OFFICE OF THE
SECRETARY OF DEFENSE

UNMANNED AERIAL VEHICLES ROADMAP

APRIL 2001

2000 - 2025

OFFICE OF THE SECRETARY OF DEFENSE

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SUBJECT: Unmanned Aerial Vehicle (UAV) Roadmap

Over the past year, the staffs of USD(AT&L) and ASD(C3I) have worked in concert, leading a multi-organizational team to prepare a consolidated UAV Roadmap. The aim of the UAV Roadmap is to stimulate the planning process and to provide a forum for mutual discussion. This document does not presume nor does it seek concurrence by the Services. It does not impose any requirement upon the Services to program or fund any item described herein. Cost estimates and proposals for concepts of operations are notional objectives and have not been studied or validated by the Services.

Although the Roadmap is not directive in nature, conclusions and opportunities are highlighted based on the trends and future needs. The UAV Roadmap includes:

- Program details on UAV systems used operationally, as well as on developmental programs
- A list of prioritized UAV missions, as generated and validated by the warfighting CINCs
- A trend analysis of technology areas to forecast opportunities, as well as a summary of on-going science and technology programs for UAV-related platforms, sensors, communications, information processing, and payloads
- A discussion on UAV experimentation, demonstration, battle lab, and modeling & simulation facilities that are crucial to understanding UAV roles, concepts of operations, development, training, and tactics
- A discussion that highlights overarching technical, programmatic, political, regulatory, and operational issues

In order to provide a common vision of where we should proceed with future UAV-related efforts, it is our desire to share this Roadmap with industry and with our Allies, in addition to the military services.

We've seen how the advent of precision weapons changed the way we fight and our expectations of combat. Achieving information superiority, minimizing collateral damage, fighting effectively in urban areas against widely-dispersed forces, and striking precisely are areas where UAVs will continue to assist us. Our hope is that this Roadmap will provide visibility and support for technology areas and evolving UAV missions, and will encourage the Department, and our industry partners, to aggressively proceed with UAV-related developments.

David R. Oliver
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Executive Summary

This document presents the Department of Defense's (DoD) roadmap for developing and employing unmanned aerial vehicles (UAVs) over the next 25 years (2000 to 2025). It describes the missions identified by theater warfighters to which UAVs could be applied, and couples them to emerging capabilities to conduct these missions. A series of Moore's Law-style trends are developed to forecast technological growth over this period in the key areas of propulsion, sensor, data link, and information processing capabilities. The result is a roadmap of capability-enhancing opportunities plotted against the life spans of current and projected UAVs. It is a map of opportunities, not point designs - a descriptive, not a prescriptive, future for UAVs.

This study does not necessarily imply future officially sanctioned programs, planning, or policy. Further, the conclusions at the end of this study (section 6.5) are not currently funded or programmed within the military Services' plans. This section is not direction to any DoD organization to pursue any specific course of action. It is merely intended to highlight opportunities in the broad areas of technology, operations, and organizations, that the Services, industry, or other UAV-related organizations may wish to consider when developing plans and budgets for future UAV activity.

The U.S. military has a long and continuous history of involvement with UAVs, stretching back to the Sperry/Curtiss N-9 of 1917. UAVs have had active roles in the Vietnam conflict (3435 sorties), Persian Gulf War (over 520 sorties), and in the ongoing Balkan operations, providing critical reconnaissance in each. With recent technologies allowing more capability per pound, today's UAVs are more sophisticated than ever. As the military's recent operational tempo has increased, so too has the employment of UAVs. Over the past decade, the Department of Defense has invested over $3 billion in UAV development, procurement, and operations, and will likely invest over $4 billion in the coming decade. Today, the DoD has 90 UAVs in the field. By 2010, this inventory is programmed to grow to 290, with UAVs performing a wider variety of missions than just reconnaissance.

New capabilities projected for UAVs over the next 25 years include:

- Silent flight as fuel cells supplant internal combustion engines in some systems.
- 60 percent gains in endurance due to increasingly efficient turbine engines.
- Rotorcraft capable of high speeds (400+ kts) or long endurance (24+ hrs) while retaining the ability to hover.
- Endurance UAVs serving as GPS pseudo-satellites and airborne communications nodes to provide theater and tactical users with better connectivity, clearer reception, and reduced vulnerability to jamming.

- Faster cruise missile targeting due to more precise terrain mapping by high altitude UAVs.

- Self-repairing, damage compensating, more survivable UAVs.

- Significantly speedier information availability to warfighters through onboard real-time processing, higher data rates, and covert transmission.

The advantages offered by UAVs to the military commander are numerous and often subject to debate. These advantages accrue most noticeably in certain mission areas, commonly categorized as "the dull, the dirty, and the dangerous." In an era of decreasing force size, UAVs are force multipliers that can increase unit effectiveness. For example, due to its vantage point and multiple sensors, one hovering unmanned sentry could cover the same area as ten (or more) human sentries ("the dull"). The threat of nuclear, biological, or chemical (NBC) attacks on the U.S. or its military forces abroad will likely remain a key national security concern for the next 25 years, prompting the need for means to conduct operations in their aftermath. UAVs could reconnoiter contaminated areas without risk to human life[1] ("the dirty"). In a climate more demanding of lossless engagement, UAVs can assume the riskier missions and prosecute the most heavily defended targets. Unaccompanied combat UAVs (UCAVs) could perform the high-risk suppression of enemy air defenses (SEAD) missions currently flown by accompanied EA-6s or F-16s ("the dangerous"). In such a role, UAVs would be potent force multipliers, directly releasing aircraft for other sorties.

Finally, and most fiercely debated, is the potential cost advantage offered by UAVs. Serious comparisons of manned versus unmanned system *acquisition* costs tend to show little advantage for the latter (the adjusted costs for reaching first flight for the U-2 in 1955 and the RQ-4/Global Hawk in 1998 were roughly the same). Likewise, any savings in *procurement* costs cited for UAVs by deleting the cockpit, its displays, and survival gear is typically offset by the cost of similar equipment in the UAV ground element. However, with innovative concepts of operation, UAVs may offer increased efficiencies in *operations and support* costs due to the reduced need to actually fly pilot proficiency and continuation training sorties. Such reductions in UAV O&S costs offer the potential for life cycle cost savings if adopted and managed correctly within the overall weapon system tasking tempo directed by the Defense Planning Guidance.

UAVs will play a major role in the increasingly dynamic battle control that will evolve in the 21st century. There will be micro air vehicles as well as behemoths. UAVs will stay airborne for weeks or months and longer, fly at hypersonic speeds, sense data in revolutionary ways, and communicate their data at unprecedented rates. Challenges, such as providing an adequate C^3 infrastructure to capitalize on unmanned as well as manned operations, remain to be overcome. However, the decisions made now will lay the foundation for how far and how fast these advances are implemented. Only our imagination will limit the potential of UAVs in the 21st century.

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[1] U.S. pilots flew similar missions in the late 1940s, exposing themselves to life-threatening levels of radiation to characterize the effects of our nuclear weapons tests in the Pacific.

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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 2000 to 2025. It is intended to assist Department of Defense (DoD) decision makers in developing a long-range strategy for UAV development and acquisition in the forthcoming Quadrennial Defense Review (QDR) and beyond. 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 the future Army's Brigade Combat Teams (BCTs), the Navy's DD-21 destroyers, and the Air Force's Aerospace Expeditionary Forces (AEFs). As an example, the Army's current "Transformation" initiative envisions each BCT 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 the most comprehensive, authoritative sources of warfighter needs. Link these requirements to capabilities needed in future UAV platforms, sensors, communications, and information processing.

2. Develop a series of forecasting trends ("Moore's Laws"[2]) 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 will become available for fielding.

[2] Moore's Law (Gordon Moore of Intel Corp.) originated in 1965 as a forecast that the capability (number of transistors on an integrated circuit) of microchip processors would double every 12 to 18 months. Based on historical performance, not physics, it has nonetheless proved useful for predicting when a given technology level will become available. The semiconductor industry has used it to define its technology roadmap for sustained growth over the past 35 years.

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:

- 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 now for use in the far term for inclusion in the Defense Technology Objectives, the Joint Warfighting Science and Technology Plan, and the Defense Technology Area Plan.

1.3 Scope

Like its highway namesake, this roadmap is descriptive, not prescriptive, in nature. It describes the options of routes (current and future technologies) available to reach a number of destinations (mission needs). It neither advocates specific UAV programs nor prioritizes the requirements, as this is the responsibility of the Joint Requirements Oversight Council (JROC) and the Services. It does, however, identify future windows when technology will 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. The roadmap's span of 25 years was chosen to accommodate the usual 15 years required to transition a demonstrated laboratory capability into an operationally fielded system, followed by 10 years of spiral development of the system until the ultimate derivative is in production, or production ends. This constitutes one (the next) generation of aircraft and payload technology.

The information presented in this study is current as of 31 December 2000.

2.0 Current UAV Programs

This chapter provides condensed descriptions of current Defense Department UAV efforts as background for the focus of this roadmap—requirements and technologies for future UAV capabilities. It categorizes the Department's UAVs as *operational* (those currently operated by 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.

2.1 Operational UAV Systems

2.1.1 RQ-1 Predator

RQ-1 Predator/General Atomics ASI/Air Force

Weight	Length	Wingspan	Ceiling	Radius	Endurance
2,250 lbs	26.7 ft	48.7 ft	25,000 ft	400 nm	24+ hrs

Payload Weight: 450 lbs

The Air Force RQ-1 Predator began as an Advanced Concept Technology Demonstration (ACTD) in 1994 and transitioned to an Air Force program in 1997. It takes off and lands conventionally on a runway and can carry a 450 lb payload for 24+ hours. Operationally, it is flown with a gimbaled electro-optical/infrared (EO/IR) sensor and a synthetic aperture radar (SAR), giving it a day/night, all-weather (within aircraft limits) reconnaissance capability. It uses both a line-of-sight (C-band) and a beyond-line-of-sight (Ku-band SATCOM) data link to relay color video in real time to commanders. Since 1995, Predator has flown surveillance missions over Iraq, Bosnia and Kosovo. The Air Force operates two squadrons of Predators, and is building toward a force of 12 systems consisting of 48 aircraft. Initial Operating Capability (IOC) is anticipated in 2001. *www2.acc.af.mil/library/factsheets/predator*

2.1.2 RQ-2 Pioneer

RQ-2 Pioneer/PUI/Navy

Weight	Length	Wingspan	Ceiling	Radius	Endurance
452 lbs	14 ft	17 ft	15,000 ft	100 nm	4 hrs

Payload Weight: 75 lbs

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 4 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 currently fields three Pioneer systems (one for training) and the Marines two, each with five aircraft. Pioneer is to be replaced by the Fire Scout Vertical Takeoff and Landing Tactical UAV (VTUAV) beginning in FY03.
http://uav.navair.navy.mil/pioneer

2.1.3 RQ-5 Hunter

RQ-5 Hunter/TRW/IAI/Army

Weight	Length	Wingspan	Ceiling	Radius	Endurance
1,600 lbs	23 ft	29.2 ft	15,000 ft	144 nm	11.6 hrs

Payload Weight: 200 lbs

The RQ-5 Hunter was originally intended to serve as the Army's Short Range UAV system for division and corps commanders. It takes off and lands (using arresting gear) on runways and can carry 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 in 1999 to Kosovo to support NATO operations. Although production was cancelled in 1996, seven low rate initial production (LRIP) systems of eight aircraft each were acquired, four of which remain in service: one for training and three for doctrine development and exercise and contingency support. Hunter is to be replaced by the Shadow 200 (Tactical UAV, or TUAV) starting in FY03.
www.redstone.army.mil/jtuav

2.2 Developmental UAV Systems

2.2.1 RQ-4 Global Hawk

RQ-4 Global Hawk/Northrop Grumman/Air Force

Weight	Length	Wingspan	Ceiling	Radius	Endurance
25,600 lbs	44.4 ft	116.2 ft	65,000 ft	3,000 nm	36.0 hrs

