UAVs intended for infantry squads to "see over the next hill" on to long-endurance theatre assets such as Global Hawk. A joint-service UAV interoperability working group has been established to define, to the maximum extent possible, critical interfaces for this broad range of UAVs with the intent of maximizing interoperability and standardization without unduly restricting small or, eventually, micro UAVs. This UAV Interoperability Integrated Product Team is co-led by U.S. Joint Forces Command and OASD(C3I).

Interface Standards

Interface Standards are intended to ensure that UAVs system elements can communicate. Physical interfaces provide the hardwired of mechanical connectivity for connections within the UAV or between ground elements, or alternate means to transfer data between the UAV and ground once the UAV is recovered. Examples of physical interfaces include the wideband tape and solid-state interfaces. The electromagnetic (communications) interfaces provide the connectivity for the UAV to receive aircraft and sensor control signals from authorized control stations, or to ensure that sensor data and aircraft status information from UAVs can be communicated to any user who requires the data. Examples of communications standards include CDL, SATCOM, Link 16 standards, and communication protocols such as TCP/IP.

Flight Operations Standards

Flight Operations Standards deal with ensuring that those processes related to operation of generic air vehicles (flight clearance, air traffic control, flight airworthiness, proficiency standards for operators and others) are consistent across the services. While not suitable for inclusion in a technical architecture, other methods and guidance must be put into place if interoperability is to be achieved. For integration of UAVs into the National Airspace structure, both civil and military, a standard set of data formats are required. Logistics interoperability while critical for long-term UAV cost reduction is currently outside the scope of this document and will be addressed in future editions.

Data Standards

Data standards provide the formatting for the sensor data and associated metadata and represent the higher levels of the interface protocol. The data formats generally are designed for specific types of data, such as fixed images, motion imagery, GMTI, etc.

NATO ISR Interoperability Architecture

The NATO ISR Interoperability Architecture includes a number of standards that are applicable to ISR systems. These standards cover the critical interfaces in the ISR data chain. It should be noted that while these standards are published by NATO, they were all initiated by U.S. activities, and in many cases are directly compatible with current U.S. standards.

STANAG 4545

A still imagery format has been in place since the late 1980s. The original format was developed for national imagery and was given the name: National Imagery Transmission Format (NITF). NITF 2.1 (MIL-STD 2500B Change Notice 2) is the current version of the standard and is equivalent to the NATO Secondary Imagery Format (NSIF - STANAG 4545). Over the years the format has been extended to airborne imagery. The standard addresses still imagery taken from EO/IR/Radar sensors.

NITF/NSIF also prescribes the compression standards for this imagery. JPEG is the primary compression used for imagery but there are other compression standards that may be used for specific and unique applications (e.g. lossless JPEG, vector quantization, etc.). NIMA has proposed the implementation of JPEG 2000 in a next version of the NITF/NSIF standard. JPEG 2000 should support new CONOPS for how NITF/NSIF is to be used.

NITF/NSIF also implements data extensions to support the transmission of GMTI data. This extension is unique but was developed to enhance interoperability through the use of an existing standard and applications. The extension is based on the GMTI STANAG 4607.

It should be noted that both NITF and NSIF are being migrated to a common international standard. ISO/IEC 12087-5, the Basic Image Interchange Format (BIIF) was created as a superset of NITF/NSIF. NATO has developed a profile of BIIF that matches the current requirements identified in NITF/NSIF and the profile has been ratified and published by ISO. The current plans are to migrate both the military standard and the NATO STANAG, by deactivating the military standard and having the STANAG point to the profile as the authoritative reference. This will eliminate the current parallel standards while maintaining military control over the requirements in the standard.

All UAV systems supporting still imagery (EO/IR/MSI/HSI/radar) will comply with the most recent version of NITF/NSIF.

STANAG 4559

NATO has implemented imagery library access by taking a subset of the U.S. Geospatial Image Access Specification (GIAS) developed by NIMA. This standard, defined in STANAG 4559 – the NATO Standard Image Library Interface (NSILI), provides the same image library access as GIAS, but does not include some of the enhanced features of GIAS such as image submission and geospatial data access. NATO is examining the requirements for including the wider capabilities of GIAS in STANAG 4559.

STANAG 4607

In 1998, ASD(C3I) directed the USAF to lead an effort to develop a common GMTI data format. The USAF expanded the scope of this effort to include NATO and Australia. As a result, NATO Air Group IV has initiated a task to develop STANAG 4607, NATO GMTI Data Format, based on the Air Force's original activity. This format is based on the NATO EX format, the Joint STARS GMTI data format, and the ASARS 2A GMTI format. The format is also capable of being encapsulated in STANAG 4545 (also applicable to NITF) and STANAG 7023, the NATO Primary Imagery Format.

It is anticipated that by October 2003 STANAG 4607 will be ratified by the nations of NATO and subsequently promulgated by NATO. The US at that point will need to implement 4607 to be interoperable with other NATO GMTI implementations. For example, the UK ASTOR system is implementing STANAG 4607. As UAVs become operational, they will need to implement this STANAG to insure interoperability not only with NATO, but also with US forces. STANAG 4607 will be a mandated standard in the next version of the JTA.

STANAG 4609

In 1998, the National Imagery and Mapping Agency (NIMA) chartered the Motion Imagery Standards Board (MISB) to develop a Motion Imagery Standards Profile (MISP). The current version is MISP 2.0a. This standard is completely based on commercial standards, specifically MPEG-2. Instead of having to depend on government-sponsored developments for motion imagery processing, this standard promotes the use of commercial applications and hardware. In addition, in 2001 NIMA also began to lead the STANAG process to develop a NATO digital motion imagery

STANAG. The MISP serves as the master baseline standards document. STANAG 4609 has been specifically based on MISP2.0a to facilitate NATO acceptance of motion imagery standards. STANAG 4609 will replace MISP 2.0a as the operative digital motion imagery standard for the US. Currently MISP2.0a mandates the migration and development of video systems to a fully digital format typically referred to as High Definition TV (HDTV). Today, no UAV motion video system supports the STANAG 4609 format.

STANAG 7023

STANAG 7023 is the NATO Primary Image Format. This format is intended for applications that require real-time recording or data link transmission of sensor data with little or no processing. STANAG 7023 was initiated by the US as the format for the ATARS program. As the ATARS program was redirected, the format was changed, and US interest in STANAG 7023 disappeared. However, many NATO nations (particularly the UK, France, Germany, and Denmark) have developed systems that implement the format. In order for US ground systems to be interoperable with the NATO systems, the US will have to implement the format for exploitation. In addition, it may be desirable to use this format in those applications where size, weight, and power (SWAP) constraints preclude on-board processing of sensor data into NITF/NSIF formatted files.

Signals Intelligence (SIGINT)

Many standards applicable to UAV SIGINT data are addressed in Section 4 of the Joint Airborne SIGINT Architecture (JASA) Version 2.0. Due to programmatic issues leading to cancellation of JSAF, the JASA is being reviewed for future applicability and necessary changes. However, NATO Air Group IV has initiated a study to examine the use of ELINT and ESM data within the community with an aim to standardize the data formats of both aspects of electromagnetic collection.

Measuring And Signature Intelligence (MASINT)

MASINT is predominantly a process, which uses a low-probability signal within a high noise environment to extract information not obtainable by other means. This process can be applied to data collected by sensors which are exclusively MASINT (e.g. nuclear materials detectors) or from sensors developed for other purposes (i.e., imagery, radar, weather, SIGINT sensors). In virtually every case, the requirements for data integrity and metadata capture are greater. MASINT does not have dedicated collection and transmission capabilities within the traditional warfighter ISR or C2 infrastructure, and must use existing assets and capabilities for mission accomplishment. To ensure that the MASINT data and products can be successfully incorporated within these existing systems, existing data formats are used where feasible. For example, the expansion of EO/IR systems into multi-band collectors begins to blur the line between IMINT and MASINT in this regime. The NITF2.1/NSIF standard has always been capable of handling the multispectral sources of imagery. NIMA expanded NITF to accommodate multispectral and hyperspectral sources with large numbers of bands and the unique metadata requirements, and now mandates MIL-STD-2500B (NITF 2.1)/STANAG 4545 (NSIF 1.0) support data extensions (SDE) for multispectral and hyperspectral sensors.

Only where no existing format can accommodate the MASINT needs will new formats and standards be developed.

Metadata

The metadata that accompanies the imagery produced by ISR sensors is critical to the use of the product. Current efforts to develop standards for common metadata for ISR applications have been initiated within ISO. ISO DIS 19115-2 is being developed to provide a common metadata set for all ISR applications. Once completed, this standard will be mandated for use in DoD (and NATO) ISR systems. ISO is also developing the tools to provide XML-based metadata sets based on 19115-2 and this will be included in ISO/IEC DIS 19139-2. Developers are encouraged to refer to the draft standards for interim guidance rather than creating new metadata dictionaries. Interoperability between UAV systems, and between UAVs and other platform types will only be accomplished when all platforms share the same common format for metadata. It is expected that this will most likely be an XML-based metadata format.

Still Imagery

As noted above, the image format (STANAG 4545) provides the basic metadata to identify the image, but relies on extensions to provide georeferencing and technical details of the imagery. These extensions are critical to the proper use of the data by common exploitation tools. The principle extensions are contained in two sets identified in the Compendium of Controlled Extensions (STDI-0002). The first set, the GEOSDEs, provides detailed georeferencing information, and the second set, the airborne SDEs, provides the details of the collection and sensor parameters. These extensions are mandated for all UAV systems using still imagery sensors (EO/IR/MSI/HIS/radar) in order to achieve interoperability within the user community.

Motion Imagery

The requirement for full metadata supporting video is an emerging standard in development. The current metadata standard is the Key Length Value (KLV) standard detailed in Society of Motion Picture and Television Engineers document SMPTE 336M-2001, although research is underway to harmonize this with the metadata of the other sources of imagery.

MASINT

A critical element of MASINT is metadata. This refers to both metadata related to the data collection (e.g. weather conditions in the sensor field of regard) and to metadata concerning the sensor itself (temperature of the focal plane array in an IR system at the time the data was collected). Both types of metadata must be preserved and made available down-stream for the MASINT process to be successful. The development of standards for data, products, and metadata has been initiated by the CMO in conjunction with NIMA and other agencies, to ensure that the data integrity remains high, and the metadata required is identified and preserved. The JTA will evolve to include any new standards that are developed for MASINT.

Other Data Types

Adoption of the following three STANAGS, 3809, 550, and 7074, is mandatory for the success of UAV system interoperability and will be required in UAV systems where applicable. Adoption of the last two, STANAGs 3377 and 4250, is not mandatory but is encouraged.

STANAG 3809

STANAG 3809 provides the format for digital terrain elevation data (DTED) geographic information data exchange. This data is used for a number of different applications, including mission planning, mapping, ISR sensor visibility calculations, etc. All exchange of DTED data should be accomplished using STANAG 3809.

STANAG 5500

The NATO Message Text Formatting System (ADatP-3) provides the format for digital messages usable by ADP systems. A number of different message types are defined and encoded so that recipient systems can interpret each.

STANAG 7074

Digital Geographic Information Exchange Standard (DIGEST Version 1.2a) is the standard used to define all types of geographic data. This format is compatible with STANAG 4545, and some of the extensions defined in STANAG 7074 are used by STANAG 4545 to incorporate precision geographic information.

To enhance UAV interoperability and flexibility, it is recommended that the UAV Control System (UCS) should also be compliant with the following STANAGs:

STANAG 3377

Air Reconnaissance Intelligence Report Forms are included in STANAG 3377. These forms are used to report the results of imagery interpretation and include forms for rapid exploitation, detailed exploitation, and radar analysis. This standard provides both the free text and automated data processing forms of each of the forms.

STANAG 4250

The NATO Reference Module for Open Systems Interconnection is defined in STANAG 4250. This model is based on the ISO Open Systems Interconnect model, using seven layers to define the elements of the interface protocol. The lowest level is the physical layer, defining the physical and electrical parameters of the actual connection. The highest layer defines the support for the applications that use the data being transported across the interface.

Other Data Formats

Digital Feature Analysis Data (DFAD) is data that describes the surface features of the terrain. This allows a more complete analysis of terrain than is available through the use of elevation data alone. Feature analysis includes both the natural surface and man-made features. The World Geodetic System - 84 (WGS-84), contained in MIL-STD-2401, provides the reference ellipsoid for use in elevation calculations. In some cases, the ellipsoid is modified with variations of the gravitational vector through the designation of a reference geoid as well. In either case, developers should take care to ensure that metadata specifications are properly followed with respect to using the proper elevation reference.

Interface Standards

Interface standards include both those required for physical connections between the elements of the UAV ISR system, and the electromagnetic connectivity for data links. It also includes the file transfer protocols necessary for the data exchange.

Physical Media

The physical media includes the use of digital tape and advanced media such as solid-state memories and advanced disk arrays.

STANAG 7024

Tape media has been standardized for some time. Initially, the Common Imagery Ground/Surface System (CIG/SS) Acquisition Standards Handbook specified either the ANSI ID-1 or Ampex Digital Cassette Recording System Incremental (DCRSI) tape standard for ground segments. These two standards still apply for the current Distributed Common Ground/Surface System (DCGS) and ISR architectures. They are further instantiated through STANAG 7024, NATO Tape Media Standard.

One problem with tape media is the availability of a “golden tape” to calibrate tape recorders and players. Without the ability to calibrate this equipment, tape media cannot be exchanged between airborne and ground segments much less between ground segments. Despite this difficulty of calibration, tape generally still offers the best economical means of archiving large amounts of data.

JTA mandates the use of these specific tape media standards for use within the ISR community.

STANAG 4575

Solid state recording capabilities cover everything from rotating disk (the standard hard drive in a computer) to Personal Computer Memory Card International Association (PCMCIA) cards to custom-design solid-state memory systems. Custom memory systems or PCMCIA cards provide excellent means to safely record and play back stored data. In addition the data stored in these devices can be randomly accessed greatly enhancing access performance. The technology behind solid-state storage has made significant progress over the past five years. In concert with the advance of technology, NATO and the US determined that a new standard interface to this solid-state media was required. The interface is embodied in STANAG 4575, NATO Advanced Data Storage Interface. This particular standard has been ratified by the US and is soon to be ratified by other NATO nations. Once ratification is complete, promulgation is expected by July 2003 with several implementations both here and in Europe. The JTA had identified

STANAG 4575 as an emerging standard but will change it to a mandatory standard, once it is promulgated as well as mandating its use for solid-state storage. This standard will be implemented for UAVs once ratified by NATO.

Communications

For Data Interchange services, at a minimum, the following National Communications Support Plan (NCSP) mandated standards should be implemented to achieve interoperability.

Common Data Link/STANAG 7085

The Common Data Link (CDL) has been the DoD standard for high-bandwidth, data link for intelligence dissemination since 1991. Additionally, Assistant Secretary of Defense (C3I) guidance mandates the use of CDL in all Service and Agency imagery and signals intelligence collection systems and requires ISR wideband SATCOM systems to be interoperable with CDL. The CDL waveform is documented in the CDL Waveform Standard and is managed by the Services with the USAF as the Executive Service Agent. The CDL Waveform Standard is reviewed and updated regularly as new, enabling technologies emerge to better meet warfighter needs. The current revision of the specification is "Revision F".

CDL will have an expanding role as the intelligence community and the entire DOD migrate toward network-centric warfighting capabilities. Although CDL has been used traditionally as a point-to-point ISR data link, the CDL Waveform Standard Revision F, along with future revisions, will include the necessary networking and interface standards to better assure end-to-end interoperability. Improved ISR end-to-end interoperability facilitates integration across all ISR assets supporting the warfighter.

In parallel, the US has cooperated with NATO to develop STANAG 7085 which embodies the CDL specification. Additionally, it should be noted that STANAG 7085/CDL is a key component of interoperability for CIGSS/DCGS.

While the CDL specification and STANAG 7085 define the basic requirements for interoperability, the numerous options available within the standard allow for non-interoperable implementations that are all compliant. A set of profiles is being developed within the NATO community to provide more specific guidance for users of CDL systems. Developers will adopt one of the profiles whenever possible to minimize the proliferation of compliant, but non-interoperable data link systems.

Any UAV system supporting data rates over 10Mb/s will implement and support CDL version F. This includes the current UAV systems: Shadow 200, Pioneer Improvement Program, Predator, Predator B, and Global Hawk.

Link 16

Link 16 is an encrypted, jam-resistant, nodeless tactical digital data link network established by Joint Tactical Information Distribution System (JTIDS)-compatible communication terminals that transmit and receive data messages in the Tactical Data Information Link (TADIL) J message catalog. Link 16 can provide a range of combat information in near-real time to U.S. and NATO allies' combat aircraft and C2 centers. The TADIL J messages and protocols are defined in STANAG 5516, while the communication element is defined in STANAG 4175. Operating procedures are defined in Allied Data Publication-16 (ADatP-16) or alternatively in the Joint Multi-TADIL Operating Procedures (JMTOP) (Chairman Joint Chiefs of Staff Manual CJCSM 6120.01.

Military Satellite Communications

Military Satellite Communications (MILSATCOM) systems include those systems owned or leased and operated by DoD and those commercial satellite communications (SATCOM) services used by DoD. The basic elements of satellite communications are a space segment, a control segment, and a terminal segment (air, ship, ground, etc.). An implementation of a typical satellite link will require the use of satellite terminals, a user communications extension, and military or commercial satellite resources.

For 5-kHz or 25-kHz single-channel access service supporting the transmission of either voice or data: MIL-STD-188-181B, Interoperability Standard for Single Access 5-kHz and 25-kHz UHF Satellite Communications Channels, 20 March 1999.

For 5-kHz Demand Assigned Multiple Access (DAMA) service, supporting the transmission of data at 75 to 2400 bps and digitized voice at 2400 bps: MIL-STD-188-182A, Interoperability Standard for 5-kHz UHF DAMA Terminal Waveform, 31 March 1997, with Notice of Change 1, 9 September 1998; and Notice of Change 2, 22 January 1999.

For 25-kHz Time Division Multiple Access (TDMA)/DAMA service, supporting the transmission of voice at 2,400, 4,800, or 16,000 bps and data at rates of 75 to 16,000 bps: MIL-STD-188-183A, Interoperability Standard for 25-kHz TDMA/DAMA Terminal Waveform, 20 March 1998, with Notice of Change 1, 9 September 1998.

For data controllers operating over single-access 5-kHz and 25-kHz UHF SATCOM channels: MIL-STD-188-184, Interoperability and Performance Standard for the Data Control Waveform, 20 August 1993, with Notice of Change 1, 9 September 1998. This standard describes a robust link protocol that can transfer error-free data efficiently and effectively over channels that have high error rates.

For MILSATCOM equipment that control access to DAMA UHF 5-kHz and 25-kHz MILSATCOM channels: MIL-STD-188-185, DoD Interface Standard, Interoperability of UHF MILSATCOM DAMA Control System, 29 May 1996, with Notice of Change 1, 1 December 1997; and Notice of Change 2, 9 September 1998.