Payload Weight: 1,950 lbs

The Air Force RQ-4 Global Hawk is a high altitude, long endurance UAV designed to provide wide area coverage (up to 40,000 nm^2 per day). It successfully completed its Advanced Concept Technology Demonstration (ACTD) and its Military Utility Assessment in June 2000. It takes off and lands conventionally on a runway and carries a 1950 lb payload for 36 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 line-of-sight (X-band) and/or beyond-line-of-sight (Ku-band SATCOM) data links to its Mission Control Element (MCE), which distributes imagery to up to seven theater exploitation systems. ACTD residuals consist of four aircraft and two ground control stations. The Air Force has budgeted for two aircraft per year starting in FY02; IOC is expected to occur in FY05.
www2.acc.af.mil/library/factsheets/globalhawk

2.2.2 Fire Scout

Fire Scout is a vertical take-off and landing (VTOL) tactical UAV (VTUAV) currently in Engineering and Manufacturing Development (EMD). Fire Scout can remain on station for at least 3 hours at 110 nm with a payload of 200 lbs. Its Modular Mission Payload (MMP) consists of a gimbaled EO/IR sensor with an integral laser designator/rangefinder. MMP data is relayed to its ground control station and to remote data terminals in real time via a Ku-band LOS data link, with a UHF backup for control. The Navy selected the Fire Scout in February 2000 to fill a need for a UAV that could operate from all air-capable ships. Fire Scout will also fill a requirement for the Marines, who require a UAV to support Marine Expeditionary Units that can operate from amphibious assault ships (LHA/LHD/LPDs). Together, the Navy and Marine Corps plan to acquire twenty-three systems of three aircraft apiece with IOCs in FY07 (Navy) and FY03 (Marine Corps). Additionally, the Coast Guard is also considering Fire Scout for its proposed Deep Water recapitalization program. http://uav.navair.navy.mil/vtuav

Fire Scout/Northrop Grumman/Navy

Weight	Length	Rotor Diameter	Ceiling	Radius	Endurance
2,550 lbs	22.9 ft	27.5 ft	20,000 ft	110 nm	6+ hrs

Payload Weight: 200 lbs

2.2.3 RQ-7 Shadow 200

The Army selected the RQ-7 Shadow 200 (formerly the TUAV) in December 1999 to meet its Close Range 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. Eventual procurement of 44 systems of four aircraft each is expected with IOC planned in early FY03.
www.tuav.redstone.army.mil

RQ-7 Shadow/AAI/Army

Weight	Length	Wingspan	Ceiling	Radius	Endurance
327 lbs	11.2 ft	12.8 ft	15,000 ft	68 nm	4 hrs

Payload Weight: 60 lbs

TABLE 2.2.3-1: SUMMARY HISTORY OF RECENT UAV PROGRAMS.

System	Manufacturer	Lead Service	First Flight	IOC	Number Built	Number in Inventory	Status
RQ-1/Predator	General Atomics	Air Force	1994	2001	54	15	87 ordered
RQ-2/Pioneer	Pioneer UAVs, Inc	Navy	1985	1986	175	25	Sunset system
BQM-145	Teledyne Ryan	Navy	1992	n/a	6	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	2005	5	0	In E&MD
RQ-5/Hunter	IAI/TRW	Army	1991	n/a	72	42	Sunset system
Outrider	Alliant Techsystems	Army	1997	n/a	19	0	Cancelled '99
RQ-7/Shadow200	AAI	Army	1991	2003	8	0	176 planned
Fire Scout	Northrop Grumman	Navy	1999	2003	1	0	75 planned

2.2.4 Tactical Control System

The Tactical Control System (TCS) is an open architecture, common interoperable control system software for UAVs and supported C4I nodes currently in Engineering and Manufacturing Development (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. IOC for TCS will coincide with the fielding of the Navy and Marine Fire Scout and with the Army Shadow 200 Block II upgrade. *http://uav.navair.navy.mil/tcs*

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 have recently deployed with operational units using trained, uniformed operators. Eighty-two *BQM-147 Exdrones* (an 80-lb delta wing communications jammer) remain from over 500 built, 45 of which 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 currently 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 to also begin experiments with 30 Exdrones within the year.

BQM-147 Dragon Drone/BAI/Marine Corps

Weight	Length	Wingspan	Ceiling	Radius	Endurance
90 lbs	5.25 ft	8.2 ft	10,000 ft	26 nm	2.5 hrs

Payload Weight: 15 lbs

Approximately 50 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, Special Operations Command Europe (SOCEUR) employed one system (3 aircraft) in Europe, 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

The Army's Night Vision Electronic Sensors Directorate (NVESD) operates four *Sentry* UAVs (acquired in 1997), four *Flight Hawk* mini-UAVs, three Camcopters, and a *Pointer* system as testbeds for evaluating various night vision sensors and employment concepts.

FQM-151 Pointer/AeroVironment/Navy

Weight	Length	Wingspan	Ceiling	Radius	Endurance
10 lbs	6 ft	9 ft	1,000 ft	3 nm	1 hr

Payload Weight: 2 lbs

Sentry/Meggitt/Army

Weight	Length	Wingspan	Ceiling	Radius	Endurance
250 lbs	8 ft	11 ft	16,000 ft	90 nm	8 hrs

Payload Weight: 75 lbs

2.3.2 Concept Exploration UAV Systems

Service laboratories have developed a number of UAVs tailored to explore specific operational concepts. The Marine Corps Warfighting Laboratory (MCWL) is currently exploring three such concepts. The first, *Dragon Warrior* (or Cypher II) was intended to perform over-the-shore, fixed-wing flight, then land, remove its wings, and convert to a hovering design for urban operations. This effort was transferred to the auspices of the NVESD in late 2000, and the MCWL is now proposing a refined version of its Dragon Warrior concept. Neither has yet flown. www.mcwl.quantico.usmc.mil/images/downloads/dragonwarrior

Dragon Warrior/Sikorsky/Marine Corps

Weight	Length	Wingspan	Ceiling	Radius	Endurance
260 lbs	6 ft	10.25 ft	10,000 ft	80 nm	3 hrs

Payload Weight: 25 lbs

K-Max BURRO/Kaman/Marine Corps

Weight	Length	Rotor Diameter	Ceiling	Radius	Endurance
11,500 lbs	52 ft	48.3 ft	25,000 ft	140 nm	2.8 hrs

Payload Weight: 6,000 lbs (external)

A converted K-Max helicopter is being used to explore the Marines' *Broad-area Unmanned Responsive Resupply Operations (BURRO)* concept of ship-to-shore or ship-to-ship resupply by UAV. It has been flying since early 2000.

Dragon Eye is a mini-UAV (2.4 foot wingspan and 4 lbs weight) developed as one potential answer to the Navy's Over-The-Hill Reconnaissance Initiative and the Marines' Interim Small Unit Remote Scouting System (I-SURSS) requirement. Its design is still evolving; the first prototype flew in May 2000. Each of the three Marine Expeditionary Forces will evaluate ten *Dragon Eyes* (30 total) during 2002. *www.mcwl.quantico.usmc.mil/images/downloads/dragoneye)*

The Counter Proliferation ACTD, sponsored by the Defense Threat Reduction Agency (DTRA), envisions deploying several mini-UAVs (*Finder*) from a larger Predator UAV to conduct point detection of chemical agents and relay the sensor results back through Predator. Fifty Finders are to be built as part of this ACTD. *www.jhuapl.edu/colloq/foch*

Dragon Eye/NRL/Marine Corps

Weight	Length	Wingspan	Ceiling	Radius	Endurance
4 lbs	2.4 ft	2.4 ft	1,000 ft	6 nm	0.5 hr

Payload Weight: 1 lb

Finder/NRL/DTRA

Weight	Length	Wingspan	Ceiling	Radius	Endurance
58 lbs	5.25 ft	8.6 ft	15,000 ft	345 nm	10 hrs

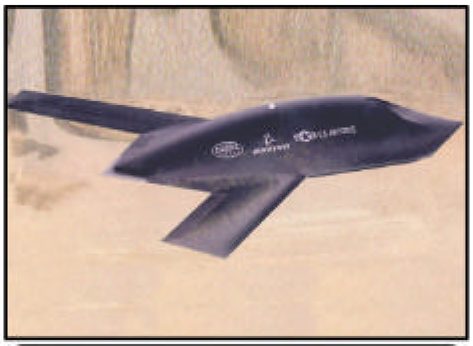
Payload Weight: 13.5 lbs

The Naval Research Laboratory (NRL) has a history of exploring new aerodynamic and propulsion concepts for maritime UAVs. Besides the Dragon Eye and Finder projects described above, the NRL has built and flown nearly 20 original small and micro UAV designs in recent years. The Naval Air Warfare Center Aircraft Division (NAWC/AD) maintains a small UAV test and development team at Webster Field, Maryland, and operates a small fleet with nine types of UAVs. This team managed the evolution of the Exdrone into the Dragon Drone for use by the MCWL. Together, NRL and NAWC/AD operate nearly 30 models of UAVs, many of which are in-house designs.

2.3.3 DARPA UAV Programs

The Defense Advanced Research Projects Agency (DARPA) is currently sponsoring five innovative UAV programs. The DARPA/Air Force *X-45* Unmanned Combat Air Vehicle (UCAV) prototype contract was awarded to Boeing in March, 1999. Its public debut was in September 2000, and first flight is anticipated in the Summer/Fall of 2001. The goal of the UCAV is to perform the suppression of enemy air defenses (SEAD) mission with an aircraft that costs one-third as much to acquire as a Joint Strike Fighter (JSF) and is one-quarter as expensive to operate and support. *www.darpa.mil/tto/programs/ucav*

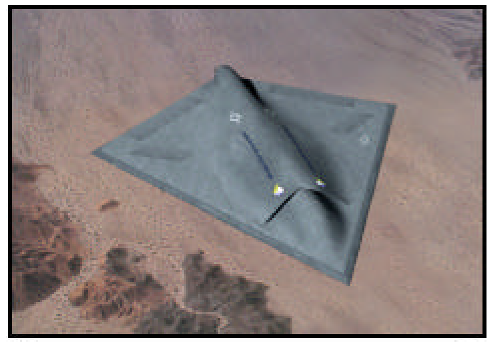
A similar DARPA/Navy Advanced Technology Demonstration (ATD) is to develop UCAV-Navy (*UCAV-N*) prototypes and examine concepts for an eventual carrier-based UCAV for the surveillance, strike, and SEAD missions. Its goal is to cost a third as much to acquire as a JSF and one half as much to operate and support. Two definition contracts are underway, with prototype flights possibly beginning in 2002. Neither the Air Force nor the Navy UCAV ATD is expected to lead to a fielded UCAV design before 2010. (*www.darpa.mil/darpatech2000/speeches/ttospeeches/ttoucav-n(scheuren*)



X-45 UCAV/Boeing/DARPA

Weight	Length	Wingspan	Ceiling	Radius	Endurance
15,000 lbs	27 ft	34 ft	45,000 ft	650 nm	3 hrs

Payload Weight: 2000 lbs

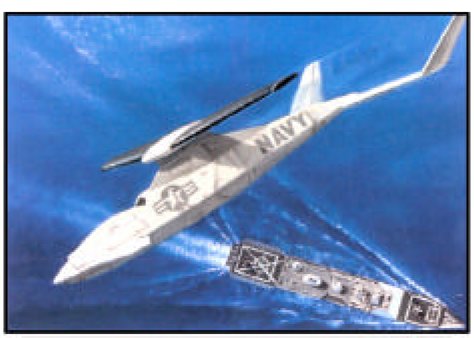


Pegasus UCAV/Northrop-Gurmman/DARPA

Weight	Length	Wingspan	Ceiling	Radius	Endurance
5,500 lb	28 ft	28 ft	-	-	-

Payload weight: 625 lbs

The Advanced Air Vehicle (AAV) program is developing two rotorcraft projects, the *Dragon Fly* Canard Rotor Wing (CRW) and the *A160 Hummingbird*. The CRW will demonstrate the ability to takeoff and land from a hover, then transition to fixed wing flight for cruise. The result will be a high speed (400+ kts) rotorcraft UAV. CRW is expected to fly in late 2001. The A160 UAV uses a hingeless, rigid rotor to achieve a high endurance (24+ hrs), high altitude (30,000 ft) rotorcraft. It is to fly in late 2002. *www.darpa.mil/tto/programs/aav*



Dragon Fly/Boeing/DARPA

Weight	Length	Rotor Diameter	Ceiling	Radius	Endurance
1,785 lbs	17.7 ft	14 ft	10,000 ft	108 nm	4 hrs

Payload Weight: 200 lbs

A160 Hummingbird/Frontier/DARPA

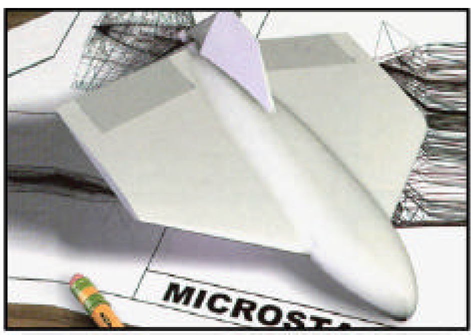
Weight	Length	Rotor Diameter	Ceiling	Radius	Endurance
4,000 lbs	35 ft	36 ft	30,000 ft	3,000 nm	24+ hrs

Payload Weight: 300+ lbs

Finally, DARPA was exploring four designs for micro air vehicles (MAV) - aircraft less than 6 inches in any dimension. Two, the Lutronix *Kolibri* and the Microcraft *Ducted Fan*, rely on a shrouded rotor for vertical flight, while the Lockheed Martin Sanders *MicroStar* and the AeroVironment *Black Widow* are fixed wing, horizontal fliers. The envisioned utility of MAVs is to aid the individual soldier/Marine engaged in urban warfare. The micro air vehicle program pushed the envelope in small, lightweight propulsion, sensing, and communication technologies. As of FY01, all MAV funding was put toward defining the *Organic Air Vehicle* (OAV) within the DARPA/Army Future Combat Systems program. *www.darpa.mil/tto/programs/mav*

2.3.4 UAV Definition Studies

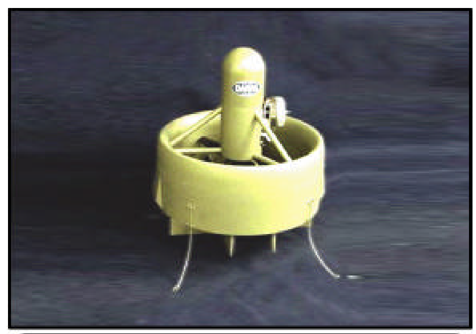
The Services are currently funding efforts to define three UAV systems for possible fielding in the post 2010 timeframe. The Air Force's involvement in DARPA's X-45/UCAV ATD may, depending on its outcome, lead to an operational version (*UCAV-AF*) for the SEAD mission. The Navy is studying the feasibility of developing a naval combat UAV (*UCAV-N*) from its parallel ATD. The Navy is also in the process of defining the Multi-Role Endurance (*MRE*) UAV, whose performance would be in the realm between that of the tactical Fire Scout and the strategic Global Hawk. A fourth effort, the Air Force Research Laboratory's (AFRL's) *Sensorcraft*, moved from being an unfunded concept to a funded initiative in FY01; its design is to be optimized for future sensing capabilities. *http://uav.navair.navy.mil/mre*



MicroStar/Lockheed Martin/DARPA

Weight	Length	Wingspan	Ceiling	Radius	Endurance
0.2 lbs	0.5 ft	0.5 ft	500 ft	3 nm	0.3 hr

Payload Weight: 0.04 lb



Micro Air Vehicle/DARPA

Weight	Length	Wingspan	Ceiling
0.2 lb	0.5 ft	0.4 ft	500 ft

2.4 UAV Program Timelines

Between 1990 and 1999, the Department of Defense invested over $3 billion in UAV development, procurement, and operations. It plans to invest $2.3 billion more by 2005 (see Figure 2.4-1). Projecting this rate out to 2010, DoD will likely invest $4.2 billion in UAVs in the first decade of the new century. By 2010, the U.S. UAV inventory is expected to grow from 90 today to 290 and to support a wider range of missions.

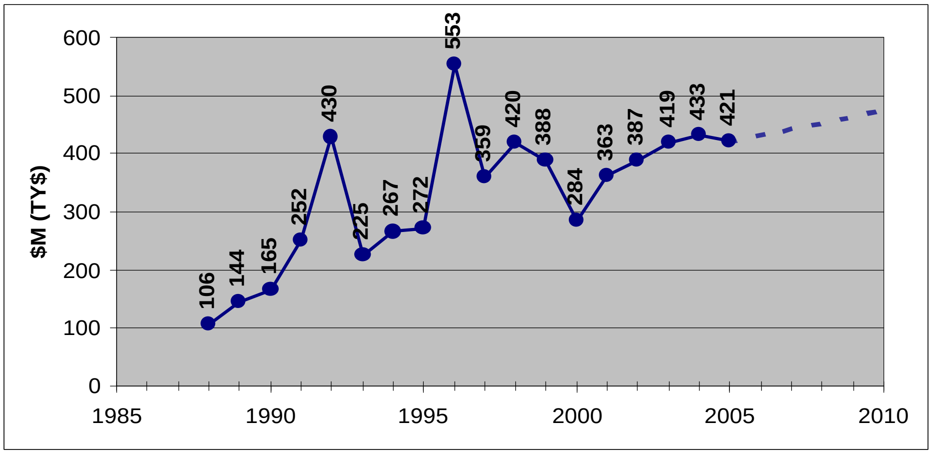


FIGURE 2.4-1: DoD ANNUAL FUNDING PROFILE FOR UAVs.

A consolidated snapshot of Service UAV programs is illustrated in Figure 2.4-2, which presents a 40-year picture (1985-2025) of historical and planned U.S. UAV procurement. End dates were estimated for those programs without a planned date for withdrawal from service.

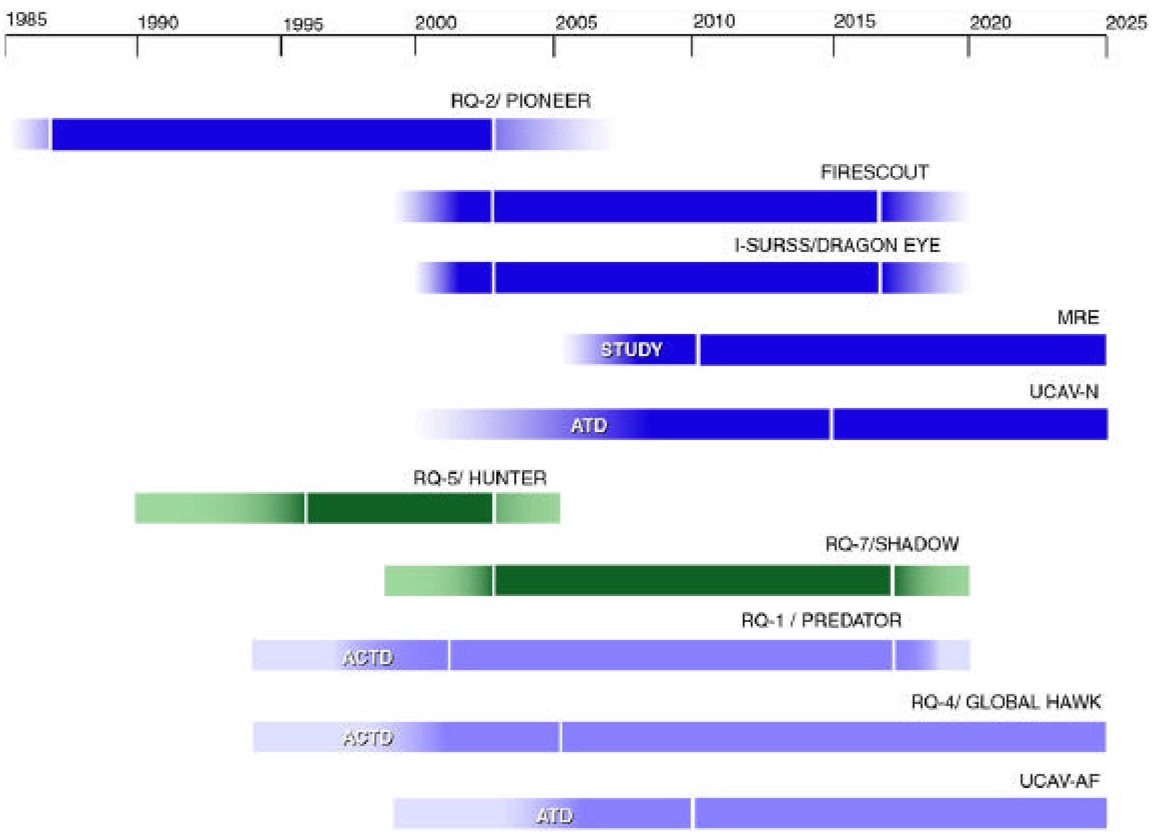


FIGURE 2.4-2: TIMELINE OF CURRENT AND PLANNED DoD UAV PLATFORMS.

Currently, some 32 nations manufacture more than 150 models of UAVs; 55 countries operate some 80 types of UAVs, primarily for reconnaissance. Table 2.4-2 categorizes current military uses of selected foreign UAVs to identify any mission niches 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[3].** 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 (a Mach 3 reconnaissance drone spun-off from the SR-71) and the RQ-3 *DarkStar*, relied on supersonic speed or stealth as well as high altitude for their survivability.

TABLE 2.4-2: CLASSES OF WORLDWIDE MILITARY RECONNAISSANCE UAVS.

	Tactical		Specialized		Endurance	
Country	Over-the-Hill	Close Range	Maritime	Penetrating	Medium Rng	Long Rng
United States	Pointer	Hunter/*Shadow*	*Fire Scout*	_______	Predator	*Global Hawk*
France	*Lulleby*	Crecerelle	*Marvel*	CL-289	*Eagle/Horus*	
Germany	Luna	Brevel	*Seamos*	CL-289	*under study*	
United Kingdom	*Sender/Observer*	Phoenix				
Italy	*Dragonfly*	Mirach 26		Mirach 150	*Predator*	
Israel	*Eyeview*	Searcher			*Heron*	
Russia	*R90*	Shmel/Yak-61		VR-3 Reys VR-2 Strizh		

[3] Key findings driving recommendations are emphasized in bold throughout the text.

3.0 Requirements

The purpose of this chapter is to identify emerging requirements for military capabilities which could possibly be addressed by UAVs. A *requirement* is defined here as an unmet need for a capability. The key question addressed in this section is: *What are the requirements for military capabilities that could potentially be met by employing UAVs?*

3.1 Warfighters' Roles for UAVs

The primary source for identifying requirements are the Integrated Priority Lists (IPLs), which are submitted annually by each of the nine Unified Command CINCs to prioritize the warfighting capability shortfalls of each theater. They are the seminal source of joint requirements from our nation's warfighters. Taken as a whole, IPLs offer the advantages of being "direct from the field" in pedigree, joint in perspective, enumerating worldwide (vice service- or theater-centric) requirements, and not originating from a UAV-centric forum.

Of the 146 requirements submitted in the combined 1999 IPLs for funding in the FY02-07 Future Year Defense Plan (FYDP), 57 (39 percent) identified needed capabilities that have previously been associated in some form (a flight demonstration, a technical study, etc.) with UAVs, i.e., requirements that could potentially be filled by using UAVs, as shown in Table 3.2-1. These 57 requirements can be organized into 15 mission areas, as shown in Figure 3.1-1.