File Transfer Protocols

Numerous file transfer protocols have been developed in the commercial world. Some are applicable to ISR systems and are defined below.

Transport Control Protocol

The Transport Control Protocol (TCP) [RFC 761] provides a connection oriented reliable byte stream service. TCP is a bi-directional protocol, which has no concept of messages. Any framing has to be added at the application level. TCP contains an acknowledgement scheme which makes it reliable (bytes are delivered correctly and in order) and which implements flow control.

The use of a single end-to-end network and transport communications protocol allows an entire system to be managed and administered as if it were a single entity, even if it is sub-divided into individual communities for local management and administration.

Internet Protocol

The Internet Protocol (IP) generally used in the NCSP is IPv4 (RFC 791, 792, 919,922, 1112)/ IPv6 (RFC 2460-4, 2375, 2236). The UAV architecture will adhere to the IP version selected by the wider defense community within which they are integrated. In the near-term, systems will need to support the current version of IP [IPv4, RFC 791]. In the longer term, as digitization progresses, it is possible that the new version of IP [IPv6, RFC 1883] will be adopted by the military to overcome perceived weaknesses in IPv4. IPv6 increases the available address space, reorganizes the protocol headers and improves support for security, throughput, latency, error rate and cost.

File Transfer Protocol

File Transfer Protocol (FTP) shall be used to transfer processed information. It can be used in support of HTTP to transfer files, but needs additional support for providing an index to the information stored on the file server. Once the file has been transferred to the C4I system it is then the responsibility of the C4I to provide applications to process the file.

Network Time Protocol

Network Time Protocol v3 (NTP), April 9, 1992, NTP (RFC-1305) provides the mechanisms to synchronize time and coordinate time distribution in large, diverse Internets. It uses a returnable-time design in which a distributed subnet of timeservers operating in a self-organizing, hierarchical-master-slave configuration synchronizes local clocks within the subnet and to national time standards via wire or radio. The servers can also redistribute reference time via local routing algorithms.

World Wide Web Standards

Hypertext Transfer Protocol (HTTP) shall be the main protocol used for web browsing. Web browsing provides a common and powerful mechanism for sharing information. HTTP and applications associated with the use of HTTP are used to index, access and transfer processed information. The ability to search the web server can be provided using COTS applications. A C4I user needs a Web browser (e.g., Netscape or Internet Explorer), the Uniform Resource Locator (URL) of the page and communications connectivity to access the information.

Control Standards

Multiple levels of interoperability are feasible among different UAV systems. Improved operational flexibility can be achieved if the UAV systems support appropriate levels of UAV system interoperability defined in the draft STANAG 4586

Level 1: Indirect receipt of secondary imagery and/or data. (provided by other standards in the NIIA - STANAG 4586 not required)

***Level 2**:* Direct receipt of payload data by a ground station other than the primary UAV Control System (UCS); where "direct" covers reception of the UAV payload data by the ground station when it has direct line-of-sight with the UAV or a relay device which has direct line-of-sight with the UAV. (provided by other standards in the NIIA - STANAG 4586 not required)

***Level 3**:* Level 2 interoperability and control of the UAV payload by a second UCS (handover of sensor control as defined in STANAG 4586).

***Level 4**:* Level 3 interoperability and UAV flight control by a second UCS (handover of air vehicle control as defined in STANAG 4586).

***Level 5**:* Level 4 interoperability and the ability of an alternate UCS to launch and recover the UAV (handover of tactical control of UAV as defined in STANAG 4586).

The interoperability levels defined above can be achieved through the standardization of interfaces between the UAV airborne elements and the UAV Control System (UCS), between the air vehicle elements and external C4I elements, and between the UCS and external C4I Systems. In order to achieve interoperability, the UCS Architecture and interfaces must support the appropriate communication protocols and message formats for legacy as well as new UAV systems. Level 2 and above (2+) of interoperability requires the use of a Ground Data Terminal (GDT) that is interoperable with the Air Data Terminal (ADT), as defined in CDL/STANAG 7085 (e.g., connectivity between the GDT and ADT is prerequisite for level 2+ interoperability). At all levels, the data formats and data transfer protocols must also comply with the NIIA standards. For level 1 or level 2, the NIIA standards for data format and data transfer provide the required interface requirements. For levels 3 and above, STANAG 4586 provides the sensor and airborne platform control functionality for the higher levels.

The UAV interoperability working group is addressing UAV control through the development of a standards-based approach that will likely result in changes to the draft STANAG 4586. The interoperability working group is focusing near term efforts on development of a situational awareness interface providing critical UAV platform data (vehicle ID, location, speed, altitude, route, etc). This development standard will be required on virtually all UAVs, both new acquisitions and most legacy systems, and will require updating as UAVs become more autonomous.

There are already a number of existing or emerging STANAGs that are applicable to UAV systems. They provide standards for interoperable data link (STANAG 7085), digital sensor data between the payload and the AV element of the data link (STANAG 7023, 4545), and for on board recording device(s) (STANAG 7024, 4575). Additionally, the draft STANAG 4586, Unmanned Control System (UCS), describes interfaces applicable to ground control stations and air vehicles, to include air vehicle control. Although somewhat limited as to broad mission area application, this draft STANAG contains an interface description, the Data Link Interface (DLI), which provides an excellent starting point for the development of a robust air vehicle interface, to include vehicle control functions.

Thus, the approach to achieving the desired level of UAV interoperability is based on compliance with existing standards or establishing new standards for a number of UAV functions.

- A data link system(s) that provides connectivity and interoperability between the UCS and the AV(s). The data link system(s) must accommodate legacy as well as future systems. STANAG 7085, Interoperable Data Links for Imaging Systems, specifies a data link system that would provide the required connectivity and interoperability.
- Format for payload/sensor data for transmission to the UCS via the data link and/or for recording on the on-board recording device. STANAG 7023, NATO Primary Image Format Standard, with addition for non-imagery sensors, (e.g., Electronic Support Measures (ESM)), and STANAG 4545, NATO Secondary Imagery Format, are the required data formats for imagery. If GMTI data is to be used, STANAG 4607 defines the required format, and STANAG 4609 defines the format for digital motion imagery.
- Recording device for on board recording of sensor data, if required, STANAG 7024, Imagery Air Reconnaissance Tape Recorder Standard, and STANAG 4575, NATO Advanced Data Storage Interface, specify standard recording devices and interface respectively.
- An example of a standard required, but not yet fully developed, is a standard describing the interfaces and messages necessary to control an air vehicle. A starting point for this activity is the Data Link Interface (DLI) segment of the draft STANAG 4586, Unmanned Control System (UCS).

Flight Operations Standards

Flight operations standards are those standards required to operate the UAV in the real world airspace occupied by both manned and unmanned aircraft. These include the standards for flight clearance, operations with Air Traffic Control, aircraft certification standards, aircrew training requirements, etc. While many of these standards will parallel those used by manned aircraft, they must all be tailored to the specific environment of the unmanned platform. The details of these standards are [TBD].

Operational Architecture (OA) and Systems Architecture (SA).

In an ideal world, Operational and Systems Architectures would be defined for UAVs. This would allow development of a consistent Technical Architecture (TA), which would establish the interoperability requirements for UAVs. The OA and SA would undergo periodic review and update as new UAVs were developed, new capabilities introduced and new interoperability requirements were generated. This in turn would lead to appropriate changes to the TA, while generating acquisition requirements for evolving interoperability requirements. In all likelihood, each different class of UAVs (large, medium, and small) could be accommodated in a common interoperability framework, although interoperability requirements could vary to accommodate the different operational thrusts of each UAV class and to recognize the accompanying design constraints. Thus each class of UAV would become totally interoperable, while maintaining some appropriate degree of interoperability between UAV classes.

Process for selecting standards.

UAV standards are usually selected for implementation by a development program from those in the JTA. New standards are added to the JTA periodically and existing ones updated based on technological advancement. However, the JTA is very broadly written to encompass the full range of interoperability needs. Therefore, subsets must be chosen for specific mission areas, such as UAVs. Additionally, some needed standards are not specifically included in the JTA, due to time lag as new technologies emerge or due to lack of specificity for lower level protocols. Currently, there is not a formal process in-place for choosing subsets of the JTA standards for UAV application except during development of the UAV roadmap. The fundamental criterion for standards selection should be whether or not the proposed standard will improve UAV systems interoperability. The process for selecting standards should closely parallel the JTA rule set.

- Must be the minimal set required for interoperability or reuse
- Standards are technically mature and stable
- Technically implementable
- Publicly available
- Consistent with law, regulation, policy, or guidance documentation

Preferred standards are those that are commercially supported in the marketplace with several validated implementations by multiple vendors (e.g., mainstream products). The order of standards precedence for the JTA is:

- International industry standards
- National industry standards
- Government standards
- Military standards
- Proprietary standards (single vendor) are normally unacceptable but may be used in singular applications by exception.

Way Ahead for Correcting Deficiencies

One of the key issues associated with UAV standardization is lack of a defined Operational, Systems, and Technical Architecture for UAVs. It is proposed to work with the Joint Staff to develop UAV Operational and System Architectures prior to issuance of the next DoD UAV Roadmap version. By establishing UAV Operational and System Architectures, it will be possible to resolve the key interoperability issues facing each different class of UAVs (micro, small and endurance) with their diverging requirements and differing design constraints. Thus each class of UAV would achieve optimal interoperability within the broader manned aviation, ISR, and strike communities.

New technologies being incorporated into UAVs must be accompanied by equivalent development of the appropriate standards. It is proposed to work with the Joint Staff and USJFCOM to develop an overarching UAV Joint Operational Concept (JOC) and Joint Operational Architecture (JOA) prior to issuance of the next OSD UAV Roadmap. Therefore, new technologies, such as hyperspectral imagery, may be developed and ready for implementation prior to establishment of appropriate interoperability standards. Budgetary authority must be established to work standards concurrently with the technology, else stovepipe systems and/or delay in fielding new technologies results. Formal acquisition programs developing new technologies must be made responsible for developing and coordinating appropriate standards to ensure interoperability. A standard UAV interface providing critical vehicle data should be defined by FY04.

Standards Compliance

A formal standards process must be put in-place for choosing subsets of the JTA standards for UAV application and feed development of the UAV roadmap. Wherever possible, this must be worked as part of broader manned aviation, ISR and strike community activities. This should be implemented through expansion of the UAV Standards Working Group charter to address these issues as a standing body. The primary activity would be to coordinate with existing standards development bodies to ensure UAV peculiar needs were addressed. This UAV Standards Working Group made up of AT&L, C3I and JS/J-8 representative will evaluate each DoD UAV program on an annual basis for standards compliance. This IPT will provide recommendations to AT&L, C3I and JS/J-8 for specific UAV programs. These recommendations would then be used in the annual Service budget evaluations to make any required adjustments.

Appendix G: Airspace

Vision

The vision for UAV flight operations in the future is for UAVs to be able to file a DD Form 175 flight plan and fly within hours. For military operations, UAVs must integrate with manned aircraft in and around airfields using concepts of operation that make on- or off-board distinctions transparent to airfield control authorities and airspace regulators. The operations tempo at mixed airfields must not be diminished by the integration of unmanned aviation. UAVs must also be compatible with military Air Tasking Orders and must require no special Joint Forces Air Component Commander-imposed provisions that impede other aircraft from sharing airspace with unmanned assets

Background

Because the current ROA systems do not have the same capabilities as manned aircraft to safely and efficiently integrate into the National Airspace System (NAS), military ROA requirements to operate outside of restricted and warning areas are accommodated on a case-by-case basis. The process used to gain NAS access was jointly developed and agreed to by the DoD and FAA in 1999. Military operators of ROA are required to obtain a Certificate of Authorization (COA) from the Federal Aviation Administration. The process can take up to 60 days, may vary among the FAA's nine regional authorities, and because ROA do not have a see-and avoid capability, may require such additional and costly measures as providing chase planes and/or primary radar coverage. COAs are typically issued for one-time events, limited to specific routes or areas, and are valid for no more than 1 year. An exception will be the National COA now being negotiated on behalf of Global Hawk

With a COA, the ROA is accommodated into the system when mission needs dictate, but because the ROA lacks the ability to operate as a manned aircraft it is segregated from manned aviation rather than integrated with it. As the DoD concept of operation of ROA systems matures and as we ensure the airworthiness of our ROA systems, we will look toward developing new procedures in order to gain access to the NAS. Toward that end, the DoD and FAA have agreed to review the current guidance contained in FAAH 7610.4, Military Operations, and will refine or replace the COA process if mutually beneficial to both DoD and FAA.

From the DoD perspective, three critical issues must be addressed in order to supplant the COA process: UAV reliability, FAA regulations, and the see-and-avoid principle. Focusing on the regulatory aspect, air traffic management procedures must be addressed with the FAA. Aircraft airworthiness certification and aircrew qualification standards must be addressed in parallel within DoD.

OSD and the FAA, in concert with the Air Force Flight Standards Agency (AFFSA), are engaged in establishing the air traffic regulatory infrastructure for integrating military UAVs into the National Airpsace System (NAS). By limiting this effort's focus to *traffic management* of *domestic* flight operations by *military* UAVs, it is hoped to establish a solid precedent for subsequently extending such regulation to civilian

UAVs domestically and to civilian and military flights in international and foreign airspace. As depicted in Figure G-1, this initiative (shown by the brown brick) is intended to serve as the first brick in the larger, interwoven wall of regulations governing worldwide aviation. Several precepts are being followed as this DoD-FAA effort progresses:

- Do no harm - avoid enacting regulations for the military user that would later unnecessarily restrict civilian UAV flights; where feasible, leave hooks in place to facilitate the adaptation of these regulations for civilian use. This also applies to recognizing that "one size does NOT fit all" when it comes to establishing regulations for the wide range in size and performance of DoD UAVs.
- Conform rather than create - build around the existing Title 14 Code of Federal Regulations (formerly known as Federal Aviation Regulations, or FARs), adapting them to also cover unmanned aviation while avoiding the creation of dedicated UAV regulations. The goal is achieving transparency between unmanned and manned flight operations, not putting UAVs in a special treatment category.
- Establish the precedent - although focused on domestic use, any regulations enacted will likely lead, or certainly have to conform to, similar regulations governing UAV flight in international (ICAO) and foreign (specific countries') airspace.

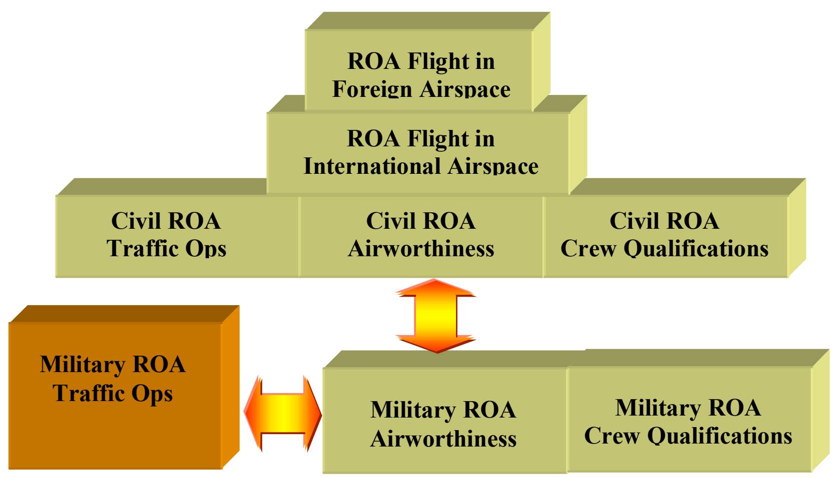


FIGURE G-1: JOINT FAA/OSD APPROACH TO REGULATING UAVS.

Before the vision of "file and fly" can occur, significant work must be accomplished in the mutually dependent areas of UAV reliability, regulation, and the see-and-avoid concept.

Reliability

UAV reliability is the first hurdle in airspace considerations because it underlies UAV acceptance into civil airspace—whether domestic, international, or foreign. Today's UAVs suffer mishaps at one to two orders of magnitude greater than the rate per 100,000 hours incurred by manned military aircraft (see Figure G-2). Improving reliability is necessary for winning the confidence of the general public, the acceptance of other aviation constituencies (airlines, general aviation, business aviation, etc.) and the willingness of the FAA to regulate UAV flight. FAA regulation of UAVs is important because it will provide a legal basis for UAV operation in the NAS for the first time; and a legal basis is necessary for determining liability in accidents and, therefore, insurability for UAV operators. Regulation of UAV operations by the FAA also should lead to acceptance by international (ICAO) and foreign civil aviation authorities of UAV operations. Such acceptance will greatly facilitate obtaining overflight and landing privileges when our larger, endurance UAVs deploy in support of contingencies. In addition, regulation will save time and resources within both the DoD and the FAA by providing one standardized, rapid process for granting flight clearances. Third, regulation will encourage the use of UAVs in civil and commercial applications, resulting in potentially lower production costs for the military market.