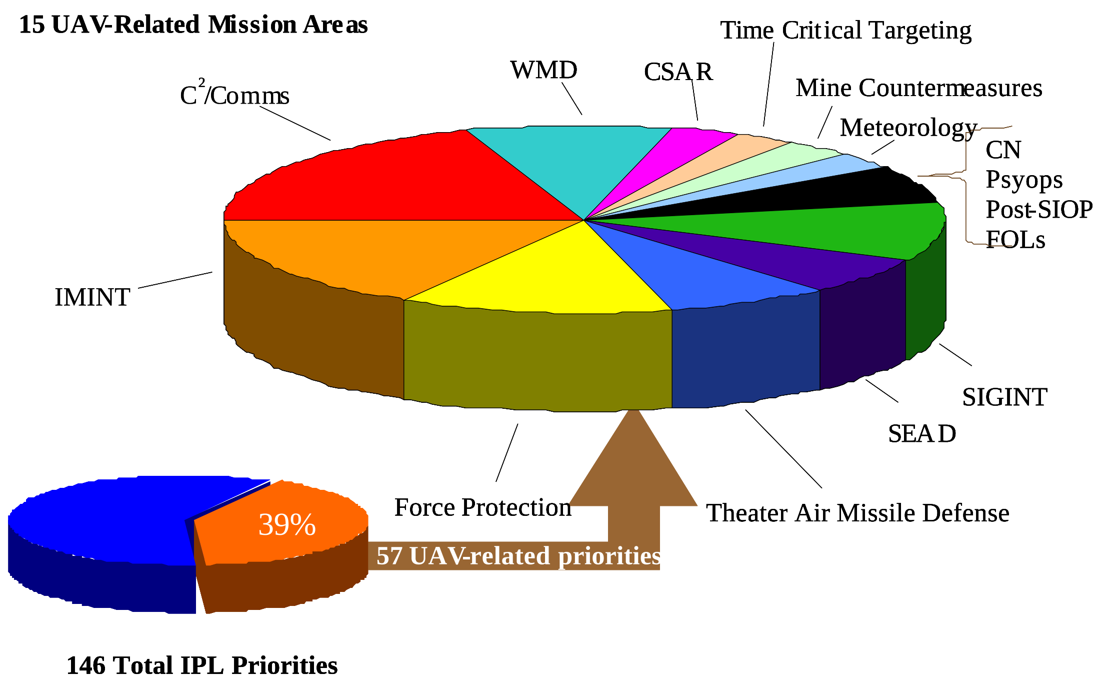


FIGURE 3.1-1: IPL PRIORITIES LINK TO UAV MISSIONS.

3.2 Requirements Association with UAVs

Despite only EO/IR/SAR sensors being operationally fielded on DoD UAVs to date, Table 3.2-1 shows a number of nontraditional payloads which perform tasks within these 15 mission areas have been previously flown on UAVs in proof-of-concept demonstrations. These demonstrations show that UAVs can be *a candidate solution* for certain requirements. Whenever possible, UAVs should be *the preferred solution* over their manned counterparts for those requirements posing 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	UAV Mission Attributes Involved			UAV Experience
(Mission Areas)	“Dull”	“Dirty”	“Dangerous”	(UAV/Payload and/or Place Demonstrated and Year)
Imagery Intelligence (IMINT)	x		x	Pioneer, Exdrone, Pointer/Gulf War, 1990-91 Predator, Pioneer/Bosnia, 1995-2000 Hunter, Predator, Pioneer/Kosovo, 1999
Communications	x			Hunter/CRP, 1996; Exdrone/TRSS, 1998 Global Hawk/ACN, Predator/ACN, ongoing
Force Protection	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
Time Critical Targeting (TCT)			x	Predator w/JSTARS/Nellis AFB, 1999
Mine Counter Measures (MCM)			x	Pioneer/COBRA, 1996
Meteorology and Oceanography (METOC)	x		x	Aerosonde/Visala, 1995 Predator/T-Drop, 1997
Counter Narcotics (CN)	x		x	Predator/Ft Huachuca, 1995
Psychological Ops			x	Non-DoD UAV/leaflet dispensing, 1990’s
Post Single Integrated Operations Plan (SIOP)		x	x	DarkStar mission (canceled)
Forward Operating Location (FOL)	x			Global Hawk/Linked Seas demo, 2000

In response to a recent Joint Staff-led, Joint Requirements Oversight Council-validated survey, Unified Command and Service staffs prioritized twelve mission areas in terms of their desirability for being performed by Predator, Global Hawk, Shadow 200, and Fire Scout; see Tables 3.2-2 and 3.2-3. Although one-to-one alignments of these 12 missions with the previously described 15 priorities from the IPLs for UAVs is inexact, the priorities of the two for concurrent mission areas are in general agreement; see the last column of Table 3.2-2 for a comparison.

TABLE 3.2-2: CINC/SERVICE UAV MISSION PRIORITIZATION MATRIX--2000

Mission	Predator	Global Hawk	TUAV	VTUAV	IPLs
Recon[redacted]aissance	1	1	1	1	1
Signa[redacted] Intel	3	2	7	4	4
Mine [redacted]untermeasures	7	12	4	5	10
Targe[redacted]Designation	2	11	3	2	-
Battle[redacted]anagement	8	7	5	7	-
Chem[redacted]io Reconnaissance	10	10	6	9	5
Coun[redacted] CC&D	4	5	8	11	-
Electr[redacted]ic Warfare	6	4	9	10	7
Comb[redacted] SAR	5	8	10	8	8
Comm[redacted]nications/Data Relay	9	3	2	3	2
Infor[redacted]tion Warfare	11	6	11	6	-
Digiti[redacted]Mapping	12	9	12	12	-

U.S. Special Operations Command's (SOCOM's) priorities differed substantially from those of the other CINCs due to its unique mission requirements and are therefore enumerated separately (see Table 3.2-3). SOCOM added seven missions: psychological operations (PSYOP), covert/clandestine sensor emplacement, decoy/pathfinder, team resupply, battle damage assessment (BDA), differential GPS, and weather reporting Although all 19 SOCOM missions were prioritized for both TUAV and VTUAV, only 14 of these missions were deemed applicable to Global Hawk and 12 to Predator, explaining the lack of entries under some missions for these UAVs. Also, some SOCOM priorities, such as "day/night/all-weather surveillance," were considered to be part of the overall "reconnaissance" priority, which explains the double entries for some missions.

TABLE 3.2-3: SOCOM UAV MISSION PRIORITIZATION MATRIX--2000

Mission	Predator	Global Hawk	TUAV	VTUAV
Reconnaissance	-	5	7,8	7,8
Signals Intel	-	7	15	11
Mine Countermeasures	10	12	11	11
Target Designation	6	6	6,14	6,14
Battle Management	7	8	16	16
Chem-bio Reconnaissance	1	1	1	1
Counter CC&D	-	10	18	18
Electronic Warfare	-	-	19	19
Combat SAR	-	11	17	17
Communications/Data Relay	4,11	3	4,13	4,13
Information Warfare	8	9	5	5
Digitial Mapping	5	4	-	-
PSYOP (broadcast/leaflets)	2	2	2	2
Covert sensor emplacement	2	-	3	3
Decoy/Pathfinder	-	-	9	9
Team Resupply	9	-	10	10
Battle Dammage Assessment	12	-	12	12
GPS Psuedolite	-	13	-	-
Weather	-	14	-	-

4.0 Technologies

Aircraft achieve their operational capabilities through the integration of a number of diverse technologies. Manned aircraft rely, in some measure, on the pilot (or aircrew) to provide this integration. Lacking them, unmanned aircraft therefore require even further integration, particularly in their sensing and communication capabilities. The key question addressed in this section is: *What advances in platform, payload, communication, and information processing technologies are necessary to provide the CINCs' desired capabilities?*

Today's UAVs compose 0.6 percent of our military aircraft fleet, i.e., there are 175 manned aircraft for every unmanned one in the inventory. For every hour flown by military UAVs, manned military aircraft fly 300 hours. UAVs currently suffer mishaps at 10 to 100 times the rate incurred by their manned counterparts. UAVs are predominantly relegated to one mission: reconnaissance. Before the acceptance and use of UAVs can be expected to expand, advances must occur in three general areas: reliability, survivability, and autonomy. All of these attributes hinge on technology.

Enhanced reliability, a product of technology and training, is key to ensuring better mission availability of UAVs. Although today's UAVs tend to cost less than their manned counterparts, this savings is achieved largely by sacrifices in reliability—omitting system redundancy and using components not originally developed for use in the flight environment—shortcuts which would be unacceptable if an aircrew is involved. The trade-offs involved between increased cost and extended life must be carefully weighed to avoid driving UAV costs to unacceptable levels. Technology offers some options for improving reliability today (e.g., electric versus hydraulic actuators), and more are needed for the future. Section 5.3 discusses the reliability issue further.

Survivability, a product of technology and tactics, must be improved to ensure UAVs remain mission effective. As with reliability, survivability considerations are often traded for lowered costs; higher attrition becomes a more acceptable risk without an aircrew being involved. While this plays directly to one of unmanned aviation's strong suits—performing the overly dangerous mission—it detracts from a commander's willingness to use UAVs when missions repeatedly fail to accomplish their objective. Section 4.1.3 examines survivability issues.

Autonomy, a product of technology and doctrine, must be developed for UAVs to expand into new roles and to grow in unmanned mission effectiveness. Increasing current limited capabilities to make time sensitive decisions onboard, making them consistently and correctly, and making them in concert with other aircraft, manned and unmanned, is critical for combat UAVs to achieve their full potential. The doctrine to allow using such autonomy in a commander's rules of engagement (ROE) must be evolved in lockstep with the technology that enables it. Autonomy is discussed further in section 4.4.

4.1.1 Capability Requirements

Based on the CINC IPLs, the most desired platform capability, in the context of enhancing reconnaissance and surveillance, is increased coverage, which can be met by increasing the number, endurance, and/or sensing capability of stand-off assets. For penetrating assets, the addition of survivability features contributes to increasing their coverage capability. The following sections discuss technology-based opportunities for improving the endurance, sensing, and survivability features of future UAVs.

4.1 Platforms

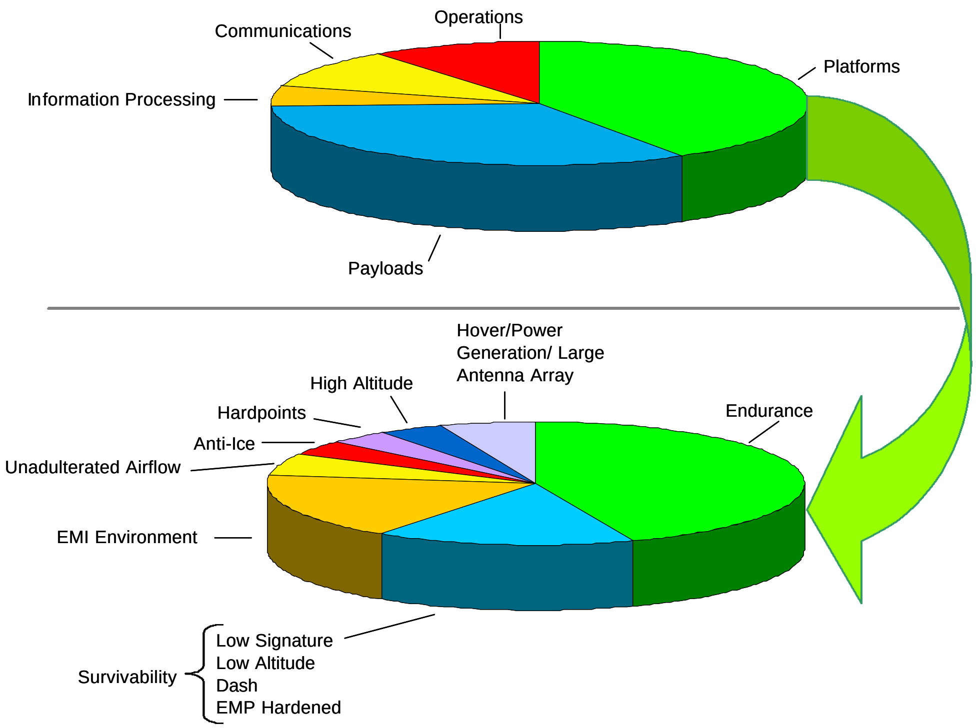


FIGURE 4.1-1: UAV PLATFORM REQUIREMENTS.

4.1.2 Propulsion

Endurance is driven by propulsion, both in terms of system efficiency (i.e., specific fuel consumption (SFC) or, for batteries and fuel cells, specific energy) and performance per unit mass (mass specific power, or MSP). SFC is the amount of fuel burned per time for the amount of power delivered by a combustion engine (i.e., pound (fuel)/hour/pound (thrust)). MSP is the ratio of the power delivered to the weight of the engine/battery/fuel cell (i.e., horsepower/pound).

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 by 60 percent (see Figure 4.1.2-1). 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.