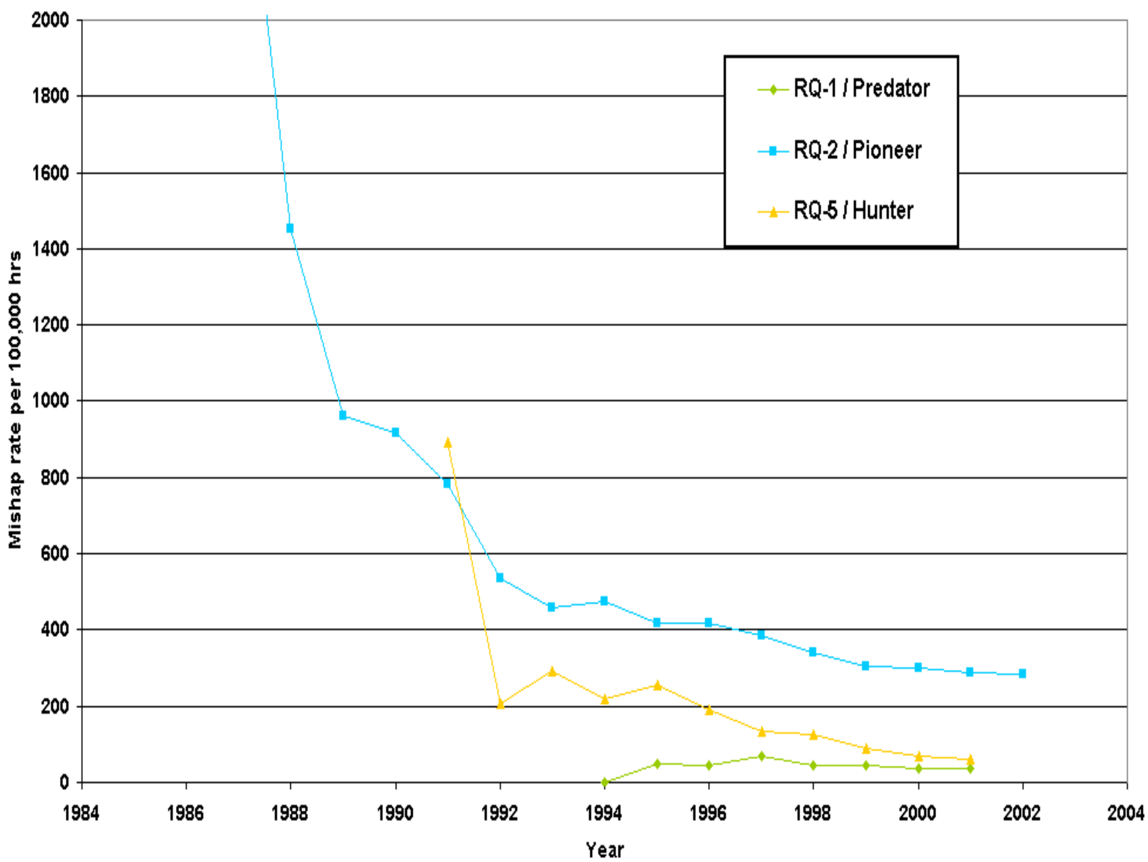


FIGURE G-2: US MILITARY UAV MISHAP RATES, 1986-2001

Regulation

Regulation: Air Traffic Operations. The FAA's air traffic regulations are meant to ensure the multitude of aircraft flown in the NAS are operated safely and pose no hazard to people or property on the ground or in the air. FAA's air traffic management focus is on the day-to-day operation of the system and the safe, expeditious movement of air traffic. Aircraft are separated by time, altitude, and lateral distance. Additionally, classes of airspace are established that include specific requirements for aircraft equipage, pilot qualifications and flight plan filing. Regardless of the class of airspace aircraft are operating in, pilots are required to See-and-Avoid other air traffic. This requirement exists even when ground controllers provide traffic advisories or where onboard collision avoidance systems, such as the Traffic alert and Collision Avoidance System (TCAS) is required. See-and-avoid is a key issue in allowing ROAs into civilian airspace and is discussed in detail in a following section.

There are six defined classes of airspace in the U.S. Class A airspace exists from flight level (FL)-180 (about 18,000 feet) to FL-600 (about 60,000 feet). Flights within Class A airspace must be IFR and under the control of ATC at all times.

Class B airspace surrounds several major airports (generally up to 10,000 feet Mean Sea Level (MSL)) to reduce mid-air collision potential by requiring ATC control of IFR and VFR flights in that airspace.

Class C airspace surrounds busy airports (generally up to 4,000 feet AGL) that don't need Class B airspace protection, and requires flights to establish and maintain two-way communications with ATC while in that airspace. ATC provides radar separation service to flights in Class C airspace.

Class D airspace surrounds airports (generally up to 2,500 feet AGL) that have an operating control tower. Flights in Class D airspace must establish and maintain communications with ATC, but VFR flights do not receive separation service.

Class E airspace is all other airspace in which IFR and VFR flights are allowed. Although Class E airspace often extends to the surface, it generally begins at 1200 feet AGL and extends upward until it meets a higher class of airspace (A-D).

Class G airspace (there is no Class F airspace in the U.S.) also is called uncontrolled airspace because ATC does not control aircraft there, and IFR is not permitted. Class G airspace can extend to 14,499 feet MSL, but generally exists below 1200 feet AGL, and below Class E airspace.

Accordingly, Classes B, C, and D relate to airspace surrounding airports where increased mid-air collision potential exists; and Classes A, E, and G primarily relate to altitude, and the nature of flight operations that commonly occur at those altitudes. ATC provides separation services to all flights in Class A, provides it to some flights in Class E, and does not provide it in Class G. Regardless of the class of airspace, or whether ATC provides separation services, pilots are required to see and avoid other aircraft whenever weather permits.

The FAA defines an aircraft as "a device that is used or intended to be used for flight in the air" (14 CFR 1). While model airplanes fit this definition, there is no 14 CFR Part associated with them, i.e., they are **not regulated**. The FAA does, however, publish an Advisory Circular (AC 91-57) that encourages voluntary safety standards for their use. Because neither the AC nor 14 CFR provides metrics to differentiate model aircraft from other aircraft, the presumed difference is the onboard presence of the pilot. Accordingly, it is envisioned that military UAVs having similar metrics, and operated in a similar manner to model aircraft, would not require FAA regulatory attention. Examples of such UAVs are the hand- or bungee-launched types such as Pointer and Dragon Eye.

The FAA also recognizes the existence of "ultralight vehicles." Two Advisory Circulars (AC 103-6 and 103-7) as well as 14 CFR 103 provide advice and regulations on ultralights and operating them. It is important to note that 14 CFR 103 addresses ultralights as **vehicles** and not as aircraft, but does regulate them in terms of metrics such as weight, speed, etc. Air-traffic regulations for ultralights are contained in 14 CFR 103, and prohibit ultralight flights in areas of aircraft congestion; specifically, ultralight flights are permitted only in Class E and G airspace. Operators of ultralights also are required to exercise see-and-avoid (14 CFR 103 states that ultralight vehicles are manned). As certain military UAVs share many operating characteristics and physical metrics with ultralight vehicles, it is envisioned that 14 CFR regulations related to UAVs will take into account the nature of ultralights and their operating environments as an analog. Examples of these UAVs range from the Exdrone to the Shadow 200 and the Pioneer—weighing 80 to 450 lb.

Finally, some U.S. military UAV types operate chiefly at medium and high altitudes where, in civil airspace, most of the ATC-controlled aircraft operate. Regulations for aircraft operations are well established in 14 CFR (particularly Part 91), and it is envisioned that these same regulations will govern the operation of military UAVs in civil airspace. Figure-3 summarizes several types of U.S. military UAVs and the classes of airspace in which they typically operate.

In summary, current FAA regulations recognize "flying devices" as either **aircraft** (and regulates them), as **regulated air vehicles** (like ultralights), or as **unregulated air vehicles** (like RC models). Further, it applies the term Remotely Operated Aircraft (ROA) to UAVs in the first category. Military UAVs, then, could be categorized as operating in three regimes. 1) The very low-altitude regime where VFR line-of-sight operations of small UAVs resemble model aircraft operations and are not regulated; 2) the low-altitude regime where day Visual Meteorological Conditions (VMC) operations in the absence of ATC are similar to ultralight operations that are regulated by one simple 14 CFR part; and 3) the medium and high-altitude regimes in which Visual Flight Rules (VFR), Instrument Flight Rules (IFR), and all-weather operations are routine under well-established regulations and procedures. Table G-1 summarizes the envisioned regulatory baseline for operating military UAVs in civil airspace.

TABLE G-1. ALIGNMENT OF UAV CATEGORIES WITH FAA REGULATIONS.

	Remotely Operated Aircraft (ROAs)	**Regulated Air Vehicles (RAVs)**	**Unregulated Air Vehicles (URAVs)**
Parent Regulation	14 CFR 91	14 CFR 103 for VFR 14 CFR 91 for IFR	None (AC 91-57)
Requirements			
Licensed Pilot	Yes	No	No
Aircraft Certified	Yes	On Request	No
Implications			
Airspace Useage	All	Class E & G only	Class G only
MTOW Limit, lb	None	254 plus pilot, etc.	55 (proposed)
Airspeed Limit, KIAS	None	NTE 250	TBD (proposed)
See & Avoid Scheme	Airborne/Active	Airborne/Passive	Ground-based
Example Types	Predator	Pioneer, Shadow	Dragon Eye

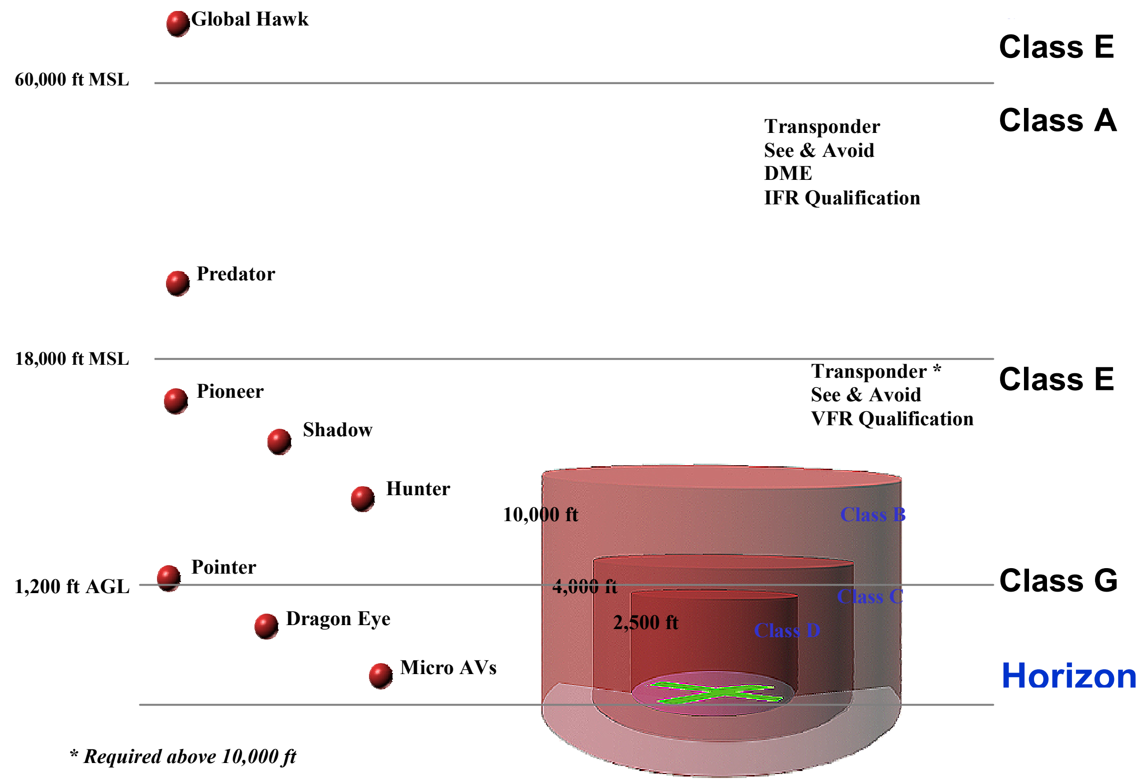


FIGURE G-3: UAVS AND AIRSPACE CLASSES OF THE NATIONAL AIRSPACE SYSTEM.

Although Table G-1 indicates notional categories for UAVs, it is important to note that the FAA uses the term, 'category,' in two different taxonomies (14 CFR 1). As used with respect to the certification, ratings, privileges, and limitations of airmen, the term 'category' means a broad classification of aircraft. Examples include: airplane; rotorcraft; glider; and lighter-than-air. As used with respect to the certification of aircraft, the term 'category' means a grouping of aircraft based upon intended use or operating limitations. Examples include: transport, normal, utility, acrobatic, limited, restricted, and provisional. When discussing right-of-way rules in 14 CFR 91.113, however, the FAA uses non-mutually exclusive categories such as balloon, glider, airship, airplane, rotorcraft, and engine-driven aircraft for determining which flight has the "right-of-way. As ultralight vehicles are not aircraft, 14 CFR 103 requires them to yield the right-of-way to all aircraft. Similarly, model airplanes are not aircraft, but the FAA provides avoidance (right-of-way) advice in an Advisory Circular.

It is clear that a taxonomy for UAVs will need to be developed that helps define their operating privileges, airworthiness standards, operator training and certification requirements, and their place in the right-of-way rules. Currently, as neither model airplanes nor ultralights are 'aircraft,' they do not have airworthiness certificates nor do their operators require certification. Similarly, military aircraft do not have airworthiness certificates and are not assigned to a 14 CFR 1 category (above). Military aircraft are required to comply with 14 CFR 91.113 right-of-way regulations and, therefore, would be presumed to fit into that taxonomy.

In addition to regulatory changes necessary for routine operation of military UAVs in civil airspace, changes to several other documents, such as Advisory Circulars and FAA Order 7610.4J (Special Military Operations), will be required. For the near term, military UAVs are not envisioned to require the use of civilian airports surrounded by Class B, C, or D airspace. Once their safe and reliable operation in transit between military airfields through class A, E, and G airspace has been established, rules for opening other airspace to them—beginning with Class D—can be formulated and eventually implemented.

Regulation: Airworthiness Certification. The FAA's airworthiness regulations (14 CFR Parts 23, 25, 27, 29, 31, 33, 35, 36, 39, and 43) are meant to ensure that aircraft are built and maintained so as to minimize their hazard to aircrew, passengers, and people and property on the ground. Airworthiness is concerned with the integrity of the individual aircraft and the prevention of it coming apart in midair and/or its parts raining down on victims on the ground. Over the 19-year period from 1982 to 2000, an annual average of 2.2 percent of all aviation fatalities involved people being hit by falling parts of aircraft. A UAV that must be available for unrestricted operations worldwide (a Global Hawk requirement) in all classes of airspace compels consideration for the safety of people on the ground. The operational requirements for UAV operation in civil airspace means flight over populated areas must not raise concerns based on overall levels of airworthiness, therefore, UAV standards cannot vary widely from those for manned aircraft without raising public and regulatory concern.

FAA regulations do not require "public aircraft" (ones government owned or operated) to be certified airworthy under FAR standards. However, because virtually all non-military public aircraft are versions of aircraft previously certified for commercial or private use, the only public aircraft not certified airworthy by FAR standards are almost always military aircraft. Instead, these aircraft are certified through the military's internal Operational Safety, Suitability, and Effectiveness (OSS&E) process, which parallels the FAR process. Unmanned military aircraft are also subject to the OSS&E process, so their airworthiness need not be addressed in new or revised FARs; this is true for any future unmanned public aircraft. Certification of non-public UAVs remains an open issue for commercial or private UAV builders and operators.

Regulation: Aircrew Qualifications. The FAA's qualification standards (14 CFR Parts 61, 63, 65, and 67) are meant to ensure the competency of aircrew and aircraft maintainers. As in the case of airworthiness certification, these Parts do not pertain to military personnel, who are certified in a similar, parallel process. Among the Services, however, this process can vary greatly, from certifying personnel as UAV operators whose training does not involve their learning to fly to accepting only those with formal flight training and a prior flying assignment. Under current rules, the FAA would not distinguish between these two extremes if the military certified both as competent UAV operators. Given the distinction drawn between ROAs and regulated/unregulated air vehicles in the Air Traffic section above, only ROA operators would be required to be IFR-qualified, certified pilots.

A question does arise, however, when civilian pilots, such as those working for an aircraft manufacturer building UAVs for the military, need to fly their company's product during the performance of a military contract, such as for test, production delivery, and acceptance (DD Form 250) flights. The Defense Contract Management Agency

(DCMA), who is responsible for such activities leading up to the acceptance of aircraft by the government, has established a letter policy (DCMA-AO letter dated 31 May 2001) requiring all contractor UAV operators to hold a current FAA Private or Commercial Pilot and Instrument rating to fly outside of restricted or warning areas. Qualification standards for non-military UAV pilots and maintainers remains an open issue for commercial or private UAV builders and operators.

See-and-Avoid Principle

The key to providing the "equivalent level of safety" required by FAA Order 7610.4, Special Military Operations for Remotely Operated Aircraft (ROA, the FAA term for UAVs), is the provision of some comparable means of see and avoid (S&A) to that provided by pilots onboard manned aircraft. The purpose of S&A is to avoid mid air collisions, and this should be the focus of technological efforts to address S&A rather than trying to mechanize human vision. Relying simply on human vision results in mid airs accounting for an average of 0.8 percent of all mishaps and 2.4 percent of all aviation fatalities incurred annually (based on the 3-year average from 1998 to 2000). Meaningful see-and-avoid performance must alert the operator to local air traffic at ranges sufficient for reaction time and avoidance actions by safe margins. The FAA does not provide a quantitative definition of S&A, largely due to the number of permutations of pilot vision, collision vectors, sky background, and aircraft paint schemes involved in seeing oncoming traffic, but it does define the minimal field of regard that must be provided from the cockpit in its Advisory Circular 25.773-1. Having a sufficient field of regard for a see-and-avoid system is fundamental to actionable information and meeting the goal of assured air traffic separation. As for resolution comparisons, the human with 20/20 vision has a resolution of 3.28 milliradians.

From a technical perspective, the S&A capability can be divided into the detection of oncoming traffic and the execution of a maneuver to avoid a midair. The detection aspect can be further subdivided into passive or active techniques applicable in cooperative or non cooperative traffic environments. The **active, cooperative** scenario involves a radar scanning a sector ahead of the UAV to detect oncoming traffic by activating a transponder on the other aircraft. Its advantages are it provides both range and bearing to the traffic and can function in both visual and instrument meteorological conditions (VMC and IMC). Its disadvantages are its relative cost. Current systems available in this category include the various Traffic-alert and Collision Avoidance Systems (TCASs), which generally run $250,000 installed, and the less expensive Traffic Information System (TIS) for the general aviation market.

The long-term FAA plan is “to move away from infrastructure-based systems towards a more autonomous, vehicle-based system” for collision avoidance (*2001 Federal Radionavigation Systems Plan*). Installation of TCASs is increasing across the aviation community, and TCAS functionality supports increased operator autonomy. Research and testing into a complementary system, known as Automatic Dependent Surveillance-Broadcast (ADS-B), may afford an even greater capability and affirms the intent of the aviation community to support and continue down this path. With ADS-B capabilities, the cockpit situational awareness of cooperative traffic would extend to 60 nm in front of the aircraft. Such equipment complements basic see-and-avoid, adds to the situational awareness, and helps provide separation from close traffic in all meteorological conditions.

The **active, non-cooperative** scenario relies on a radar- or laser-like sensor scanning a sector ahead of the UAV to detect all traffic, whether transponder-equipped or not. The returned signal provides range, bearing, and closure rate, allowing prioritization of oncoming traffic for avoidance, in either VMC or IMC. Its drawbacks are again its relative cost, which could equal 33 to 100 percent that of typical tactical UAVs (Pioneer, Shadow) and the high bandwidth required to route its imagery. An example of an active, non-cooperative system that is currently available is a combined microwave radar and infrared sensor originally developed to enable helicopters avoid power lines that is comparable in price to TCAS.

The **passive cooperative** scenario, like the active cooperative one, relies on everyone having a transponder, but with everyone's transponder required to be continuously active. Its advantages are its lower relative cost (no onboard radar required to activate transponders) and its ability to provide S&A information in both VMC and IMC. Its disadvantage is its dependence on all traffic carrying and continuously operating transponders. Numerous examples of transponders are available, from $1000 models for skydivers and up. UAVs would require the capability to change transponder settings while in flight.