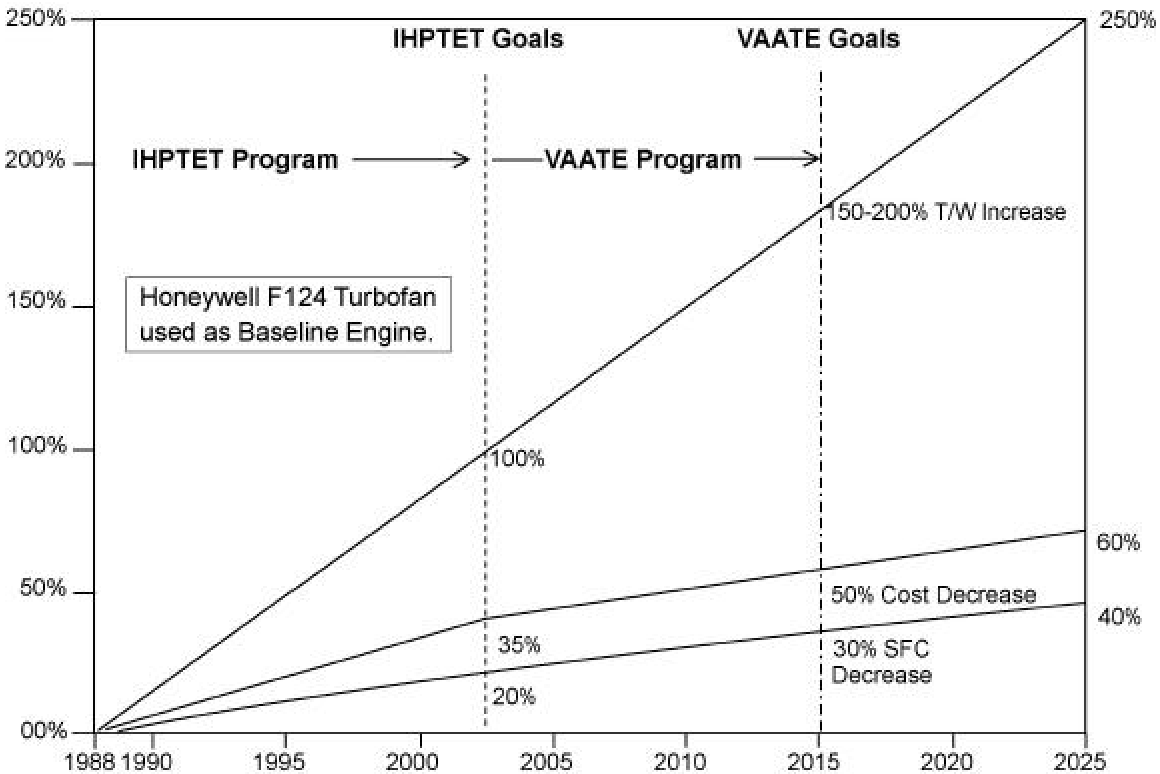


FIGURE 4.1.2-1. IHPTET AND VAATE PROGRAM GOALS AND TRENDS

Figure 4.1.2-2 shows a threefold improvement in SFC has occurred from 1955 to the present day for the two dominant types of combustion engines: gas turbines (jet engines) and internal combustion engines (ICEs). Another 60 percent improvement in gas turbine SFC and 30 percent in ICE SFC should be realizable by 2025. These improvements translate directly into endurance, and therefore coverage, increases.

Using current jet fuels, SFC should not drop below a floor value of around 0.2 lb/hr-lb force, due to the maximum combustion temperature of these fuels. Lower SFC values may be obtained in the future following the introduction of new fuels such as JP-900 or endothermic JP. These developmental fuels are expected to reduce SFC floor values by another 2% (to around 0.196 lb/hr-lb force), assuming complementary advances in materials and fuel-cooling technologies, which are needed to increase combustion temperature.

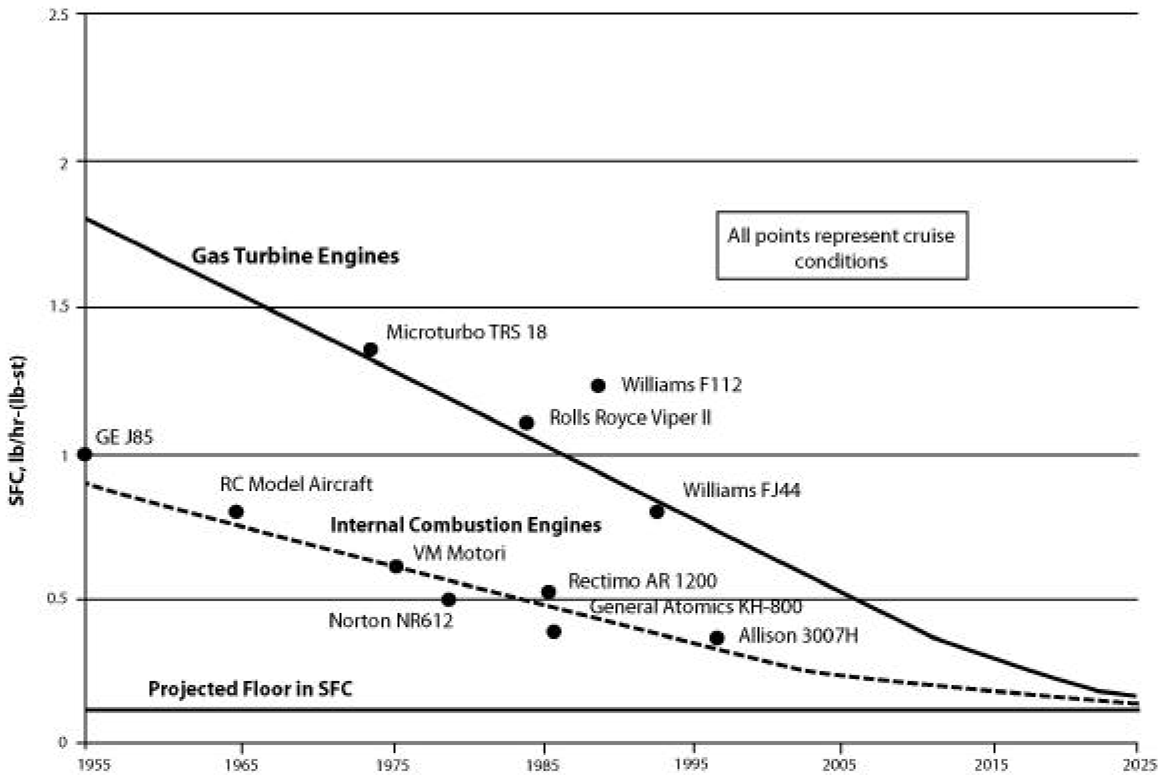


FIGURE 4.1.2-2: SPECIFIC FUEL CONSUMPTION TRENDS.

Three types of electrical propulsion systems are available for UAVs: batteries, fuel cells, and solar cells. Specific energy is the amount of energy a battery or fuel cell stores per unit mass, usually measured in watt-hours per kilogram (hp-hours per lb). Higher specific energies lead to batteries with increased lifespan, which would lead to battery-powered aircraft with increased range and endurance. Future growth in battery specific energy capability is expected with the introduction of the Lithium-polymer battery, which suffers from a rather short lifespan (the result of internal self-shorting when an electric current is passed over the metal in the polymer).

The solid oxide fuel cell (SOFC), together with the multi-carbonate fuel cell (MCFC), represents 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, enabling their use in fielding silent airborne sentries (Figure 4.1.2-2) (see section 4.1.3).**

Solar energy is a viable option for other types of UAVs, including high-altitude, long endurance UAVs, either for reconnaissance or for airborne communications relays. The AeroEnvironment Pathfinder UAV set altitude records in 1998 and 1999 for propeller-driven aircraft by using solar cells to drive 8 electric motors, which together generated roughly 10 horsepower. While storage of solar energy for use during foul weather or night conditions is a possibility, 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.

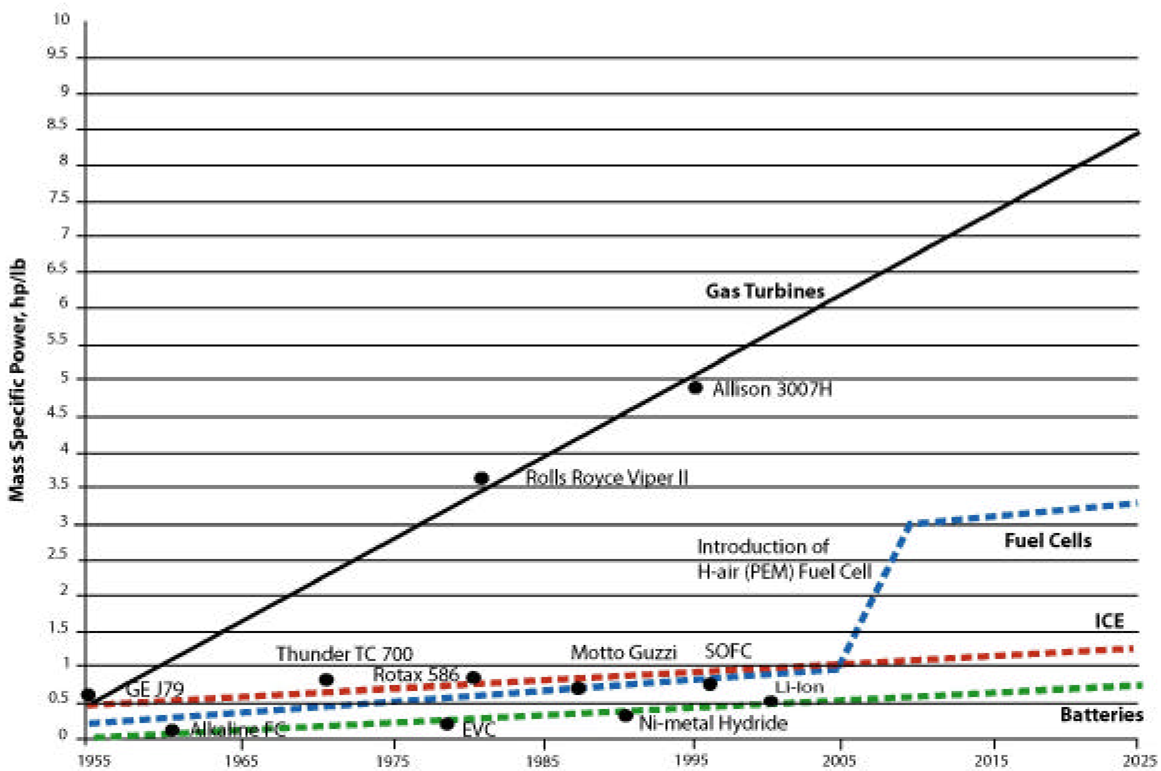


FIGURE 4.1.2-3 MASS SPECIFIC POWER TRENDS.

Emerging propulsion technologies include the following:

- 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.

- 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.

- 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.

4.1.3 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 the Air Force and the Navy UCAV demonstrators are being valued at one third the acquisition cost of their closest manned counterpart, the JSF.

Once these active and passive measures have failed 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). NASA research into ionomers shows they may be capable of sealing small holes or gaps inflight, 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 enabling successful demonstration of the Services' autonomous operation initiatives.

One low/reduced observable characteristic implicit in the CINC 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. To meet local noise ordinances around airports, aircraft noise has been reduced by around 15 percent each decade since 1960, though not nearly to the point where sophisticated unattended ground sensors would have trouble picking it up. 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 ICEs.

4.2 Payloads

The requirements for various payload capabilities identified by the IPLs can be grouped into five functional areas: imagery intelligence (IMINT), signals intelligence (SIGINT), measurement and signatures intelligence (MASINT), communications, and munitions. Meteorological sensing stands outside this breakout, yet supports all of the others to some degree. **Reporting of basic meteorological conditions can and should be made an integral part of all future sensor systems acquired for UAVs, providing the equivalent of pilot reports (PIREPS) from manned aircraft**.