The **passive non cooperative** scenario is the most demanding one and is most analogous to the human eye. A system in this scenario relies on a visual or infrared sensor to detect and provide bearing to the oncoming traffic. Its advantages are its moderate relative cost (more than a transponder, less than a radar) and ability to detect non-transponder equipped traffic. Its disadvantages are its lack of range or closure rate information, high bandwidth required, and its inability to penetrate heavy IMC. The gimbaled EO/IR sensors currently carried by reconnaissance UAVs are examples of such systems, but if they are looking at the ground for reconnaissance then they are not available to perform S&A. An emerging approach that would negate the high bandwidth requirement of any active system is optical flow technology, which reports only when it detects movement against the sky, instead of sending a continuous video stream to the ground controller. Imagery from one or more inexpensive optical sensors on the UAV is continuously compared to the last image by an onboard processor to detect minute changes in pixels, indicating traffic of potential interest. Only when such objects are detected is their bearing relayed to the ground.

Once the "see" portion of S&A is satisfied, the UAV must use this information to execute an avoidance maneuver. The latency between seeing and avoiding for the pilot of a manned aircraft typically ranges from 5.0 to 12.5 seconds in FAA and NTSB studies (Krause, Avoiding Mid-Air Collisions, p. 13). If relying on a ground operator to see and avoid, the UAV incurs the same human latency, but adds the latency of the data link bringing the image to the ground for a decision and the avoidance command back to the UAV. This added latency can range from less than a second for line-of-sight links to 3.5 seconds or more for satellite links. An alternative is to empower the UAV to autonomously decide whether and which way to react to avoid a collision once it detects oncoming traffic, thereby removing the latency imposed by data links. This approach has been considered for implementation on TCAS II-equipped manned aircraft, since TCAS II already recommends a direction to turn to the pilot, but simulations have found the automated maneuver worsens the situation in a fraction of the scenarios. For this reason, the FAA has not certified automated collision avoidance algorithms; doing so would set a significant precedent for UAV S&A capabilities.

Navigation Redundancy

The air navigation environment is changing, largely because of the demands of increased traffic flow. Allowances for deviation from intended flight paths are being reduced. This provides another means for increasing air traffic capacity as airways and standard departures and approaches can be constructed with less separation. As tolerances for navigational deviation decrease, the need to precisely maintain course grows. All aircraft must ensure they have robust navigational means. Historically, this robustness has been achieved by installation of redundant navigational systems. The need for dependable, precise navigation reinforces existing redundancy requirements.

Navigation redundancy is both an issue of military robustness to support operations in conflict and a regulatory issue intended to assure sufficient navigation confidence for traffic management and safe separation in the event of interruptions in navigation services (e.g. navaids and Satellite Navigation (SATNAV)) or onboard equipment. This section addresses the later. Military robustness is an issue for systems operational requirements documents.

Navigation is addressed by regulatory authorities. The FAA in FAR Part 91 explicitly requires appropriate navigational equipment to the ground facilities to be used. Air traffic regulators expect aircraft to have equipment compatible with the routes flown, e.g. a VOR airway requires a VOR. Further, FAA Air Circular 90-96 on Basic Area Navigation Standards (BRNAV) requires that " . . . In the event of (an Area Navigation (RNAV)) system failure, the aircraft (must) *retain the capability to navigate relative to ground-based navigation aids*."

ICAO, in its Standards and Recommended Practices (SARPs), states that "*With the failure of one item of equipment, navigation equipment must be sufficient to complete the flight."* For both domestic and national authorities, guidance directs designers away from single source vulnerabilities that may result in the complete loss of navigation for a given platform leaving an aircraft with no alternative means to comply with a filed flight plan to destination. As a result, EuroControl has required a navigation architecture that mandates a ground-based backup system for SATNAV for the foreseeable future. The backup system of choice is Distance Measuring Equipment (DME).

Redundancy requirements have been recently validated in studies that bear on national navigational policies. *President's Commission on Critical Infrastructure Protection* reported out that "the most significant vulnerability to the transportation infrastructure is the association of the modernization of the NAS with the plan to adopt the Global Positioning System (GPS) as the sole basis for radio-navigation in the US by 2010. This creates the basis for a single-point failure."

According to the *Federal Radionavigation Plan*, there is growing awareness within the transportation community of the risks associated with the GPS system being the only means for position determination. Like any radio-navigation system, GPS is vulnerable to interference that can be reduced but not eliminated. As GPS further penetrates into the civil infrastructure, it becomes a tempting target that could be exploited by individual, groups, or countries hostile to the United States. With increasing dependency on GPS for weapon targeting and weapon systems adversaries may be motivated to identify and exploit vulnerabilities. The effects of jamming and unintentional interference are primarily to increase the workload of both the users and the air traffic controllers for aircraft with backup systems. For systems solely dependent on GPS, loss of service leaves UAVs to rely on INS systems, none of which, in today's UAVs, have drift rates allowing the successful completion of a sortie through to landing.

The current *Federal Radionavigaion Plan*, signed March 2002, establishes the following national policies:

- Unaugmented GPS is approved as a primary system for use in oceanic and remote airspace.
- GPS is approved as a <u>supplemental system</u> for domestic en route and terminal navigation, and for nonprecision approach and landing operations.
- The FAA's phase-down plan for ground-based Navaids retains at least a minimum operational network of ground-based Navaids <u>for the foreseeable future.</u>
- Sufficient ground-based Navaids will be maintained to provide the FAA and the airspace users with a safe recovery and <u>sustained operations capability in the event of a disruption in Satnav service</u>.

This policy applies, as a minimum, to all aircraft flying civil airspace. As GPS moves into a more robust architecture, the prospect for relief of some redundancy requirements in manned aviation may be an option in the future. However, UAVs have a diminished prospect for relief since, unlike manned aircraft, a UAV cannot readily fallback on dead reckoning, contact navigation and map reading in the same sense that a manned aircraft can.

Future Environment

The migration of the NAS from ground based traffic control to airborne traffic management, scheduled to occur over the next decade with the implementation of "free flight," will have significant implications for UAVs. S&A will become an integrated, automated part of routine position reporting and navigation functions by relying on a combination of Automatic Dependent Surveillance-Broadcast (ADS-B) and Global Positioning System (GPS) to create a virtual bubble of airspace around each aircraft, so that when bubbles contact, avoidance is initiated. All aircraft will be required to be equipped to the same level, making the unmanned or manned status of an aircraft transparent to both flyers and to the FAA, removing the need for separate standards.

Finally, the pejorative perception that UAVs are by nature more dangerous than manned aircraft needs to be countered by recognizing that UAVs possess the following inherent attributes that contribute to flying safety:

- A UAV will never be lost because a pilot experiences vertigo.
- Many manned aircraft mishaps occur at the end of a flight, when human decisions and control inputs are substantial factors. Robotic aircraft are not programmed to

take chances; either preprogrammed conditions are met or the system goes around.

- No UAV is likely to be lost due to aircrew urgency to return to base and family.
- Since human support systems are not carried, mishaps from failed life support systems will not occur.
- Smoke from malfunctioning, but non-vital, onboard systems does not pose the same threat of loss, since smoke in the cockpit can distract operators and lead to vision obscuration.
- Automated take-offs and landings eliminate the need for pattern work, resulting in reduced exposure to mishaps, particularly in the area surrounding main operating bases.

Directed Actions

OSD directs the following actions be taken to integrate UAVs into civil airspace:

1. **Coordinate revising FAA Order 7610.4 to replace the requirement for using the COA process for all UAVs with one for using the DD175 form for qualifying UAVs. OPR: USAF. Due: FY04.**
2. Work with the FAA to define appropriate conditions and requirements under which a single pilot would be allowed to control multiple (up to four) airborne UAVs simultaneously.
3. Document and disseminate any UAV-unique lessons learned from certifying the RQ-4 Global Hawk as airworthy by means of the OSS&E process. Formal documentation as a DoD Instruction for guiding future ROA airworthiness certifications should be considered.
4. Establish a joint program, or designate a joint office, for developing and evaluating automated see-and-avoid and collision avoidance systems.
5. Equip DoD UAVs intended for Instrument Flight Rules (IFR) operations with a stand-alone, hot backup, ground-based navigation system and establish a standardized lost link procedure.

Appendix H:
Task, Post, Process, and Use Considerations

Introduction

This annex addresses Task, Post, Process, and Use (TPPU) for UAV collectors and develops an executable integration roadmap to guide long-range planning and programming in the Services and Agencies and to migrate the ISR community toward DoD ISR Vision 21. TPPU is a revolutionary way of thinking about how data is handled. Unlike Task, Process, Exploit and Disseminate (TPED), in the TPPU construct Tasking is net-centric, readily accessible to all authorized users, and fully integrated. Users/producers Post data on the network for use before it is ingested into the conventional processing, and exploitation processes. Processing is used in a broader context that can encompass exploitation, analysis, event correlation, and fusion of data and information. Users will have instant access, as posted data becomes available, replacing the dissemination notion that focused on "point-to-point" or push of information to specified users.

This annex contains seven sections: Introduction, UAV TPPU Roadmap, Current state of TPPU, TPPU Requirements, TPPU Shortfalls, TPPU Technologies, and TPPU Observations and Recommendations. It is divided into two timeframes: FYDP and 2010-2027. Requirements, shortfalls, and recommendations are considered for each timeframe.

UAV "TPPU" Roadmap

This section describes an integrated roadmap (Figure H-1) characterizing the anticipated actions necessary to guide the Services and Agencies planning and programming. Such guidance is needed to fully migrate the ISR UAV community toward the objectives of DoD's ISR Vision 21 dated 3 November 2000.

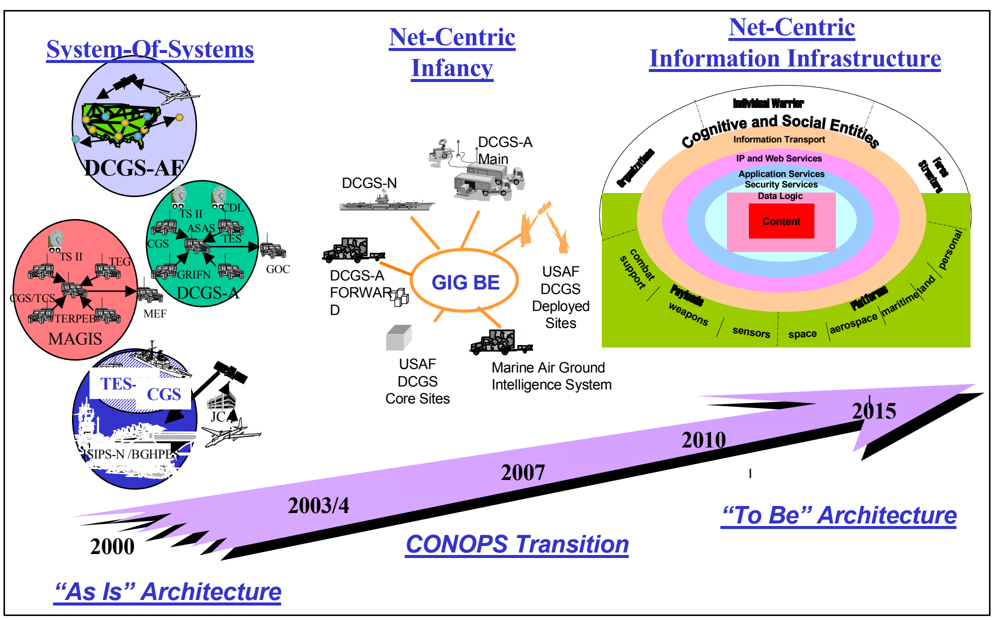


FIGURE H-1: TPPU-TRANSFORMING DCGS TO NET-CENTRICITY

The DoD ISR Vision 21 aims to provide integrated and responsive ISR capabilities operating in a collaborative enterprise assuring delivery of timely, relevant information for senior U.S. decision makers and for Joint / Combined forces.

The first period begins in the current era and continues through the end of the FYDP (FY03-09). In this period, the Services' ground station components will move toward an integration of their respective Distributed Common Ground System (DCGS) systems. In the second time period (2010-2027), deployment of the initial Global Information Grid (GIG) Bandwidth Expansion capabilities begins to offer relief from previous bandwidth constraints. As a result, advances in data processing, meta-data tagging, information applications (for exploitation, manipulation and visualization), and collaborative operations characterize the intermediate era. Many of the multi-INT, multi-ISR and multi-source correlation and fusion functions continue to be accomplished with a "man-in-the loop" technique. A separation of the sensor processes and the distributed manipulation of data and information characterize the end of this timeframe.

The end-state in 2027 is characterized by extensive on-board processing with data coming from the platforms as well as actionable information from off-board sources in real time. Sensors and platforms are automatically cued and carry out prescribed missions. All products are immediately available for use on the information net. In-depth correlation and analysis will be performed at selected intelligence centers and their products will be made available on the net.

Current TPED (DCGS As Is)

In 2002, UAV control is via Ground Control Systems (GCS) and Mission Control Elements (MCE). The data are then routed to theater users (e.g., an Air Operations Center (AOC)) and Service Distributed Common Ground System (DCGS) nodes where processing and exploitation is performed. DCGS constitute a family of systems that provide multi-intelligence (Multi-INT) exploitation to the Joint Task Force and below through a combination of forward support, collaboration, and reach back. UAVs are connected to the DCGS via the Mission Control Element (Global Hawk) or the Tactical Control System (tactical UAVs).

At the DoD level, DCGS is a Multi-INT integration strategy to achieve the objectives outlined below:

1. Achieve Joint/Coalition ISR Interoperability. This includes the ability of a Joint Commander to flexibly employ ISR capabilities from any or all Service/Coalition sources to support a military operation.
2. Produce and implement a Multi-INT and Multi-Source (U.S./Coalition surface, airborne, and national/commercial satellite) collaboration strategy.
3. Guide the Services as they transition their current ISR capabilities to a Joint distributed collaborative network centric enterprise.

DoD Agencies use DCGS as an architecture of specific standards to achieve Joint ISR interoperability at the JTF and lower echelons. For the Services, DCGS is a family of systems or elements designed to meet Service requirements implementing the DoD strategy and certified by the Joint Interoperability Test Command.

The "DoD DCGS" is a term used to refer to the entire Family of Systems (FoS) made up of the individual Service System of Systems (SoS) which are connected through designated points of interoperability. The Service DCGS architectures are composed of SoS and/or systems (i.e., DCGS elements) as determined by the Service. The requirements contained herein are applicable to each Service SoS. Internal Service architectures are not specified, since that is a matter for Services to define and develop. Individual Service DCGS architectures (i.e., SoS) shall be interoperable at requisite classification level to provide joint and combined warfighters with the required capabilities. The capabilities contained in each Service implementation can be tailored to support the mission. Each Service DCGS SoS will either interface directly with Service/allied ISR platforms and/or rely on communication linkages to other Service DCGS FoS to satisfy requirements.

Today, we have begun the evolution of military Service DCGSs to a network centric SoS that enables joint/coalition forces to securely manage ISR resources and access, process, post and use information and intelligence in a collaborative environment. The Services are making progress on their architectures and solid interoperability bases (e.g. Common Imagery Processor (CIP), CDL) have been established. Over forty-four systems have been fielded. While there are pockets of cross-Service interoperability, there is no connectivity between Service DCGS elements. Additionally, the Joint Intelligence Centers (JICs), Joint Analysis Centers (JACs), and Service intelligence production centers are not yet part of the DCGS architecture. The following graphics represent each of the Service "AS IS" operational views.

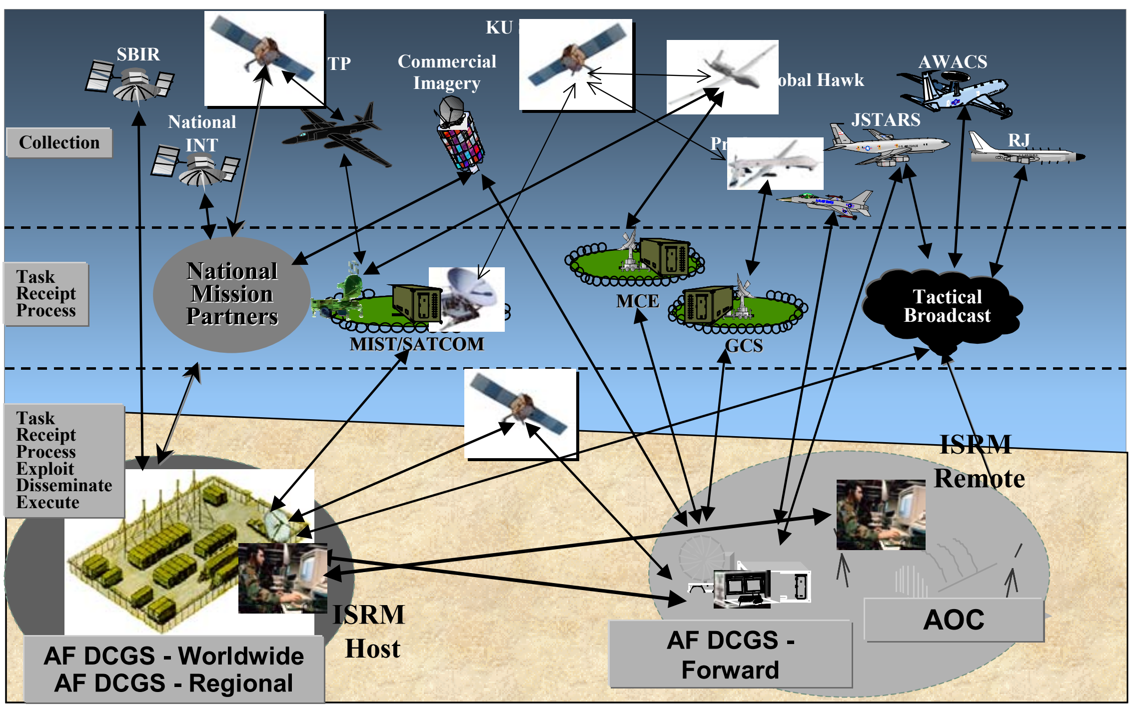


FIGURE H-2: AIR FORCE'S DCGS (DCGS-AF)