4.2.1 Capability Requirements

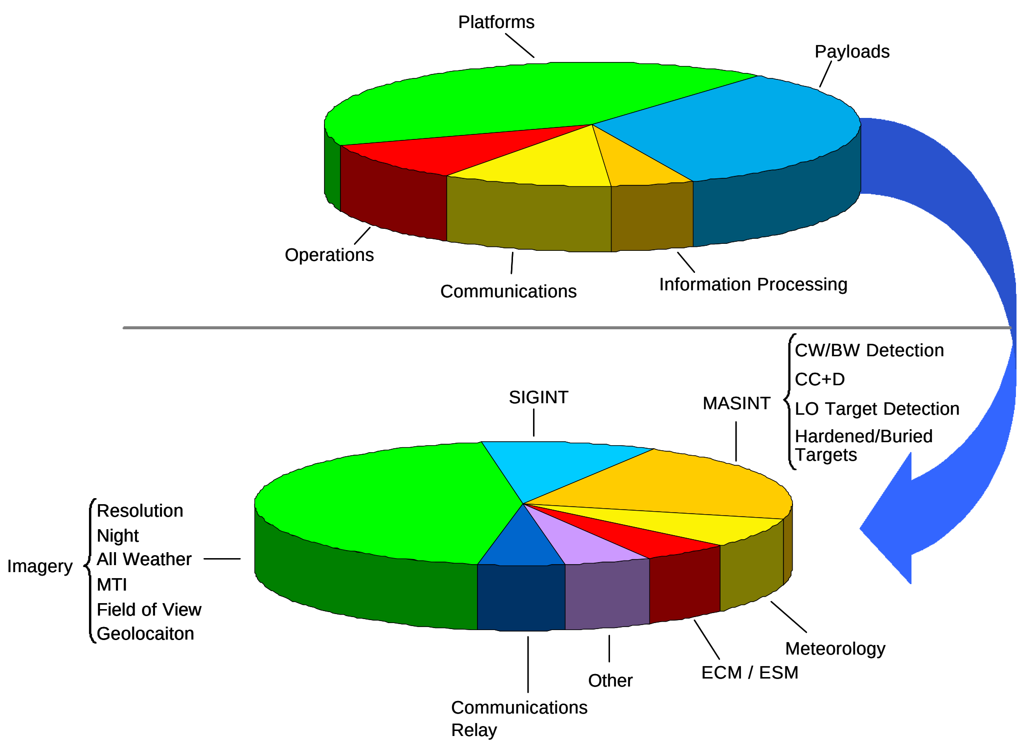


FIGURE 4.2-1: UAV PAYLOAD REQUIREMENTS.

4.2.2 Imagery Intelligence (IMINT)

The ability to detect, recognize, classify, and identify targets is the key UAV payload requirement derived from the CINC IPLs. One solution translates to obtaining improved sensor resolution from technology advances. Another possible solution would require an architectural change to reconnaissance and surveillance by relying instead on micro air vehicles to obtain close-in imagery using modest sensors. Resolution in electro-optical/infrared (EO/IR) sensors is most commonly measured in terms of ground resolved distance (GRD), the minimum separation between two distinguishable objects. Whereas GRD is a function of range, instantaneous field of view (IFOV), the smallest angle a sensor can resolve, is not. Synthetic aperture radar (SAR) uses impulse response (IPR) as its measure of resolution. Finally, the interpretability of a given image, a subjective measure of its usefulness assigned by an image analyst, is rated on the National Imagery Interpretability Rating Scale (NIIRS) for visible and infrared (IR) (passive) imagery and on the National Radar Interpretability Scale (NRIS) for SAR (active) imagery.

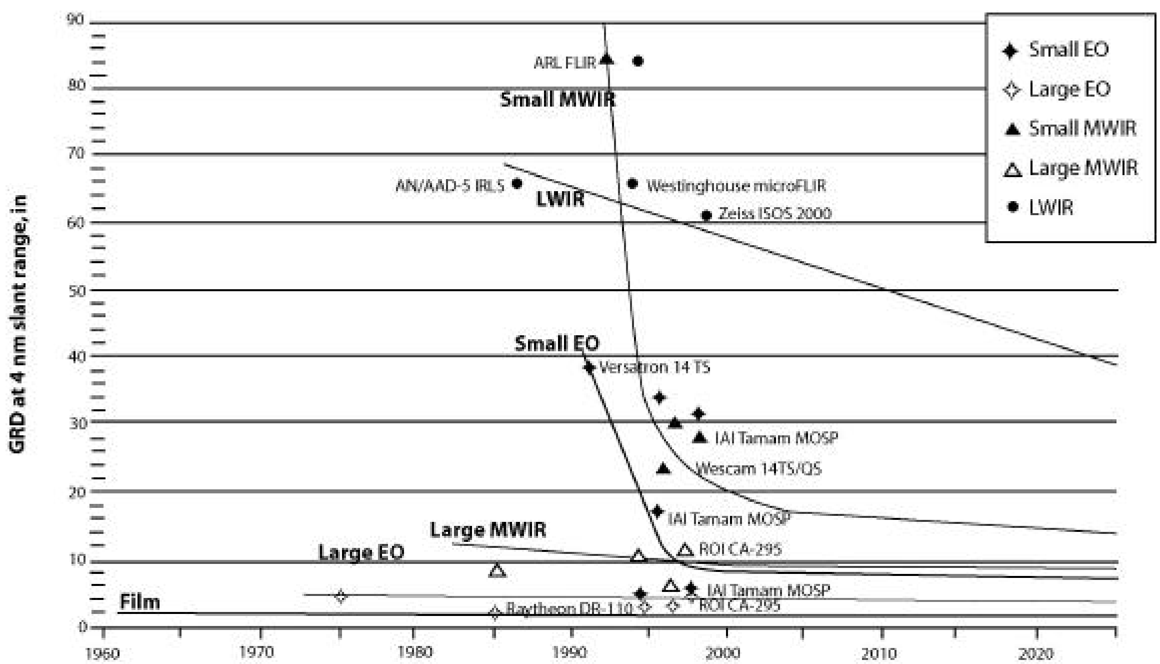


FIGURE 4.2.2-1: EO/IR SENSOR GROUND RESOLVED DISTANCE TREND.

Passive Imaging. Figure 4.2.2-1 depicts the trends in Ground Resolved Distance (GRD) at a slant range of 4 nm (maximum range of Man Portable Air Defense (MANPAD) systems) for large and small (i.e., gimbaled turrets) EO (visible), medium wavelength infrared (MWIR, 3 to 5 micron), and long wavelength infrared (LWIR, 8 to 12 micron) sensors over the past several decades. The relatively flat trends for the large systems represent the gradual, long term development of military systems, whereas the steep curves show the rapid impact of the commercial market (e.g., for police and media helicopters) for EO/IR sensors in smaller, gimbaled systems developed in the early 1990s.

By way of comparison, an unarmed individual can be distinguished from an armed one with a 4-8 inch GRD (NIIRS 8), corresponding to an IFOV of 7-14 µrad. Facial features on an individual can be identified (or at least partially discriminated) with a <4 inch GRD (NIIRS 9), corresponding to an IFOV of less than 7 µrad. Both cases assume a slant range of 4 nm, equivalent to the maximum range of most currently fielded MANPAD threats. Examples illustrating the ability of current EO/IR systems to meet these capabilities are shown in Table 4.2.2-1.

TABLE 4.2.2-1: OPERATIONAL PERFORMANCE OF CURRENT EO/IR SENSORS.

	Calculated IFOV (µrad)	Pixel Pitch/Array Size (µm / pixels)	Distinguish Armed v. Unarmed? @ NIIRS 8 (7.1 < IFOV < 14.3 µrad)		Distinguish Facial Features? @ NIIRS 9 (IFOV < 7.1 µrad)	
			Needed Pitch (µm)	Needed Array Size	Needed Pitch (µm)	Needed Array Size
Visible Wavelength						
Raytheon Integrated Sensor Suite, planned for Global Hawk UAV	10	9 / 307,200	YES	YES	NO 7.6	NO 430,071
Wescam Model 14TS/QS, employed on Predator UAV	9	8.3 / 379,392	YES	YES	NO 7.4	NO 478,024
IAI Tamam MOSP, employed on Hunter UAV	30	9 / 393,216	NO 6.2	NO 825,564	NO 4.4	NO 1,651,474
MWIR						
Wescam Model 14TS/QS, employed on Predator UAV	55	30 / 65,536	NO 15.3	NO 252,256	NO 10.8	NO 504,617
ROI CA-295	20	30 / 4,000,000	NO 25.4	NO 5,598,712	NO 17.9	NO 11,199,776
LWIR						
Indigo Alpha, uncooled	1576	51 / 20,480	NO 4.9	NO 2,258,834	NO 3.4	NO 4,518,617

As EO sensors are nearing the theoretical limits in achievable array size and pixel pitch, they will rely increasingly on evolutionary advancements in other areas of technology to increase resolution. Examples of emerging technologies for imaging systems include uncooled IR sensors, microelectro-mechanical systems (MEMS), new detector materials and better fabrication techniques, and multiple aperture optical systems. In the next few years, it is predicted that uncooled sensors will approximate the performance of their cooled counterparts while at the same time lowering costs, increasing reliability, reducing power requirements, and allowing for more compact packaging. The commercial sector is pushing applications in rifle sights and driver's viewers, while the military is focusing on applications in threat warning, long-range targeting, and unattended ground sensors. MEMS will enable the next generation of lithography for manufacturing focal plane arrays characterized by reduced pixel sizes, high fill-factors, and analog-to-digital converters on a single wafer chip, while offering increased reliability by replacing mechanical parts. A better understanding of the material characteristics of detectors, specifically Vanadium Oxide (VOx), amorphous silicon, and Barium Strontium Titanium (BST) used in uncooled LWIR detectors, and fabrication techniques of thin pixels will enable improved thermal responsivity and lower read-out noise. One of the most promising areas of optics technology development is multiple aperture optical systems. The potential increase in resolution offered by such systems would be revolutionary. The benefits of multiple apertures have been demonstrated in the RF bands and in astronomical telescopes, but it is a long-term concept in tactical optical systems using visible and IR bands.

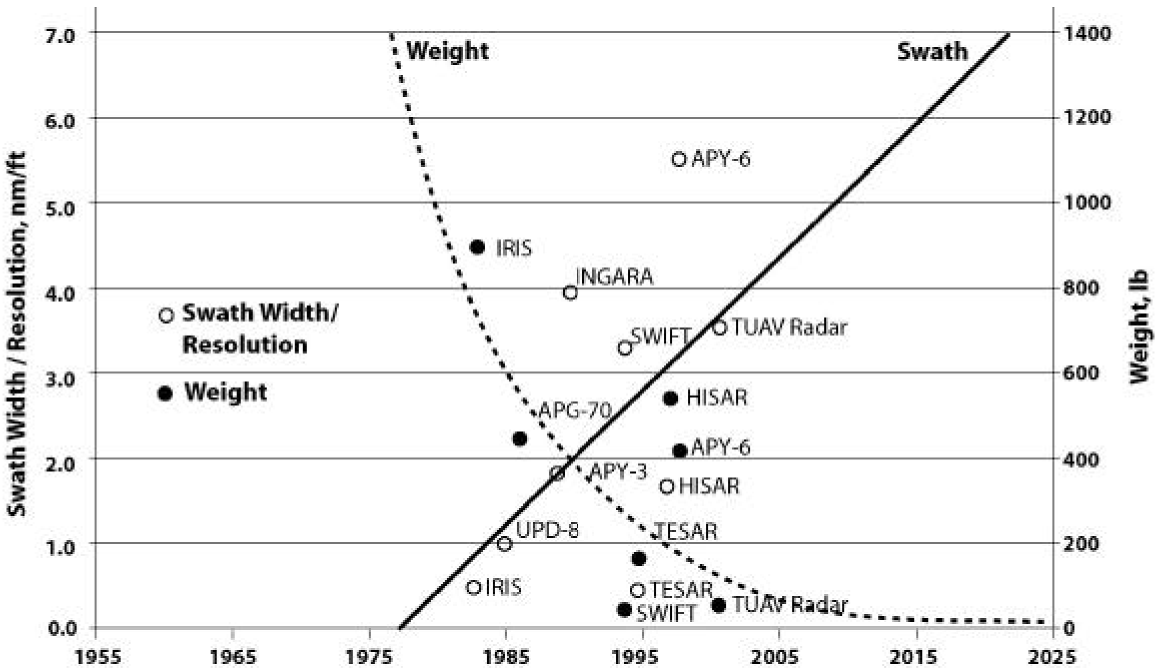


FIGURE 4.2.2-2: SAR WEIGHT AND COVERAGE/RESOLUTION TRENDS.

Active Imaging. Since airborne radars first appeared during World War II, they have been adapted to a wide variety of applications, from fire control and early warning to reconnaissance weather monitoring. Their key military value has been their ability to see farther than optical means and through conditions (night, clouds) which would otherwise deny their use. Conversely, their resolution is poorer, their use revealing to hostile forces, and their size, weight, and power (SWAP) a burden to their host aircraft, particularly to the smaller UAVs. Resolution has been significantly improved in the past two decades by the introduction of synthetic aperture radars (SARs), in which onboard processing uses the aircraft's forward motion to simulate a physically larger, fixed antenna, thereby increasing system gain and thus resolution.

As can be seen from Figure 4.2.2-2, in the short history of SAR advancement, the ratio of swath width covered to resolution achieved for SAR area search modes has increased about 1 nautical mile in width per foot of resolution every 6 years. This equates to resolution halving, or area of coverage doubling, (or a combination thereof) every 6 years compared to the previous 6 years. Concurrently the SWAP of these sensors is on a downward trend, with examples now available that are compatible with tactical

UAV payload limits (100-lb class). Transmit/receive modules (a.k.a. "tiles" or "bricks") have also shown substantial decreases in weight and cost over the past decade, while providing expanded modes of operation.

One specific mode of SARs, moving target indicator (MTI), detects the presence of moving vehicles on the ground through Doppler processing of the radar return. This can be done with a single scan of the radar through a wide area search (WAS) mode. In addition to having the resolution needed to detect the moving targets, the system must be able to surveil a large ground area per scan to be operationally useful. The amount of time required to scan a given area (revisit rate) is driven by the square of the radar's power, so to halve the revisit rate requires quadrupling the output power with current technologies.

One of the more promising near term radar development efforts is Interferometric SAR. IFSAR provides precision terrain elevations over large areas by employing a SAR transmitter with two receivers located some distance from it, in the case of airborne IFSAR, in the wingtips. The difference in the two received returns can be processed to generate Digital Terrain Elevation Data (DTED), critical for precision targeting applications such as cruise missile guidance. A preliminary evaluation of airborne IFSAR is being conducted in the Rapid Terrain Visualization ACTD. **The potential value of IFSAR to theater commanders justifies its demonstration on a large wingspan UAV (i.e., Global Hawk) in the near future**.

In the far term, range-gated laser imaging radars (LIDARs) will complement traditional radars by providing the capability to build three-dimensional images in real time of suspected targets found by the latter. Such LIDARs will enable imaging through obscurants, improve target identification by capitalizing on the higher resolution offered by using optical frequencies, and better assess target damage with 3-D images. In addition, the same light returns will be processed to extract polarization and vibration information, allowing foliage penetration and aimpoint refinement, respectively (see section 4.2.4). Future airborne imaging sensors will become multi-dimensional in nature, gathering and correlating data in real time from multiple phenomena to build a more complete target picture than that available from any one of them.

4.2.3 Signals Intelligence (SIGINT)

Although endurance-class UAVs, with their ability to be present throughout the entire development of a radio conversation, seem tailor-made for the SIGINT mission, little has been done to exploit UAVs in this role. Funding for exploring this mission on Global Hawk was deleted in 1997 but reinstated in the FY02-07 FYDP. Besides a handful of demonstrations flown on Pioneer and Hunter UAVs in 1995-97 and an extensive characterization of Predator's EMI environment in 1996-98, few current programs exist to operationalize SIGINT UAVs. **An integrated program to demonstrate continuous 24-hour airborne SIGINT collection capability at the national/theater, operational/joint task force, and tactical/unit level would address SIGINT concerns expressed by most CINCs**. Current technology would support the following feasibility demonstrations and timeframes:

TABLE 4.2.3-1. PROPOSED UAV SIGINT DEMONSTRATION PROGRAM.

Level Supported	Candidate UAV	Capabilities	Payload Available	Endurance	Demo By
National/Theater	RQ-4/Global Hawk	ELINT and COMINT	up to 1200 lbs	30+ hrs	2005-10*
Operational/JTF	RQ-1/Predator	ELINT or COMINT	up to 200 lbs	24+ hrs	2003-05
Tactical/Unit	Aerosonde	COMINT	up to 4 lbs	24+ hrs	2003-05

* Currently planned for by Air Force in the FYDP.

A SIGINT system is expected to perform three functions: emitter mapping (geolocation of emitters), exploitation (signal content), and technical analysis of new signals. Taking a long view, the primary factor that will drive RF SIGINT system design will be the reduction in received power due largely to power management, spread spectrum techniques, and use of higher frequencies with higher atmospheric absorption. Also decreasing the effective power level will be the increase in spectrum utilization, resulting in increased noise in the environment. Three choices exist to improve this situation: moving closer to the emitter, improving the antenna gain, and using coherent processing techniques.

Moving closer to the emitter would allow lower-powered signals to be collected using readily available equipment, but also increases the threat to the collector aircraft—an argument for UAV use. Improving antenna gain can be achieved through concepts like AFRL's Sensorcraft, in which the antenna becomes the wing and largely determines the flight characteristics of the aircraft.

Coherent processing techniques use additional information about the signal to wring the most energy out of the signal. One technique, matched filter processing, attempts to match the signal's size, phase and shape as exactly as possible. Another technique, cross-ambiguity function (CAF) processing, uses mathematical techniques and intensive processing to find signals even if the average noise level is 10 times that of the signal. Using conventional algorithms, the processing load increases by the fourth power of the bandwidth, i.e., to double the width of the spectrum the processing load increases by a factor of 16. If CAF and algorithm improvements can reduce the bandwidth scaling factor from a fourth to a third- or second- power function, processing time can be dramatically decreased (see Figure 4.2.3-2).

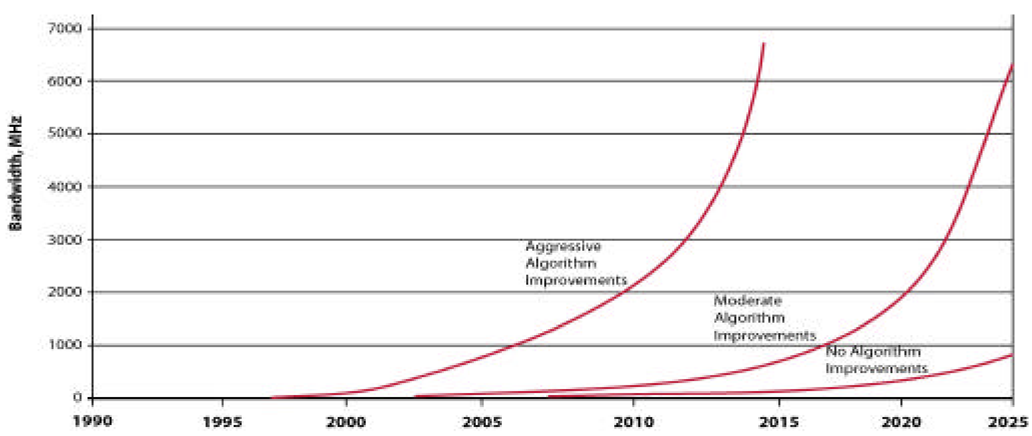


FIGURE 4.2.3-2: FORECAST OF AMOUNT OF BANDWIDTH CONTINUOUSLY PROCESSABLE.

4.2.4 Measurement & Signatures Intelligence (MASINT)

Increases in resolution are nearing a leveling point where new technologies will not produce leaps in resolution. 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. 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. 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. The capability to increase target information content is enabled by emerging multi-dimensional sensing technology.

Sensing across multiple phenomena will be most effective when used in combination, applying their additive information to culminate in target identification. One logical result could be the combination of such sensing phenomena as 2-D range gating and vibration on the same FPA used for imaging.

Characteristics of multi-phenomena sensing under development are described in Table 4.2.4-1, which describes them as either passive or active in their sensing nature, categorizes their timeframes for fielding on UAVs into near-term (0-5 years), mid-term (5-15 years), or long-term (15+ years) windows, and describes their potential military applications.

TABLE 4.2.4-1. POTENTIAL UAV MASINT SENSING APPLICATIONS.

Phenomenology	Sensor(s) Used	Sensing	Timeframe	Military Applications
Polarimetry	IR, Ladar	Passive/ Active	Mid Term	Foliage penetration Ground penetration Terrain assessment
Multi-Spectral Imaging	Spectrometer	Passive	Near Term	Camouflage detection Minefield detection Crop maturity/health
Hyper-Spectral Imaging	Spectrometer	Passive	Mid Term	Foliage penetration Chem/bio agent detection Subsurface damage assessment
Vibration	Laser	Active	Long Term	Target recognition Aimpoint refinement Target operating condition
Fluorescence	Laser	Active	Long Term	Chem/bio agent identification Fuel loading/leakage detection Drug manufacturing detection
Surface Acoustic Wave	Piezoelectric	Passive	Near Term	Chemical agent identification

Bacteriological agent detectors employ a number of techniques that key on a variety of properties produced by the suspect agent; the relation of techniques to these properties is summarized in the matrix below. All current bio-agent detection systems are point detectors, i.e., there is no standoff technique at present for detecting and identifying bacteriological agents. The Naval Research Laboratory (NRL) integrated an immunoassay-based bio-agent detector on a Telemaster UAV and tested its effectiveness in detecting and identifying an agent surrogate in January 1996. In addition, the Air Force Research Laboratory at Brooks AFB, Texas, has patented the first organic semiconductor, composed of diazoluminomelanin (DALM), which can be tailored to detect the DNA of specific bio-agents. The lab is also researching a pulsed laser or microwave radiation bio-agent detector which could detect from a standoff distance as well as kill the organisms.

TABLE 4.2.4-2: BACTERIOLOGICAL AGENT DETECTION SCHEMES.

Technique	Fluorescence	pH Change	Conductivity	Vibration	Spectroscopy	Enzyme Produced	Chromatic Change
Immunoassay*	x	x	x			x	
Immunochromatograph*							x
Polymerase Chain Reaction/ Nucleic Acid*	x		x				
Physical							
Surface Acoustic Wave				x			
Mass Spectrometry*					x		
Cantilevers				x			
Diazoluminomelanin/DNA	x		x		x		

***Currently fielded; remainder are laboratory techniques.

4.2.5 Communications Payloads

Every CINC expressed concern over communications 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/ATO 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.

4.2.6 Munitions[4]

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.

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. *CL-20* is a new, more high-energy explosive that can be used to provide the explosive power of much larger weapons into very small configurations. NSWC's *intermetallic incendiary* technology generates a 6700°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 smart bomb* (SSB), a 6-in diameter, 250-lb weapon with a 16 to 26-ft circular error probable (CEP) and the destructive power of a 2000-lb bomb, can penetrate 5 feet of concrete to destroy buried command posts and hardened shelters. Its IOC is 2007.

4.2.7 Payloads Summary

The objective in future UAV payloads, particularly those for the reconnaissance mission, should not be to simply add more sensors but to extract more and different data from the sensors at hand. As an example, ONR's Airborne Reconnaissance Optical Spotlight System (AROSS) extracts sea mine locations, maps bathymetry contours, and provides precision mensuration, all from routine EO imagery from a Predator Skyball

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[4] *The following section is derived largely from the* UAV Technologies and Combat Operations *study performed by the USAF Scientific Advisory Board in 1996.*

camera. AROSS is not hardware; it is software, a card in Predator's imaging chain. Such key operational information can be being gathered, processed, and eventually provided simultaneously with Predator's video surveillance of activities along hostile beaches. The Air Force Research Laboratory (AFRL) takes this concept further into the future, proposing Sensorcraft, an aircraft designed with maximizing the functionality of its sensor suite as its foremost criterion. As processor power grows, so increases the capabilities of onboard sensors to expand on the types and quality of information they provide today.