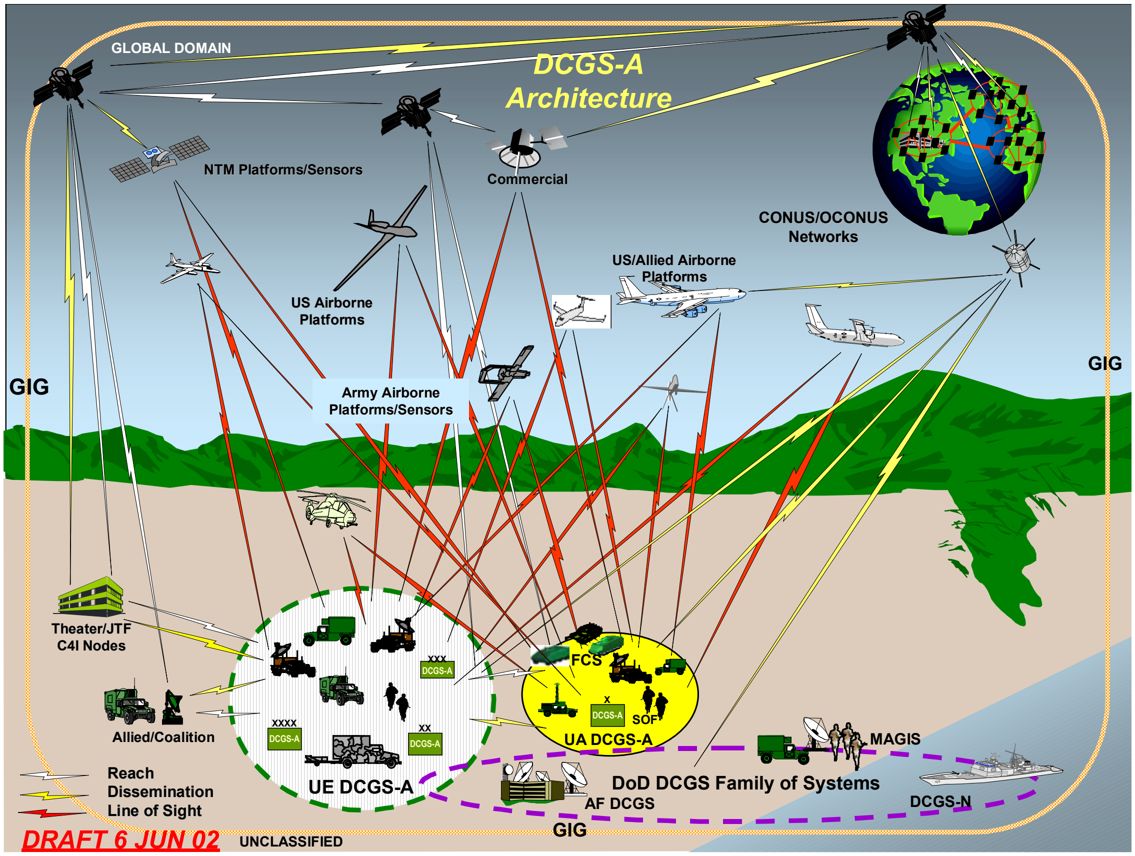


FIGURE H-3: ARMY'S DCGS (DCGS-A)

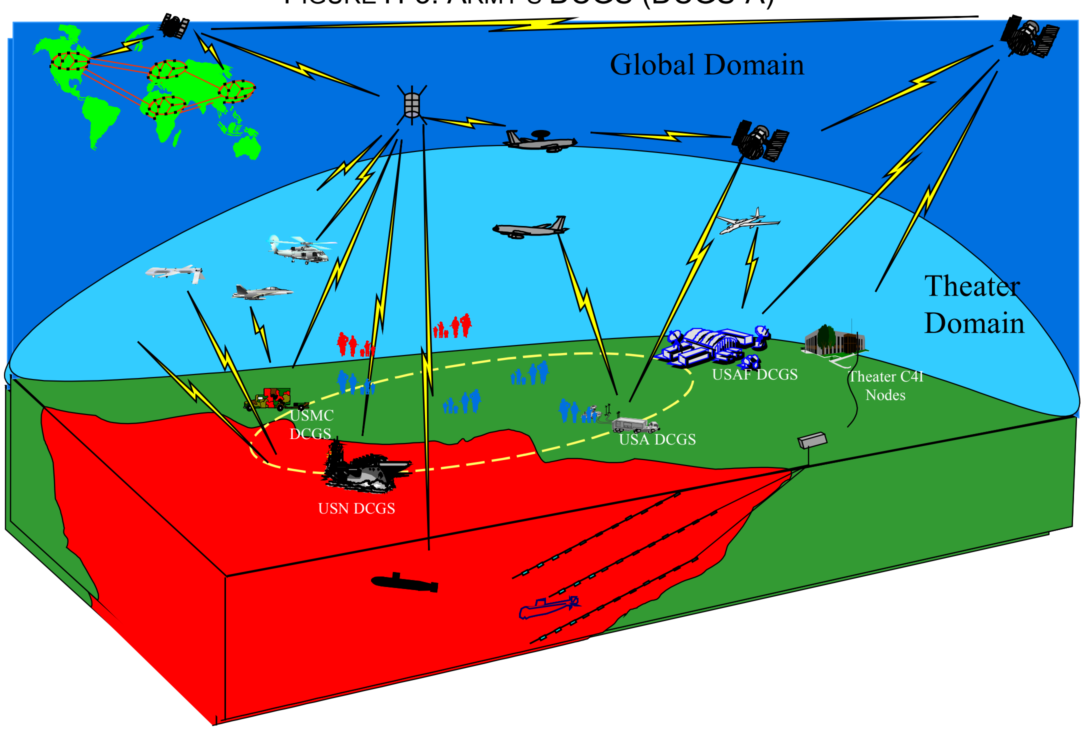


FIGURE H-4: NAVY'S DCGS (ISR NET)

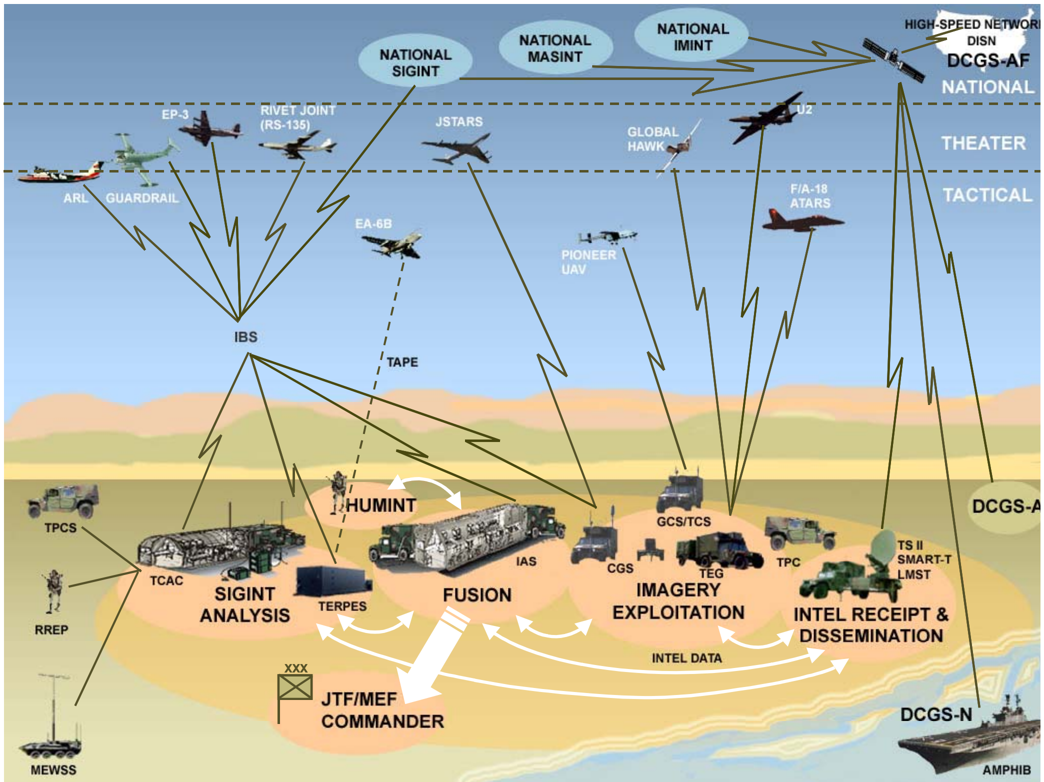


FIGURE H-5: USMC'S DCGS (MAGIS)

TPPU Requirements

The requirements section is divided into two parts. The first addresses the Program of Record (FY04-09 Program Objective Memorandum) and the objective requirements taken from the draft DCGS CRD. They fall into five categories: Tasking, Posting, Processing, Using, and General. The second part addresses requirements beyond 2010 and is derived from the Vision stated in the Roadmap section of this document.

Program of Record Requirements. **Tasking** requirements deal with common DoD format, multi-level security, automatic requests to change collection plans and directly send/receive via the Common Data Link. They must be able to receive and display all platform/sensor disposition and mission collection plans.

The requirement for **Posting** is the capability to place data and information into a common portal on the Information Grid that is accessible to all users. The system must be able to import and export data and information electronically in varying data and media formats used by DoD, coalition, and allied forces.

Processing requirements deal with the manipulation of raw, pre-processed and processed data into intelligence. These include machine to machine automation, functional manager approved/certified algorithms that automatically include accuracy estimate/confidence levels, decision aids that increase accuracy and speed while limiting human interaction, and hardware independent multi-discipline and multi-ISR common processing capabilities for all platforms/sensors.

Using deals with giving the user timely access to data as it is posted and the tools and capabilities needed to retrieve, analyze and apply the available information to achieve desired results. The systems must be capable of receiving unexploited multi-ISR data produced by all means. Standards-based automated exploitation management processes will be required. These processes must be designed to facilitate distributed and collaborative exploitation using DoD approved collaborative applications and multi-discipline intelligence databases. The databases must be capable of automatically enabling information exchange based on user defined profiles.

General requirements include the ability to use common user circuits with standard data formats and the ability to convert Service specific inputs into common formats passed through a multi-level or multi-layer security system capable of automated security parsing and dissemination of data at the appropriate security level.

Visionary Requirements 2010 –2027. In the 2010-2027 timeframe, the transition to a net-centric joint ISR framework will occur. That framework will be characterized by the following attributes:

- The net-centric joint ISR framework will be a global network structure, integrated in today's concepts of the Global Information Grid (GIG) and the various communications modernization and transformation initiatives (e.g., GIG Bandwidth Expansion, Transformational Communications System).

- Tasking will be accomplished by sensor / platform managers without direct human intervention, using a sensor / platform allocation process that is then managed by the sensor / platform operators seeking to "fill" requests for information rather than executing a static list of tasks. Sensors / platforms will also make coverage and collection decisions based upon the data they collect and either re-task themselves or task another sensor via high speed, platform-to-platform communications acting as a networked sensor "grid" or persistent surveillance based data and information production entity feeding the information portal.

- The sources of information that will be posted, accessed and exploited will include traditional ISR sources of information (e.g., space-based, airborne, ground, surface, sub-surface, cyber, and human) as well as non-traditional sources of information, such as combat platforms, personnel, and commercial sources. All of those sources of information will be available through a "post before processing" functional information domain or portal, accessible in a secure fashion by all "users" of that information.

- Posting in the 2010-2027 timeframe will require that any producer or user can plug in to the "posting domain" on the network from wherever and whenever necessary. A massive amount of data will be transmitted. A web-based system will be required to give users the ability to rapidly find the data they need. The entire network will need to be multi-level and multi-layer secure. Supporting this process will be a series of applications, information management protocols, transport mechanisms, data wrappers, and related meta-data capabilities that will enable data and information provided to the "posting domain" to be deconflicted, combined / correlated, and managed to maintain insight into the veracity, heritage, pedigree and completeness of the accessed information.

- As the amount of data collected increases with new and more capable sensors, the job of exploiting the data becomes more complex. Time will continue to be of the essence whether the data goes directly from sensor-to-shooter or through a more deliberate mission planning process. Disparate multi-source data must rapidly and in an automated fashion, be correlated and fused into information products. Advances in applications, changes in techniques, and adoption of automated processing aids and systems will be required. Further, integration and management of the various processing and exploitation capabilities residing on the network will require an adaptive set of management capabilities. These capabilities will be required to support the creation of tailored mission capability packages responsive to the defense mission being supported. This implies a robust collaborative environment that greatly exceeds the rudimentary tools in use today (e.g., NetMeeting, etc.) and relies on the resolution of the data and information management challenges identified earlier.

Characterizing these attributes with a graphic presents a challenge of keeping it simple, while conveying the net-centricity of a secure, accessible data and information structure that supports both the time critical and deliberate defense mission prosecution processes. Figure 6 presents one view of that future and is intended to convey the attributes the Department seeks to field in support of UAV, and other ISR, network centric TPPU.

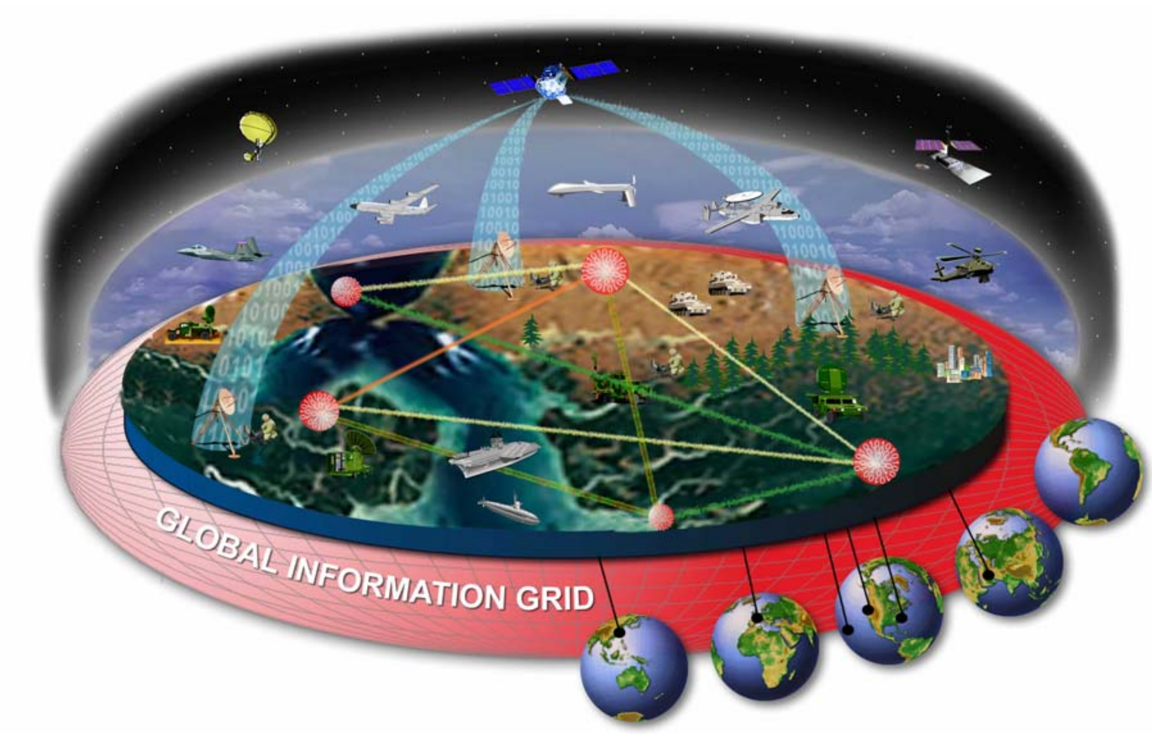


FIGURE H-6: DOD DCGS ENVISIONED STRUCTURE IN 2015

TPPU Shortfalls

Like the Requirements section, the TPPU Shortfall section is divided into two parts: those that refer to the program of record and those in the 2010-2027 timeframe. The shortfalls were developed by comparing the "as is" DCGS capabilities from section III with the requirements in section IV.

Program of Record Shortfalls. Shortfalls in the **Tasking** area deal with the ability to use standard tasking procedures and messages and the lack of a feedback mechanism that provides an interactive environment between producer and user.

Posting shortfalls are a lack of standard data and information reporting formats, a standard multi-ISR data relationship, meta-data tags for organizing and relating information, and an insufficient ability for deployed forces to plug into the network.

Shortfalls in **Processing** are the accuracy of positional data, speed of processing, the insufficiency of decision aids to automate the decision making process, and the inability of processors in all ISR domains to respond to and meet a variety of user needs.

Using shortfalls include the need to increase the quality and precision of information provided, an ability to plug into the network from anywhere and an ability to move a massive amount of data around the Global Information Grid.

Visionary Shortfalls 2010-2027. In the 2015-2027 timeframe, tasking or collection management will no longer resemble the "serial" process in use today. Rather, the segmentation of common functional capabilities residing on a networked structure should result in the creation of multiple management functions that operate almost independently of the physical structures we know today. For example, collection management as we know it today may fracture into a three part capability process defined by sensor asset allocation, data and information portal management, and processing management. In the sensor arena, collection management may no longer be required because the sensor / platform allocation process will provide coverage of "interest areas" relative to defense missions and provide persistent coverage of the interest area. Output from those allocated assets will be flowed into the "posting domain", with interaction and self-tasking of sensors and cross cueing occurring between and / or among sensors allocated to the same interest area. The exploitation management process will assemble the necessary capabilities to exploit relevant information in the posting domain, providing "value added" to the overall information available. In order to realize this sort of "value added" or "business model" approach to ISR in the future, management tools and communications networks for this dynamic interaction need to be developed along with the doctrine, techniques and training underpinnings that supports this type of activity.

In the 2027 timeframe, producers and users will proliferate to a network of fixed and deployed locations. Methods to allow users and producers to plug into the Global Information Grid on the move and receive/transmit large volumes of data must be developed. Cataloging and retrieval schemes, meta-data tags, verification and validation mechanisms, and data association applications must be developed to allow users to find and pull required data in real time.

The need for speed and accuracy of data and information will dominate the shortfalls 2010- 2027. Continued emphasis will need to be placed on decision aids and information correlation and fusion. Training and retention of analysts will become a serious shortfall.

TPPU Technologies

Program summaries of the Services and Agencies 6.1-6.4 RDT&E programs through the FYDP were reviewed when available. These indicate that considerable effort is being placed on meeting the objective requirements of the DCGS CRD. Insufficient work is planned in the areas of advanced communications, processing, and security which will be discussed in the Recommendations section.

TPPU Observations and Recommendations

A review of the Program of Record and Visionary Shortfalls reveals that there are many areas where existing programs are not going to meet requirements. This section deals with the shortfalls by category and provides recommended courses of action in either the program of record (2002-2010) and/or the visionary era (2010-2027)

- **Multi-Level Security.** This is a major stumbling block for the Intelligence Community in general and specifically for UAVs. The problem is two fold. First, sufficient funds are not being allocated toward the development of technology that will not allow security errors. The second is although this is a community wide problem, there is no accord within the Intelligence Community as to who has the authority and responsibility to mandate standards, procedures, and practices concerning multi-level security from disparate sensors/sources.

  Recommendation: The Intelligence Community (IC) must come together to agree on the scope of the problem and appoint an organization to be in charge. Funding should be made available within the FYDP for the IC to develop the necessary hardware, software, standards, procedures, and practices to make multi-level security possible.
- **Training.** With the advent of new sensors, exploitation techniques, and equipment, and the constant rotation of Service members, it is necessary to develop training programs for newly assigned and current personnel. While the training is a constant recurring need, the establishment of the programs and training aid development is non-recurring.

  Recommendation: Services and Agencies need to POM for training program development within the FYDP.
- **Exploitation Tools.** As new collection technologies become available and existing ones improve, there will be a need to develop new exploitation software and to upgrade existing software consistent with changes in the state-of-the–art of both collection and processing hardware.

  Recommendation: Services and Agencies need to include costs for data exploitation in their sensor programs and for upgrades to existing software as sensors and exploitation platforms are upgraded.
- **Mensuration/Positioning Software.** Services and Agencies are spending large amounts on this problem.

  Recommendation: Current funding levels are sufficient.
- **Tasking Standards.** In order to meet the requirement for all DCGS systems to task all UAV sensors, common tasking standards are needed.

Recommendation: The Services and Defense Intelligence Agency (DIA) need a program to develop a set of tasking standards. DIA should POM for this effort in their FYDP. Furthermore, as new sensors are developed, tasking standards must be modified or written to include them.

- **Decision Aids and Fusion.** Within the past five years it has become obvious that computers can aid in the exploitation Multi INT data. While the number of collectors and their attendant collection volumes are increasing, the number of analysts is shrinking. Services and Agencies must develop automated decision systems to aid in the exploitation and evaluation of data. This effort should include not only individual sensor types but also aid in the fusion and correlation of data from various sources. Target signature databases are needed and a standard test environment will be required to evaluate the decision aids over simulated conditions.

  Recommendation: Services and Agencies should form a joint program office to carry out this program and funds should be POM'd in the FYDP. This effort should carry on through the 2010-2027 timeframe to incorporate new sensors and advances in the state-of-the-art of computing and cognitive science.

- **Cross-cueing.** Target identification can be greatly aided by using data from multiple sensors. In the case of fleeting targets, it is necessary to immediately bring additional sensors to bare on the target. Software is needed that will allow sensors to automatically cross-cue one another on-board in real time.

  Recommendation: Platform developers need to include the cost of cross-cueing software for the sensors on their platforms. Communication paths need to be developed to facilitate the cross-cueing.

- **Posting/Cataloging Schema**. Inherent in the TPPU concept is a repository for both products and raw data. The amount of data available will increase exponentially. In order to be used, there must be schema by which the operator can easily and quickly find and retrieve it. Standard formats, messages, and products must be developed.

  Recommendation: Techniques used in industry must be adapted to meet the specifics of this DoD requirement.

Appendix I: Weapons

UAV Weaponization Overview

The UAV Weaponization Appendix is intended to provide some general insights into the various classes of UAV system designs and the associated weapons integration implications, as well as highlight both current and future UAV weaponization development efforts. This appendix is not intended to advocate for a specific service UAV system design requirement, but attempts to point out the various system design attributes associated with various mission requirements and the appropriate design trades under consideration. Finally, throughout the appendix, where and when appropriate, specific weaponized UAV systems and demonstrations will be referenced to illustrate how various service UAV programs are attempting to satisfy service derived requirements. For clarity, throughout the UAV Weaponization Appendix, the terms "weaponized UAVs" and "Unmanned Combat Air Vehicles" are used. "Weaponized UAV" denotes that weapons have been added or integrated into a principally developed ISR UAV system design. The term "UCAV" denotes a UAV system design developed from the start as a weapons delivery platform with the potential to accomplish other mission requirements like ISR, Electronic Attack, etc.

UAV Weaponization – "Understanding the End-to-End Design Trades"

Many of the system design attributes of weaponized UAVs are generally understood and readily comparable to both simple and complex manned aeronautical combat systems, with the exceptions being the final targeting and weapons control systems reside principally off board the air vehicle. Given this fundamental difference, the end-to-end design trades for weaponized UAV Systems, both for the Air Vehicle (AV) and the Mission Control System (MCS), become a more complex issue when assured weapons system safety and operational control are considered critical performance parameters. In addition, the supporting services' CONOPS generally require a more robust UAV system design due to their repeat exposure to high threat defensive systems (i.e. greater $P_{survivability}$ requirements) and the needed to achieve improved weapons effects within reduced sensor-to-shoot time periods (i.e. greater P_{Kill} requirements).

UAV Weaponization – "System Integration Issues & Design Drivers"

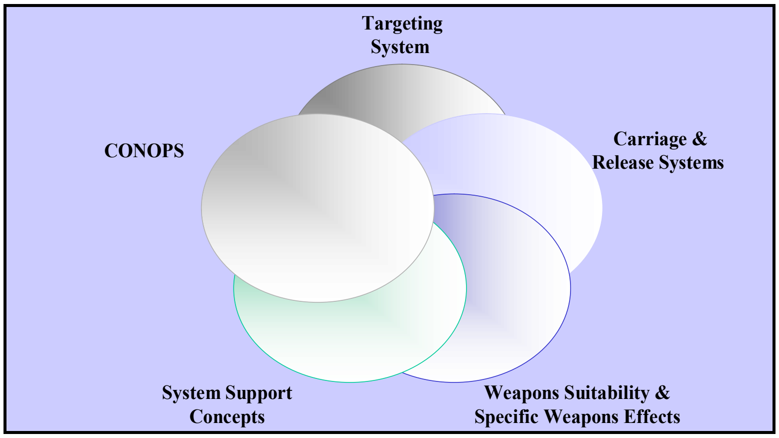


FIGURE I-1: "ISSUES & DRIVERS".

As alluded to previously, weaponized UAVs system designs are generally considered more complex systems with wider system performance margins than baseline ISR UAV systems. Yet, unlike these ISR UAV systems, weaponized UAV systems bring with them a whole host of new systems integration and weapons suitability issues into the overall UAV design trade space. Therefore, whether examining the mission/cost effectiveness of an existing ISR UAV system for weaponization or a future development UCAV system concept, a complete understanding of all the associated carriage/release, targeting sub-systems design drivers, as well as the user associated CONOPS, support concepts and desired weapons effects, will be needed.

UAV Weaponization – "Association With User Provided CONOPS"

An essential part of any weaponized UAV system concept is its association with and specific traceability to key attributes identified within a user derived Concept of Operations (CONOPS). Within the context of this CONOPS, the user generally identifies UAV Weapon System capability shortfalls and desired battlefield effects—thus loosely defining the initial UAV weaponization system design trade space and its suitability for various service missions. The following are brief descriptions of the current supporting CONOPS for various services related weaponized UAV missions:

- ***Armed Reconnaissance*** – The armed reconnaissance CONOPS takes full advantage of the existing ISR UAV system design, leveraging principally the original air vehicle, sensor, and ground control system attributes. The advantages of such an approach are producing specific, predictable weapons effects within the fixed system design limitations, while preserving the original ISR functionality. The strengths of this approach are to quickly advance new weapons delivery capabilities within specific system design and cost limitations. What generally inhibits this CONOPS is the recognition that a wider array of all weather, precise weaponry may be needed, as well as that time-critical operations require greater air vehicle performance than originally designed.

FIGURE I-2: WEAPONIZED MQ-1B PREDATOR A.

- ***Hunter-Killer*** – The next level of weaponization CONOPS helps to mitigate the aforementioned ISR system design limitations, by recognizing that when UAVs work in concert with other UAVs (or other manned vehicles), one component may be optimized as the sensor/targeting device and the other component may then effectively act as the weapons delivery vehicle.

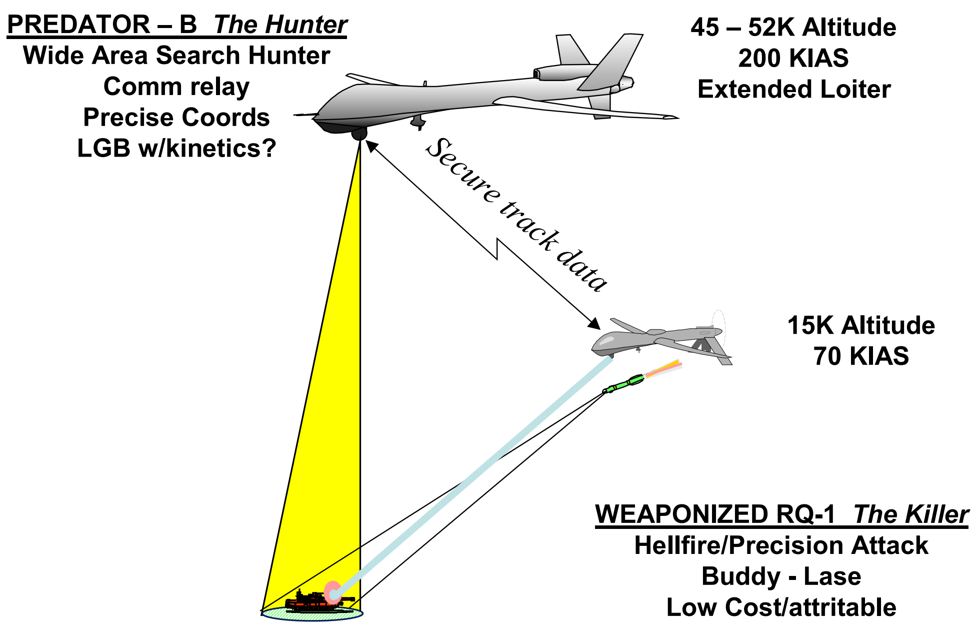


FIGURE I-3: PREDATOR/PREDATOR B, HUNTER-KILLER CONOPS.

The clear advantage of this approach is to link a more costly, yet more effective, persistent, wide area ISR sensor/targeting system to a low cost, attritable platform that accomplishes the final ordinance delivery beneath the weather, closer-in to the intended target. While this CONOPS leverages advanced sensors to independently search for targets over a wide area of interest, the system CONOPS remains largely dependent on continuous processing of large amounts ISR target correlation data, secure continuous communications between air vehicles, and remote piloting/sensor control from a GCS.

• ***SEAD/EA --*** The SEAD/EA system CONOPS for weaponized UAVs is recognized by the user as one of the most stressing system design drivers and, therefore, is often used as the primary focus for development and demonstration of emerging UCAV systems.

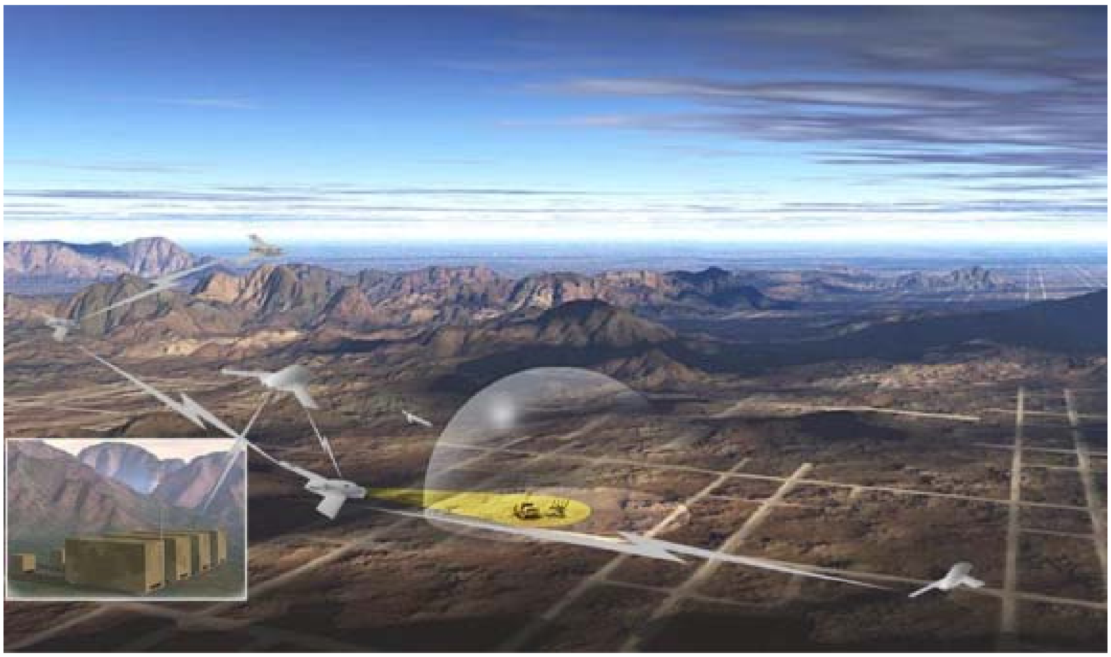


FIGURE I-4: SEAD/EA CONOPS, COOPERATIVE OPERATION.

In this operational role, UCAVs are foreseen as a "first day of the war" force enablers that complement a strike package by performing either preemptive lethal destruction of sophisticated enemy IADS in advance of the strike package or provide supportive Electronic Attack (EA) against specific threat emitters. The effectiveness of this system CONOPS relies largely on a "network centric" Mission Control System (MCS) employing autonomous, multi-ship unmanned air vehicles, and the timely fusion of on-board/off-board sensor information to rapidly find, fix, track and, based on the strike mission priorities and rules of engagement, target specific classes of threats.

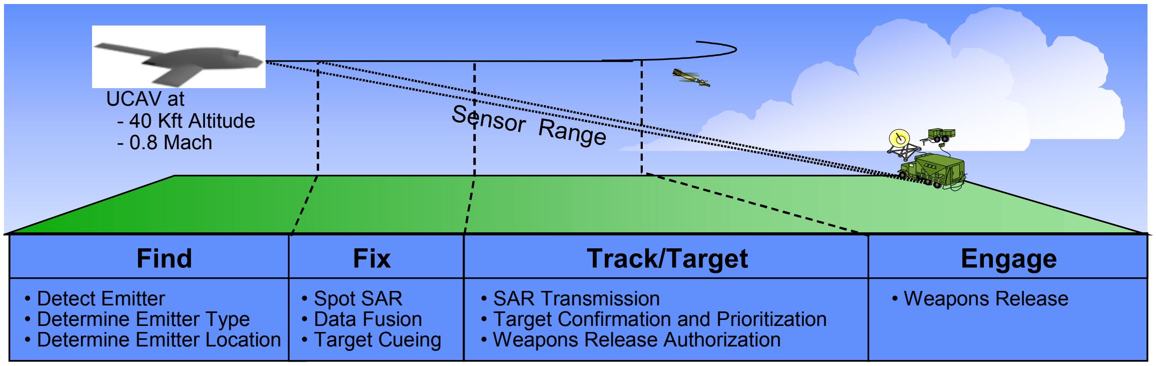


FIGURE I-5: UCAV ENGAGEMENT CONOPS.

Another key feature of this UCAV system CONOPS is the employment of multi-ship cooperative targeting using on-board Electronic Support Measures (ESM) to determine the location of emitter targets and on-board SARs to detect non-emitting targets and reduce Target Location Errors (TLE). Multi-ship ESM can be used to triangulate an emission and cue a UCAV to take a SAR image; the UCAV can then transmit the image to the operator who can authorize (or deny) the UCAVs to engage the target.

- ***Deep Strike -*** The Deep Strike UCAV system CONOPS is often viewed as a stressing requirement for the UCAV design, since extended range without in-flight air refueling and persistence over the target is the key attribute needed. Also implied in the Deep Strike system CONOPS is that some form of off-board/on-board cueing has occurred and then final target resolution and target recognition will be accomplished by the on-board, all weather sensor. The sensor normally assumed is an advanced SAR system with high resolution "Spot" mode capabilities permitting rapid transmission of one-foot resolution of SAR patch map back to the MCS. Studies remain to be performed to determine whether SAR-only imagery will be sufficient (both technically and by Rules Of Engagement) to permit weapon release. As a fallback, EO/IR sensors may be employed to provide visual target identification prior to weapon release.

- ***Other Niche CONOPS*** – Finally, there are some still evolving UCAV system CONOPS now starting to address non-kinetic "leap ahead" technologies. Due to the immaturity of these other niche system CONOPS and the security safeguards currently associated with these technology programs, they will not be addressed in this UAV weaponization appendix.

UAV/UCAV Systems – "Targeting Systems & Descriptive Attributes"

An essential attribute of any weaponized UAV system is how it consistently finds, fixes, and fires its weaponry at the intended target. In that regard, weaponized UAVs and UCAVs benefit/suffer from many of the same targeting systems solutions/limitations associated with comparable performing manned weapon systems, with some minor differences being were the associated on-board equipment may now be located with the removal of the cockpit. However, unlike the more costly, mature, higher aero-performing manned systems, weaponized UAVs and small UCAV system designs are often limited by the weight, volume, and electrical power constraints of the platform. Thus, since often challenged by air vehicle design and cost limits, weaponized UAVs and UCAV must find or develop acceptable performing, yet smaller, less costly targeting systems.

- ***EO/IR Targeting Systems*** – The principal advantage of electro-optic and infrared video camera systems for use on weaponized UAVs is that they can continue to use the basic designed requirements of the existing ISR UAV sensor, with minor adaptations for use as a targeting device for EO/IR weapons.

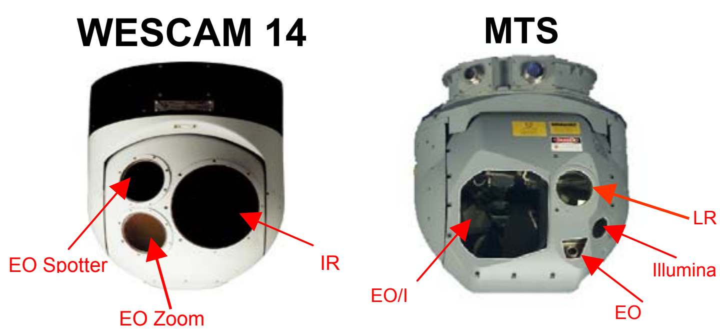


FIGURE I-6: EO/IR TARGETING SYSTEMS.

However, these EO/IR targeting systems generally experience weapons delivery accuracy degradation due to system stabilization/sensor misalignment problems, weather related limitations, or the tactics requiring weapons delivery off axis from the bore-sighted limits of the sensor. In addition, the majority of EO/IR inventory weapons have tended to exceed the single carriage capacity of most current UAV systems.

- ***Radars*** – The tactical utility of using radar data for releasing weapons through the weather near-precisely on the target continues to be greatly improved upon with the advancements in SAR, to include mobile targets with SAR GMTI.

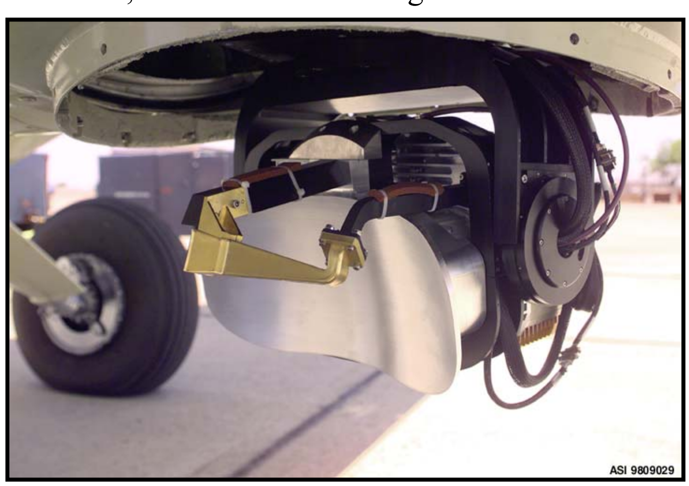


FIGURE I-7: RADAR.

In fact, it has been the ability to correlate both internal navigation systems and global positioning systems with high resolution radar images of the target that less than 3 meter weapons accuracy has been possible in all weather conditions for a single delivery aircraft. Advanced targeting techniques include advanced multi-ship ESM; image mensuration of a SAR image with a terrain database; single vehicle, multiple look SAR images; and multiple vehicle, multiple look SAR images.

However, the current array of inventory radar sensor systems, having been designed and developed principally around larger manned systems, pose significant power, weight, volume, and re-design cost challenges for weaponized UAVs and UCAV systems. In an attempt to reduce these constraints on future UCAVs systems, several conceptual targeting techniques are being demonstrated to further remove the target location errors, respond to time sensitive targeting requirements, and reduce system acquisition costs.

One conceptual approach leverages smaller, less powerful, and less costly SAR systems onboard individual UAVs flying diverse flight paths and fuses within the mission management control system their individual chipped-out views to precisely locate, identify, and target. The other approach is to extend the mission management capability of a manned system, using its larger, more powerful radar system to control smaller, sensor-less UCAVs. Both approaches are dependent on low probability of intercept tactical data links and advanced on-board or off-board processing of SAR image data.

- ***Processors -*** An integral part of every weaponized UAV system design is the sub-system processors that specifically correlate the sensor images, electronic measurements and target signatures with the mission stored targeting and weapons parameters data. It is the processing capability or limitations of the weaponized UAV system that ultimately defines the systems ability to detect identify and recognize targets from the large array of electronic or image data obtained from on-board or off-board sources. While at the same time many of these sub-system components are being developed into smaller, lighter, more compact payloads, specifically for smaller UAV system designs, it is the processing power of these components, coupled with the advancement of new target recognition algorithms initially developed for small advanced, autonomous weaponry processors, that supports greater weapons integration capabilities for UAV system designs.

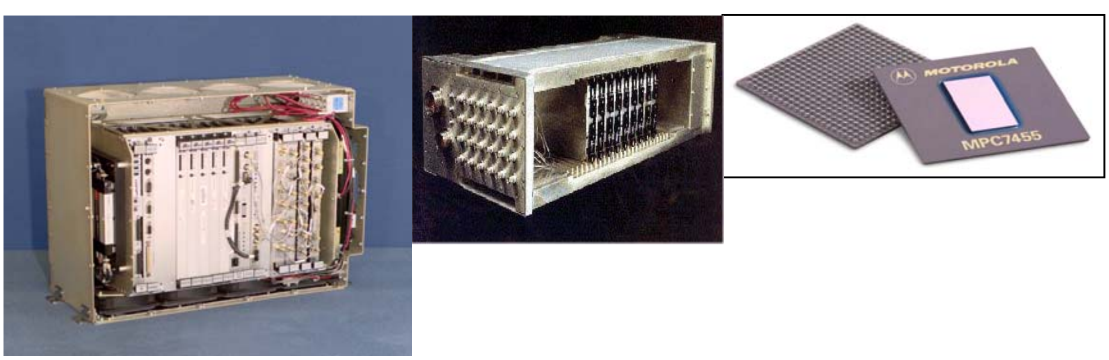


FIGURE I-8: PROCESSORS.

- ***LO Signature Aperture Considerations*** – In designing future penetrating stealthy manned/unmanned system designs, special attention is needed to ensure on-board antenna apertures and sensors do not detract form obtaining the overall system survivability (and affordability) design goals. While advanced tailless stealthy UCAV system designs have shown measurable benefits in their achieving of improved system survivability goals, they still face difficult challenges in managing the numerous new apertures and sensors often needed for unmanned air vehicles systems.

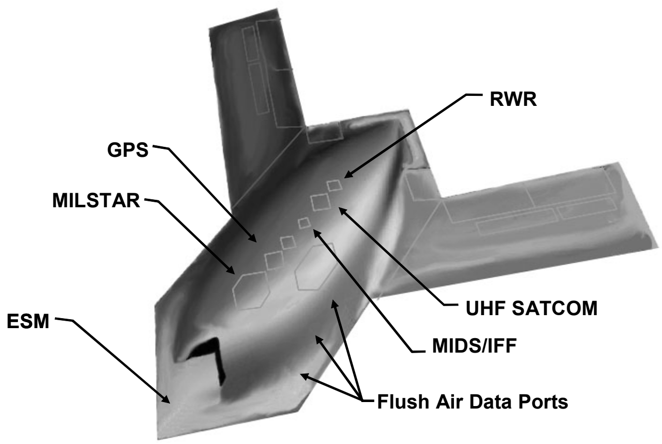


FIGURE I-9: UCAV APERTURES.

In addition, special consideration should be given on how best to attenuate the emissions and/or the radar returns that various sensors and antennas may produce when integrated on the air vehicle, without unfavorably impacting the systems ultimate ability to find, fix, track and deliver weapons in the most stressing weather and threat conditions.

UAV/UCAV Systems – "Carriage & Release Systems"

- ***Internal & External Carriage*** – A key system development consideration in the development of Weaponized UAV system is the suitability of various internal and external carriage and release systems. Initially the user desires to save development and system support costs, as well as take full advantage of existing carriage and release systems that have been developed and will be shared with other manned aircraft systems. However, specific weight, volume, and electrical power limitations on smaller, lighter weaponized UAV systems pose unique challenges. Generally, single external carriage design options for existing smaller ISR UAVs are the easiest to integrate at reduced costs. As the users requirements drive the need for more robust weapons delivery and survivability options on future UCAV systems, new internal storage and release equipment for advanced weapons must be developed. Again, because of the need to hold down weapons integration costs, the users will again insist, to the largest extent possible, to utilize advanced common carriage and release systems that are being developed and shared across the next generation manned/unmanned fleets.

- ***Impact on A/V structures & components*** – In an attempt to hold down overall UAV design weight and gain back some benefits in improved range, loiter and payload capacity, many UAV designers have employed light weight, high strength composite materials throughout much of their wing and fuselage structure. While this structural approach is very effective in holding down overall design-to-weight system costs, it requires a thorough understanding of the operational "end-state" weapons configuration so that the necessary internal and external electrical/fiber wiring, component access/placement and structural hard-points for various classes of weapons are accounted for in the final system design. For example, where a baseline ISR UAV system design used a detachable, fully composite wing structure absent of fuel tanks, electrical components and hard-point attachments, the associated costs to later add external weapons capability later is generally severe and would normally require a complete system redesign and development. Finally, as newer, more advanced compressed weapons carriage and "smart" release systems are developed for weaponized UAV systems and UCAV systems, greater attention will be needed for digital based components and the connecting fiber optic architecture stretching throughout the air vehicle.

- ***Impact on Vehicle Survivability -*** Like the sensors and apertures challenges mentioned previously, stealthy UCAV system designs must consider the appropriate placement of weapons payloads, since their location to the vehicle outer mold line plays an important part in the overall system survivability goals. While there are several options to help mitigate the negative signature effects of external weapons payloads, the most effective payload design, if the additional weight and volume growth cost and performance trades are deemed acceptable, is to optimize the air vehicle internal payload carriage. Also an added benefit of this design approach is easier entry to the supporting subsystem components accessible through the internal payload bays and wheel wells that are open during routine ground maintenance, rather than using external panels which would require repeat costly, time consuming LO resealing and maintenance.

UAV/UCAV – "Weapons Suitability for Various System Designs"

The intended purpose of this section of the Weaponization UAV Appendix is to briefly consider the suitability of various classes of weapons for different types of UAV systems (i.e. a medium altitude, non-stealthy, EO/IR senor equipped; medium altitude vs. stealthy, SAR sensor equipped; etc.)

- ***Air Vehicle Baseline Design & Weapons Suitability -*** The air vehicle baseline design is a key driver in determining the suitability of certain classes of weaponry for integration onboard a UAV system. For example, single carriage, EO/IR weapons are well suited for a medium altitude, non-stealthy, EO/IR sensor equipped UAV system when the mission environment is permissive enough to permit precision employment (i.e. in the absence of a robust IADS, advanced fighter threat and influence of bad weather on both the air vehicle and weaponry). In this permissive environment the real effect of a long-dwell weaponized UAV system that can stare persistently at a stationary or moving target and deliver a precise weapon at the place/time of choosing has been clearly shown. However, building on this long-dwell "persistence" on target and weapons delivery effect will require new highly survivable UCAV systems designs capable of carrying the broader inventory of all weather, precise weaponry providing the full range of targeting effects for the warfighter.

- ***Air Vehicle Performance -*** The combination of both air vehicle aeronautical and survivability performance largely defines the limits of suitability for specific classes of weapons which may be integrated into the weaponized UAV or UCAV system. For example, these performance attributes when examined in light of the air vehicle range/loiter/maneuver requirements will further define the weight/size of the weapons and sensor load outs.

- ***Data/Command Link Considerations -*** Often, a great deal of attention is given to the air vehicle system and weapons integration challenges, without equal consideration for the fragileness or robustness of the Data/Command Link requirements between the air vehicle and the mission control system. Unlike manned systems, overall weapon system effectiveness for weaponized UAVs or UCAV is ultimately dependent on the assured reliability of C4ISR system design components to pass targeting quality sensor data to and weapons release/withhold commands from the weapons officer now resident within the mission control system. Essentially, driven by higher weapons safety, surety and security C4ISR requirements, weaponized UAV and UCAV data/command links will require encryption, low probability of intercept, and redundant paths to ultimately assure the warfighter that the weapon system can be commanded in effect at all times.

Recommendations

Define and implement security measures required for positive control of weapons employment on weaponized UAVs by IOC of the first UCAV squadron (FY08).

Appendix J: Reliability

Background and Definitions

The combined U.S. military UAV fleet (Pioneers, Hunters, and Predators) reached the 100,000 cumulative flight hour mark in 2002. This milestone is a good point at which to assess the reliability of these UAVs. Reliability is at the core of achieving routine airspace access, reducing acquisition system cost, and improving mission effectiveness for UAVs. Although it has taken the fleet of military UAVs 17 years to reach the 100,000 flight hour milestone (see Figure J-1), this appendix highlights the first comprehensive study[9] to formally address the reliability issue for these increasingly utilized military assets. UAV reliability is important because it underlies their ***affordability, availability,*** and ***acceptance***.

Affordability. The reliability of the Defense Department's UAVs is closely tied to their affordability primarily because the Department has come to expect UAVs to be less expensive than their manned counterparts. This expectation is based on the UAV's generally smaller size (currently a savings of some $1,500 per pound) and the omission of those systems needed to support a pilot or aircrew, which can save 3,000 to 5,000 pounds in cockpit weight. Beyond these two measures, however, other cost saving measures to enhance affordability tend to impact reliability.

Availability. With the removal of the pilot, the rationale for including the level of redundancy, or for using man-rated components considered crucial for his safety, can go undefended in UAV design reviews, and may be sacrificed for affordability. Less redundancy and lower quality components, while making UAVs even cheaper to produce, mean they become more prone to in-flight loss and more dependent on maintenance, impacting both their mission availability and ultimately their life cycle cost (LCC).

Acceptance. Finally, improving reliability is key to winning the confidence of the general public, the acceptance of other aviation constituencies (airlines, general aviation, business aviation, etc.), and the willingness of the Federal Aviation Administration (FAA) to regulate UAV flight. Regulation of UAVs is important because it will provide a legal basis for them to operate freely in the National Airspace System for the first time. This, in turn, should lead to their acceptance by international and foreign civil aviation authorities. Such acceptance will greatly facilitate obtaining overflight and landing privileges when larger, endurance UAVs deploy in support of contingencies. Regulation will also save time and resources within both the DoD and the FAA by providing one standardized, rapid process for granting flight clearances to replace today's cumbersome, lengthy (up to 60 days) authorization process. A third benefit of regulation is that it could potentially lower production costs for the military market by encouraging the use of UAVs in civil and commercial applications.

This overview presents reliability from several perspectives commonly used in reliability analysis.

[9] UAV Reliability Study, Office of the Secretary of Defense (Acquisition Technology, and Logistics)

Reliability is the probability that an item will perform its intended function for a specified time under stated conditions. It is given as a percentage which represents the probability that a system or component will operate failure-free for a specified time, typically the mission duration. It relates closely to Mean Time Between Failure.

Mean Time Between Failure (MTBF) describes how long a repairable system or component will continue to perform before failure. For non-repairable systems or components, this value is termed Mean Time To Failure (MTTF).

Availability is a measure of how often a system or component is in the operable and committable state when the mission is called for at an unknown (random) time. It is measured in terms of the percentage of time a system can be expected to be in place and working when needed, or mission available rate (MAR) in percent.

Class A Mishap Rate is the number of accidents (significant vehicle damage or total loss) occurring per 100,000 hours of fleet flight time. As no single U.S. UAV fleet has accumulated this amount of flying time, each fleet's MR represents its extrapolated losses to the 100,000 hour mark. It is expressed as mishaps per 100,000 hours. It is important to note that this extrapolation does not reflect improvements that should result from operational learning or improvement in component technology.

Maintenance cancellations/aborts were broken out into failures of the aircraft's major subsystems. Use of these failure modes lead to a higher fidelity representation of the vehicles' reliability. In order to make uniform comparisons between systems, the following definitions were used to categorize areas of system failure leading to mission aborts or cancellations.

Power/Propulsion (P&P). Encompasses the engine, fuel supply, transmission, propeller, electrical system, generators, and other related subsystems on board the aircraft.

Flight Control. Includes all systems contributing to the aircraft stability and control such as avionics, air data system, servo-actuators, control surfaces/servos, on-board software, navigation, and other related subsystems. Aerodynamic factors are also included in this grouping.

Communication . The datalink between the aircraft to the ground.

Human Factors/Ground Control. Accounts for all failures resulting from human error and maintenance problems with any non-vehicle hardware or software on the ground.

Miscellaneous. Any mission failures not attributable to those previously noted, including airspace issues, operating problems, and other non-technical factors. Because operating environments are not uniform as a variable affecting the data, weather was excluded as a causal factor in this study.

Data and Trends

Figure J-1 shows the numbers of Predators, Pioneers, and Hunters lost in Class A mishaps by year for the period 1986 through 2001. Class A mishaps are those aircraft accidents resulting in loss of the aircraft (in Naval parlance, "strike"), human life, or causing over $1,000,000 in damage. These data show a cumulative mishap rate (i.e., Class A accidents per 100,000 hours of flight) of 32 for Predator, 334 for Pioneer, and 55 for Hunter (16 since the major reliability improvements in 1996). In comparison to manned aviation mishap rates, general aviation aircraft suffer about 1 Class A mishap per 100,000 hours, regional/commuter airliners about a tenth of that rate, and larger airliners about a hundredth of that rate.

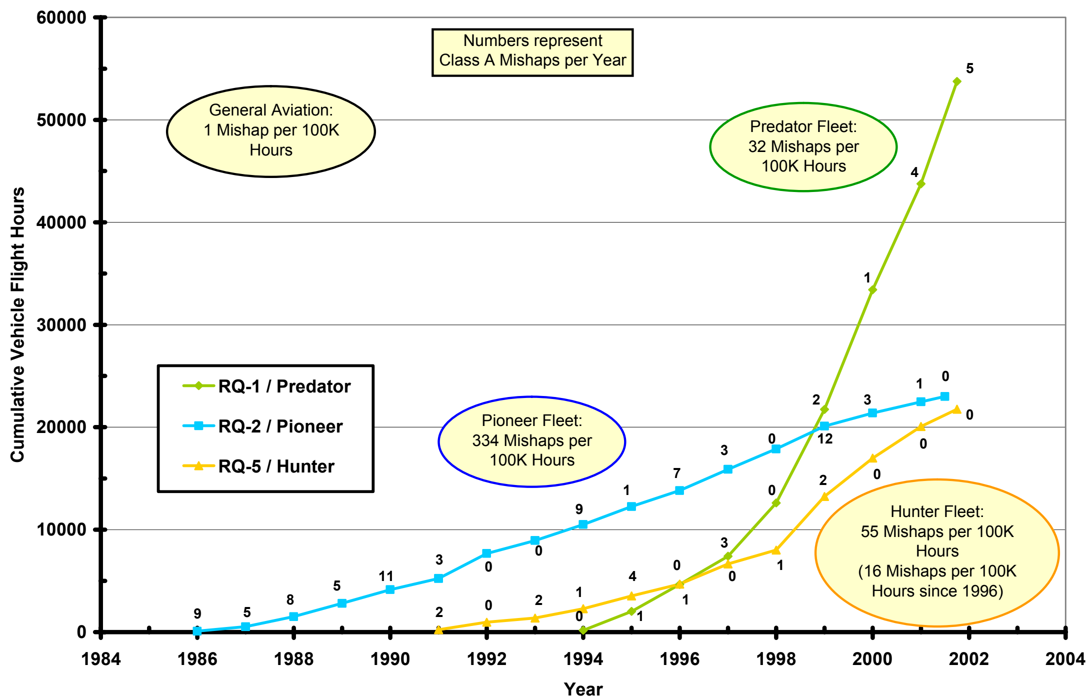


FIGURE J-1: U.S. MILITARY UAV MISHAP RATES (LIFETIME), 1986 – 2002

These statistics make it apparent that the reliability of UAVs needs to improve by one to two orders of magnitude to reach an equivalent level of safety with manned aircraft. The reliability trends calculated during these flight hours are detailed in Tables J-1 and J-2. Following these data is a discussion about the individual UAV systems (early and late models) and how their fielding and operation contribute to the reliability data.

TABLE J-1: SUMMARY OF UAV RELIABILITY FINDINGS.

		MTBF (hrs)	Availability	Reliability	Mishap Rate per 100,000 hrs (Series)	Mishap Rate per 100,000 hrs (Model)
RQ-1A/ Predator	Requirement	n/a	n/a	n/a	n/a	32
	Actual	**32.0**	**40%**	**74%**	**43**	
RQ-1B/ Predator	Requirement	40	80%	70%	n/a	
	Actual	**55.1**	**93%**	**89%**	**31**	
RQ-2A/ Pioneer	Requirement	25	93%	84%	n/a	334
	Actual	**9.1**	**74%**	**80%**	**363**	
RQ-2B/ Pioneer	Requirement	25	93%	84%	n/a	
	Actual	**28.6**	**78%**	**91%**	**139**	
RQ-5/ Hunter (pre-1996)	Requirement	10	85%	74%	n/a	55
	Actual	n/a	n/a	n/a	**255**	
RQ-5/ Hunter (post-1996)	Requirement	10	85%	74%	n/a	
	Actual	**11.3**	**98%**	**82%**	**16**	

Table J-1 summarizes the reliability metrics for all military UAVs examined in this study. With respect to the required values as outlined in the operational requirements and specifications, green and red signify instances in which the actual values meet or fall short of the requirements, respectively. In the case of the mishap rate per 100,000 hours, no requirements were identified. In addition, requirements are not available for the RQ-1A/Predator due to their development after concluding its ACTD (discussed later in this Appendix).

The mishap rate per 100,000 hours is presented in two ways. The model/series mishap rate illustrates "before and after" gains made in reliability and operations between subsequent versions of the same UAV model. The model mishap rate is a snapshot of the combined performance of all versions of each UAV model. It incorporates all mishaps over that fleet's cumulative flight hours.

In all cases except for the RQ-2/Pioneer, the UAV systems examined in this study exceed operational requirements. The shortfalls in the RQ-2A reliability performance (shown in red) were amended with the next generation RQ-2B with the exception of the availability metric.

Table J-2 presents the failure modes analysis for each UAV model.

TABLE J-2: SUMMARY OF UAV FAILURE MODE FINDINGS.

	Power/ Propulsion	Flight Control	Comm	Human/ Ground	Misc
RQ-1A/ Predator	23%	39%	11%	16%	11%
RQ-1B/ Predator	53%	23%	10%	2%	12%
RQ-2A/ Pioneer	29%	29%	19%	18%	5%
RQ-2B/ Pioneer	51%	15%	13%	19%	2%
RQ-5/ Hunter	29%	21%	4%	29%	17%

There are several noteworthy trends from the summary data in Table J-2.

- The failure due to Human/Ground related issues is significantly lower for the MQ-1B Predator. This may be largely due to the increased use of simulators for Predator training, as well as enhancements made in situational awareness.
- Despite some initial integration issues, a more complex solution for over-the-horizon ATC communication via the ARC-210 radio did not increase the share of mishaps due to communication hardware and software failures for the RQ-1.
- The trends in the MQ-1/Predator and RQ-2/Pioneer failures due to Power/Propulsion are very similar. The share is in the 20-30 percent range (23% and 29%, respectively) for the early, A-model systems, but doubles to the 50 percent range (53% and 51%, respectively) in the later models. MQ-1 Block 30 upgrades address this issue.
- The trends in the MQ-1/Predator and RQ-2/Pioneer failures due to Flight Control issues are also very similar. From the A-model to the B-model, the share decreases by approximately one-half (39% to 23% and 29% to 15%, respectively). This may be attributed to a better understanding of the vehicle aerodynamics and flight control as well as self-imposed flight restrictions for certain operating environments.
- Despite any noticeable shifts of failure modes among the vehicles from the early to the late model, the reliability trends for the UAVs continued to be positive. This indicates an awareness of, and attention to, system deficiencies on the part of the designers and operators.

The average values for the failure modes for all five systems are presented in Figure J-2. This aggregate view of the Predator, Pioneer, and Hunter UAV fleet provides a good introduction into a similar perspective on foreign UAV reliability.

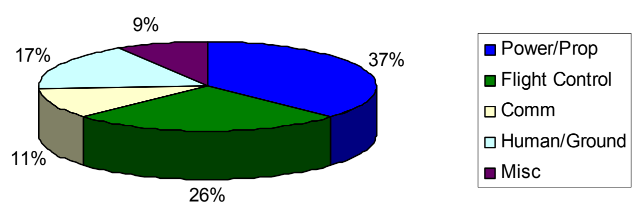


FIGURE J-2: AVERAGE SOURCES OF SYSTEM FAILURES FOR U.S. MILITARY UAV FLEET (BASED ON 97,000 HOURS)

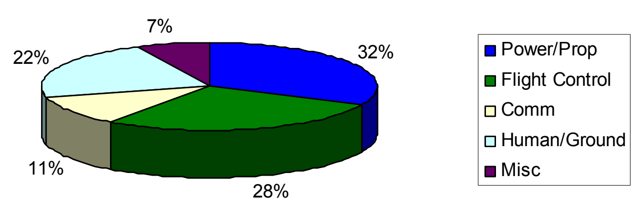


FIGURE J-3: AVERAGE SOURCES OF SYSTEM FAILURES FOR IAI UAV FLEET (BASED ON 100,000 HOURS)

Israeli Defense Forces have also accumulated over 100,000 hours of operational flight experience with their UAVs. The manufacturer of most of these UAVs, Israeli Aircraft Industries (IAI), has documented the causes of failures across the past 25 years of this experience and made recommendations for improving reliability based on this analysis. Of current U.S. UAV systems, both the Pioneer and the Hunter originated as IAI designs, and the Shadow evolved from the Pioneer's design. For these three reasons, any examination of U.S. UAV reliability would be incomplete without examining the reliability of their Israeli counterparts and predecessors.

The data trends derived from the U.S. UAV operations summarized in Figure J-2 are remarkably similar (within 5%) to that of the Israeli UAV fleet for all failure modes. Given that the IAI data is also based on a substantial number of flight hours as well, one can argue that the U.S. is facing the same technical and operational problems of other operators. Furthermore, because manufacturing techniques and supply quality differ from one country to the next, it is interesting to ask the question "Why are the failures modes still similar?" One answer points to external factors and the operating environment itself, including weather and the low Reynolds number flight regime.

MQ-1 and MQ-9/Predator

MQ-1A. The Predator experienced low mission completion rates during its initial deployments in the Balkans in 1995-1997. While the primary causal factor was weather, system failures did account for 12% of the incomplete missions. Mission-level operational data from the system deployed in Hungary was used to perform a limited assessment of system reliability based on data covering missions from March 1996 through April 1997.

Out of the 315 Predator missions tasked during that timeframe, weather and system cancellations kept nearly two-thirds on the ground (60%). Of the remaining missions that were launched, slightly under one half were subsequently aborted. These aborts were due to system (29%), weather (65%), and operational issues (6%) that included airspace conflicts, operator errors, and crew duty limitations.

Data indicates that 38 missions (12%) were scrubbed due to system failures, an additional 18 system aborts (6%) that did not result in mission cancellation (due to launch of another vehicle or weather hold), and other issues which kept the Predator on the ground 6 times (2%). Out of this total of 62 sorties affected by mission aborts or cancellations due to maintenance, operations, or human errors, the systems' failure breakout data is provided in Table J-2.

MQ-1B. The Predator transition into production led to some problems which affected vehicle reliability. As the first ACTD program to transition to production, the Predator established the precedent, as well as the lessons learned, for the transition process. First, nearly continuous deployment commitments since March 1996 have delayed operational testing. Second, development of the ORD, usually produced early in a program to guide system design, was not begun until after the ACTD ended (indicated by the N/A in Table J-1) Third, additional challenges to system reliability were introduced, such as the addition of a wing deicing system (glycol-weeping wings) as well as a redesigned control station for greater portability.

Since this rocky start, the Predator fleet has logged over 50,000 hours and has "come of age" during Operation Enduring Freedom. As a result of its unorthodox transition process, however, Predator reliability issues were discovered and addressed during operations around the world. Although the system still experiences reliability issues and vehicle losses, its performance during these operations has been remarkably good when compared to those outlined in the ORD.

The data in Table J-1 and J-2 represents all mission aborts (on the ground and in-flight) for all RQ-1B systems between January 1997 and June 2002. The share of power/propulsion failure modes has doubled in the MQ-1B compared to the MQ-1A. The Predator program office acknowledges that the engine is the primary reliability issue.

The primary distinguisher between the MQ-1A and MQ-1B models is the Rotax 914 turbocharged engine, which replaced the smaller Rotax 912 model, and was implemented primarily to increase the Predator's speed. With the new engine, a variable pitch propeller was also added. The data over this five-year period indicates that the new variable pitch propeller accounted for 10 percent of all power/propulsion aborts, while the engine made up nearly 70 percent. This is accompanied by a corresponding reduction in flight control failures as well as a large decrease in malfunctions attributable to human errors and operations and hardware on the ground. This does not necessarily mean that powerplant-related failures have increased in the B model, but that reliability improvements made in other areas (comms, etc.) have made a comparatively greater impact on system reliability.

The significant decline in human and ground related errors (from 16 percent to 2 percent) is attributed to a concerted training effort according to one Predator operator. Enhancements in situational awareness also played a role in this positive trend. For example, periodic automated updates of the weather are supplied to the control station. A VHF/UHF ARC-210 radio has also been added to provide voice relay capability to the MQ-1B pilot, enabling direct, over the horizon communication with Air Traffic Control (ATC) authorities in the area of flight. An APX-100 Identification, Friend or Foe (IFF)/Selective Identification Feature (SIF) Mode 4 transponder was added to further facilitate coordination with AWACS flight controllers. Air Force PFPS (Portable Flight Planning Software), an offshoot of the Air Force Mission Support System (AFMSS), is another tool defined in the Block 1 upgrade in which threat and mission planning information can now be passed directly to the Predator system.

The percentage of communications and flight control failures remained virtually unchanged between the two models.

MQ-9. To address certain reliability issues which arose during MQ-1B operations, the Predator B system, recently denoted MQ-9A, is scheduled to undergo specific modifications from its predecessors designed to enhance reliability. Specifically, the Predator B will have actuators with an MTBF of 2,000 hours, which is over an order of magnitude improvement over the actuator MTBF of 150 hours on the Predator A models. There will be a triplex (double redundant) flight control system, and the control surfaces survivability will increase with two rudders, four ailerons, and four elevators. The overall objective failure rate for the Predator B is on the order of 10^{-5}, or 1 in 100,000 hours of flight, a value equal to that for a number of mature manned aircraft. For a typical 15 hour flight, this translates to an operational reliability of over 99.99 percent.

RQ-2/Pioneer

RQ-2A. The reliability analysis for early-model Pioneers is based on statistical data gathered between September 1990 and April 1991 from three Marine, two Navy, and one Army Pioneer unit (total of six systems) while deployed in the Persian Gulf theater in support of Operations Desert Shield and Desert Storm. Although known as the Option II+ version of Pioneer at that time, this model was subsequently designated as the RQ-

2A. At the time of this data, it had been in service with the Navy for four years, the Marines for three, and the Army for one. By this time, it had already incorporated a number of reliability improvements to its original, imported version.

With respect to its Operational Requirements Document, the early model Pioneer achieved less than desired reliability metrics. This could be due to one of several factors. First, the Pioneer was purchased from Israel as a non-developmental system in an accelerated procurement. Once in operation, Navy and Marine users quickly identified several deficiencies that contributed to unreliability. General Charles C. Krulak, then Commandant of the U.S. Marine Corps noted "the Pioneer does not have an automatic take-off, landing, or mission execution capability and that has led to a high accident rate." Shipboard electromagnetic interference caused several crashes, and the engines were thought to be too small and easily overstressed. In addition to the need for a more reliable engine, the Marine Corps users also felt that the system needed a smaller logistical footprint and a longer endurance.

RQ2-B. The currently fielded version of Pioneer, the RQ-2B, is essentially a digital version of its analog predecessors, with the major distinction being the replacement of the analog air data system with the digital Modular Integrated Avionics Group (MIAG). RQ-2Bs are modifications of the existing RQ-2A airframes, rather than new production. All twenty-five operational (out of 49 existing) RQ-2As have been converted to RQ-2Bs. There are plans to acquire spare MIAG kits through the Pioneer Improvement Program.

The reliability analysis for later model Pioneers is based primarily on the Marine Pioneer squadron's VMU-1 and VMU-2 operations in the late 1990's. The reliability data for the RQ-2B is derived from two sources: maintenance aborts and in-flight aborts. Each offers a somewhat different perspective on the reliability of the overall vehicle. In a distribution closely resembling to the Predator MQ-1A data, the majority of the failures (66%) are attributable to the combination of malfunctions in flight control, power, and propulsion. The breakout in the flight critical systems is roughly 25 percent flight control failures and 75 percent power & propulsion failures. (Recall the corresponding RQ-2A data showed failures due to power and propulsion and flight control equally divided.) This suggests an improvement in the flight control system of the Pioneer over time, or perhaps a shift in emphasis from power and propulsion concerns. The latter explanation is supported given that the planned (1997) conversion from the Sachs to the more reliable Quattra engine was never accomplished.

RQ-5/Hunter

Following three crashes in close succession in August-September 1995, OSD terminated the RQ-5/Hunter program after LRIP completion by deciding to not award a full rate production contract. Seven systems of eight aircraft each were delivered between April 1995, and December 1996. A total of 62 aircraft were built by IAI/Malat and assembled by TRW. Since that redirection, however, the Hunter program has made numerous component quality related improvements and been used to demonstrate a wide variety of payloads including SIGINT, chemical agent detection, and communication relay for UAV use. It has supported National Training Center exercises and NATO operations in Kosovo, and it recently served as the surrogate TUAV for the Interim Brigade Combat Team at Ft Lewis, Washington.

The acquisition of the Hunter system by the Army presents a case study in the peril of ignoring, and the benefits of overcoming, reliability problems. During system acceptance testing in 1995, three Hunter aircraft were lost within a 3 week period, contributing to a decision to terminate full rate production. Wanting to benefit as much as possible from its substantial investment in the Hunter, its Program Management Office and the prime contractor (TRW) performed an end-to-end Failure Mode Effect and Criticality Analysis (FMECA) and a Fishbone Analysis on each of the critical subsystems. An interconnected network of failure analysis and corrective action boards was implemented with the authority to direct design changes to Hunter. Failures of its servo actuators, the leading culprit for the series of crashes, were identified, and their MTBF increased from 7800 hours to 57,300 hours, a sevenfold improvement. Other key components received focused attention including the datalink and engine.

Hunter returned to flight status three months after its last crash. Over the next two years, the system's MTBF doubled from four to eight hours and today stands at over 11 hours. The aircraft itself achieved its required MTBF of ten hours in 1999, and today that figure stands close to 20 hours. Prior to the 1995 stand down and failure analysis, Hunters were experiencing a mishap rate of 255 per 100,000 hours; afterwards (1996-2001) the rate was 16 per 100,000 hours. Initially canceled because of its reliability problems, Hunter has become the standard to which other UAVs are compared in reliability.

In addition to the reliability data shown in Table J-1, an in-house reliability assessment performed by the prime contractor for the period of 20 December 1995 through 15 December 2001 found a system MTBF of 16.31 hours and an availability of 0.993. Using this MTBF value, the calculated reliability for a 2.5 hour mission is 0.86. All of these contractor-generated values are higher, yet not significantly different, than those calculated from the flight data.

The failure modes analysis in Table J-2 is built on data from 19 June 1994 to 16 July 2001. This data shows that Hunter's failures, as opposed to previous system level breakouts for Predator and Pioneer, are generally much more evenly distributed among the failure modes. This is likely due to the concerted effort of the prime contractor – after a rigorous assessment of overall system reliability – to focus improvement on those areas in which the early vehicle's reliability was lacking. The 17 percent of failures attributed to "Miscellaneous" is composed of malfunctions with the flight termination system and parachute vehicle recovery system.

The high mishap rate of the early Hunters is comparable to that of the early Pioneers and, based on that similarity can be largely attributed to poor Israeli design practices for their UAVs in the 1980s. The significant improvement in Hunter's mishap rate achieved since the mid-1990s is reflective of (1) joint government/contractor-focused oversight, (2) a rigorous review and analysis process being put in place, and (3) qualitative improvements in a number of failure-critical components (servo-actuators, flight control software, etc.).

Technology Enhancing Solutions

To address the reliability shortcomings identified above, examples of current and developmental technologies are presented in Table J-3. These technologies – provided in detail in the OSD UAV Reliability Study – are provided as examples of commercial and government off-the-shelf (COTS/GOTS) solutions which have the potential to significantly enhance UAV reliability. Technologies/processes for each of the major failure modes are presented at three levels of cost/complexity.

TABLE J-3: TECHNOLOGY TO ENHANCE UAV RELIABILITY.

	Low Level COTS/GOTS	High Level COTS/GOTS	Next Generation
Power and Propulsion	Lighter Engine Blocks	Heavy Fuel Engine	Fuel Cell Technology
Flight Control	Better Component Selection Methodology	Advanced Digital Avionics Systems	Self-Repairing, "Smart" Flight Control Systems
Communications	Better Environmental Control	Electronically Steered Arrays	Film and Spray-on Antennas
Human/Ground	Enhanced Pilot Training	Auto Take-Off and Recovery	Enhanced Synthetic Vision

Recommendations

Based on the preceding reliability data and trends analysis, it is possible to distill a focused set of recommendations which will have a measurable impact on UAV reliability growth.

R-1 Introduce joint standardization of reliability data tracking for operational UAV systems.

Data collection for this study provided insight into an inconsistent (and at times inaccurate and incomplete) reporting framework for tracking the reliability growth of various UAV fleets. This makes it particularly difficult to gauge not only the reliability of one system, but also any trends across system and Service lines. A single format, with jointly agreed definitions for data fields for key reliability metrics, needs to be developed and implemented.

R-2 Perform a cost-benefit trade study for incorporating/retrofitting some or all of the Predator B's reliability enhancements into production Predator A models.

R-3 Perform cost-benefit trades for low and high level COTS/GOTS approaches identified in Table J-3 to improve reliability for each fielded UAV system.

R-4 Develop and implement a Reliability Specifications Standard for UAV design.

Design changes can cost 1,000 and 10,000 times more at the LRIP and final production phases, respectively, than the same change would during product design. As a result, cost increases at the early stage (for reliability downstream) can in most cases be justified.

R-5 Incorporate the emerging technologies identified in Table J-3 into the Defense Technology Objectives and the Defense Technology Area Plan.

R-6 Encourage more research into low Reynolds number flight regimes.

Just as UAVs come in many categories, so too do the flight environments in which they operate. As a result, Reynolds number effects must be better understood to provide insight into such areas as (1) steady and unsteady flow effects, (2) three-dimensional laminar/turbulent flow transition, and (3) ideal airfoil and wing geometries at Reynolds and Mach numbers which encompass the spectrum of UAV flight profiles.

Investments in low Reynolds number engine components is also critical. Turbomachinery for UAVs at low speeds or high-altitudes face flight environments which are different than those to which modern propulsion has traditionally catered. Heat rejection, turbine and compressor tip losses, and low dynamic pressures are a few of the factors which can degrade the performance of a small propulsion system at these low Reynolds number conditions.

R-7 Investigate the potential role of advanced materials and structures for enhancing UAV reliability and availability.

High temperature materials and light-weight structures can offer significant weight savings for UAV airframes. On the horizon, smart materials such as shape memory alloys will offer alternatives to the servos, flight control surfaces, and even de-icing systems of existing aircraft designs, which in turn will reduce components count and increase reliability.

R-8 Incorporate and/or develop all-weather practices into future UAV designs.

Icing has been a primary factor in two Hunter mishaps and three Predator losses. UAV cold weather tolerance, as well as operation in precipitation and suboptimal wind conditions, should be a focus for UAV designers to enhance UAV reliability and availability in real world operations.

Improving UAV reliability is the single most immediate and long reaching need to ensure their success. Their current levels of reliability impact their operational utility, their acquisition costs, and their acceptance into airspace regulations. The value of making reliability improvements must be weighed against not only acquisition cost, as is traditionally the case, but also against the less quantifiable returns to be gained by a commander. As a critical resource to the commander, UAVs must be available when they are called upon and have the ability to operate freely and respond quickly in any airspace. These recommendations are structured to ensure that this occurs.