4.3 Communication

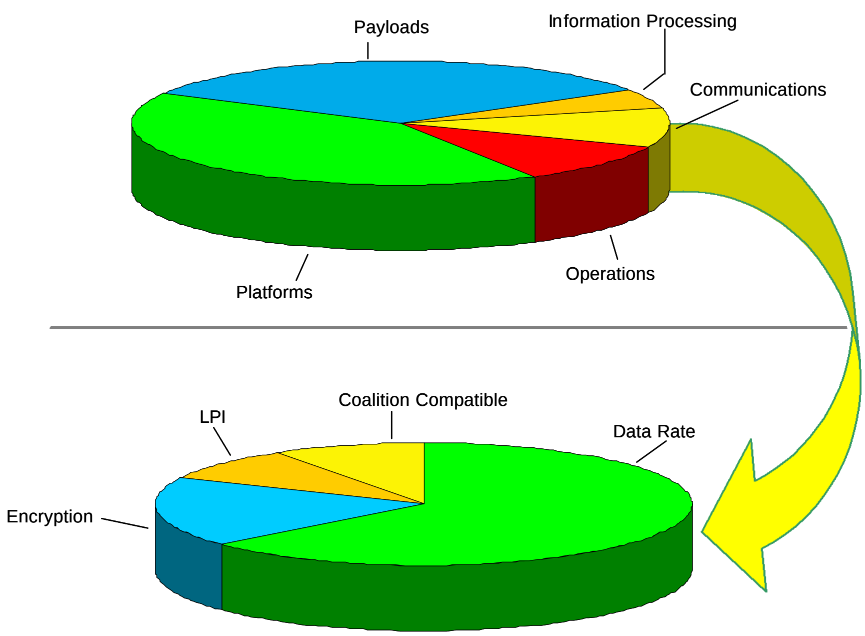

FIGURE 4.3-1: UAV COMMUNICATIONS REQUIREMENTS.

The key trend in (and CINC requirement for) future airborne communication systems is increasing data rates, primarily brought on by migration towards higher RF frequencies and the emerging dominance of optical over RF systems. Optical systems are laser-based systems, which will offer data rates two to three orders of magnitude greater than those of the best future RF systems. The advantages of optical communication were demonstrated in 1996 when a ground-based laser communications (lasercom) system provided rates of 1.1 terabits/second (Tbps) at over 80 nm range. Airborne and spaceborne Tbps lasercom systems will certainly be possible by 2025. Although lasercom will shortly surpass RF in terms of 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 will continue to progress out to 2025.

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.

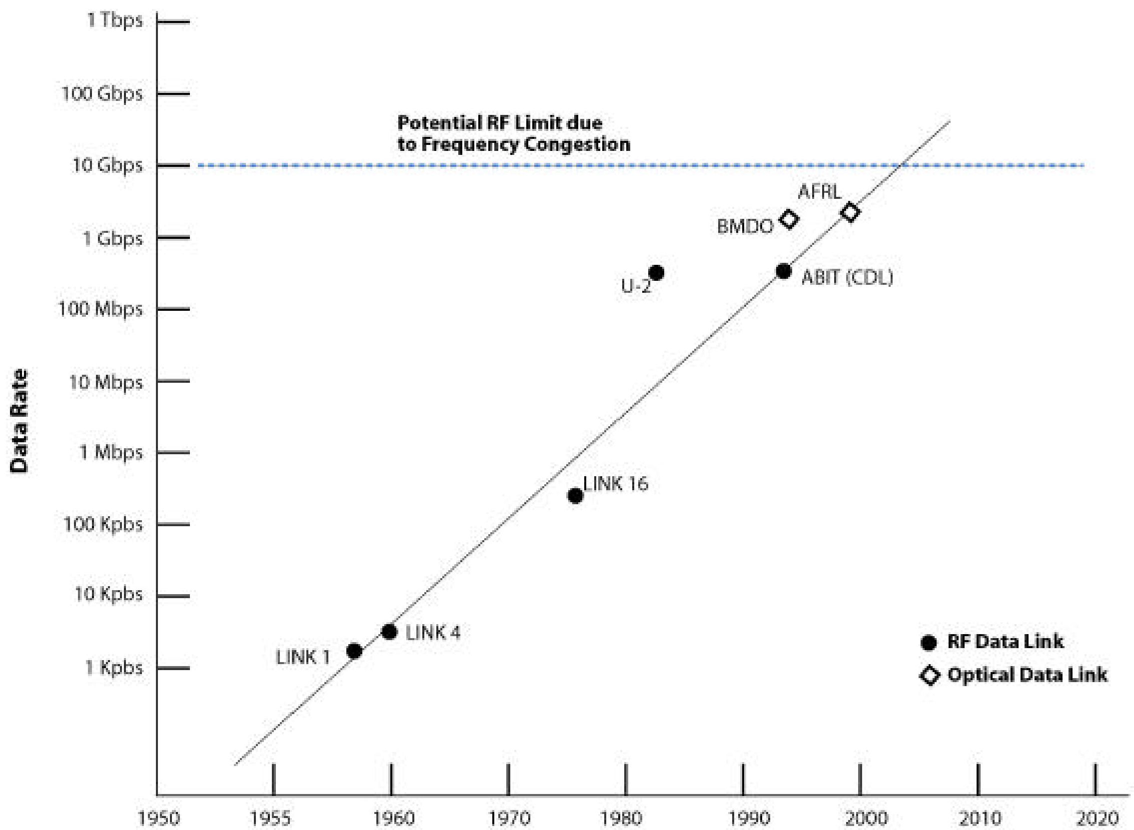

FIGURE 4.3-2: AIRBORNE DATA LINK DATA RATE TRENDS.

Figure 4.3-2 shows the trend in data rates for both airborne RF and lasercom communication data links. In the case of RF, limited spectrum and the requirement to minimize airborne system SWAP have been strong contributors for limiting data rates. Rates up to 10 GHz (40 times currently fielded capabilities) are considered possible at current bandwidths by using more bandwidth-efficient modulation methods. At gigahertz frequencies, 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.

With airborne lasercom, data rates have held steady for two decades because the 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, therefore attracting investment dollars, 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. We are approaching the cusp of a growth curve in lasercom capability.

One innovative developing data link technology offers high bandwidth, covert communications at extremely low weight and cost. The Naval Research Laboratory has demonstrated an IR laser data link using a multiple quantum well (MQW) modulating retro-reflector to pass data at 400-kbps rates from a hovering UAV and predicts this system could support rates up to 10 Mbps. In the MQW concept, the UAV carries no communications system at all. Rather, the ground station provides this via a laser beam focused on a spherical array of voltage modulated polymer panels. Onboard sensors modulate panel voltages, which cause amplitude and frequency modulation on beams striking the array's surface. Detection apertures on the ground pick up the reflected power and demodulate the sensor data. Potentially dozens of ground stations could simultaneously tap into a single platform's sensor data. MQW technology is currently considered viable over ranges of only a few kilometers, making it a candidate for use in micro air vehicles and UAV communications to special operations units.

4.4 Information Processing

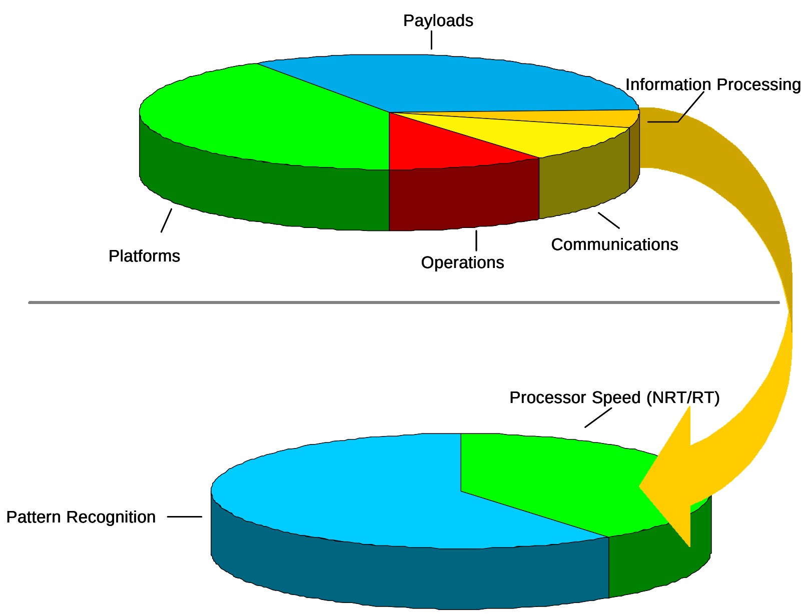

FIGURE 4.4-1: UAV INFORMATION PROCESSING REQUIREMENTS.

Increased onboard processing will be the key enabler of 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 Sensorcraft initiative. AFRL has defined ten levels of autonomous capability (ACLs), shown in Figure 4.4-2, to serve as a standard for measuring progress. For reference, the RQ-4/Global Hawk is defined as being between

ACL 2 and 3 in autonomy. The Navy goal is to demonstrate ACL 7 by 2008, while the Air Force intends to demonstrate ACL 6 by 2007 and ACL 8 by 2013. 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 ROEs for contingencies from peacekeeping to force-on-force.

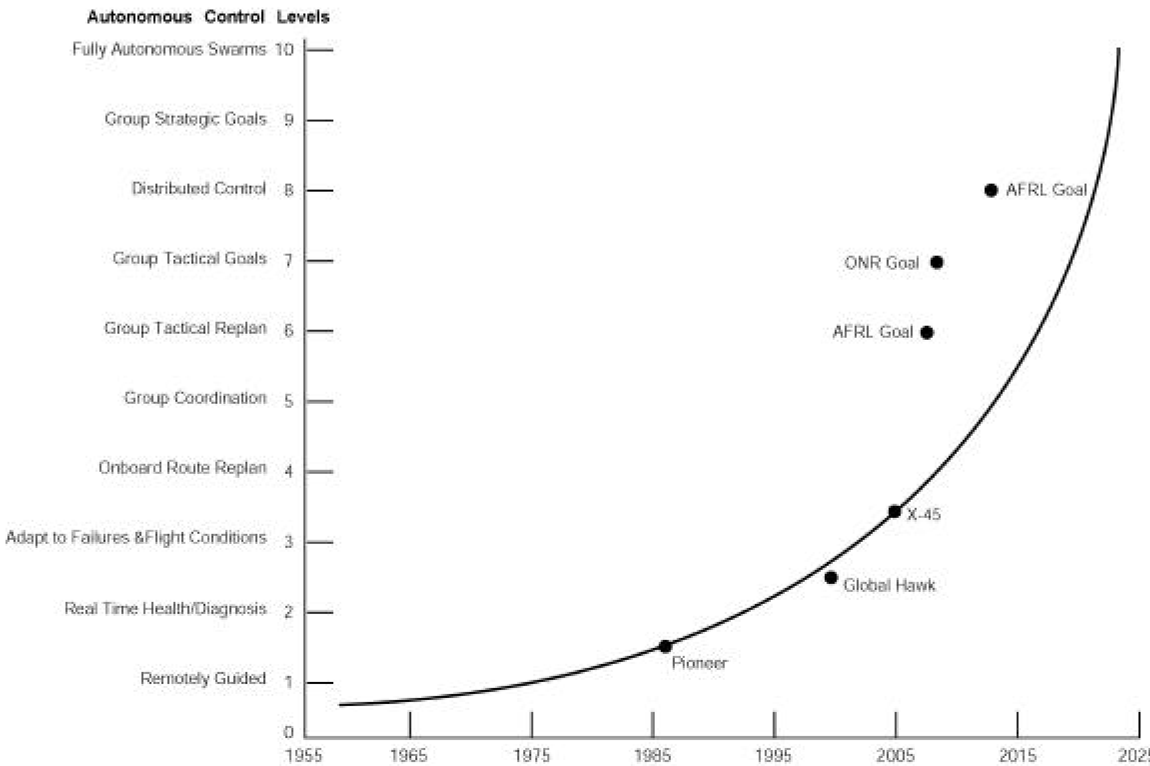

FIGURE 4.4-2: AUTONOMOUS CONTROL LEVEL TREND.

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 CINCs receive their information in real time (RT), near real time (NRT), or the next day (ND).

Figure 4.4-3 illustrates this trend in microprocessor speed and extrapolates a trend based on speeds doubling every 18 months. From it, GHz processors should become commercially available within the year (2001) and THz (1000 GHz) processors by 2013.

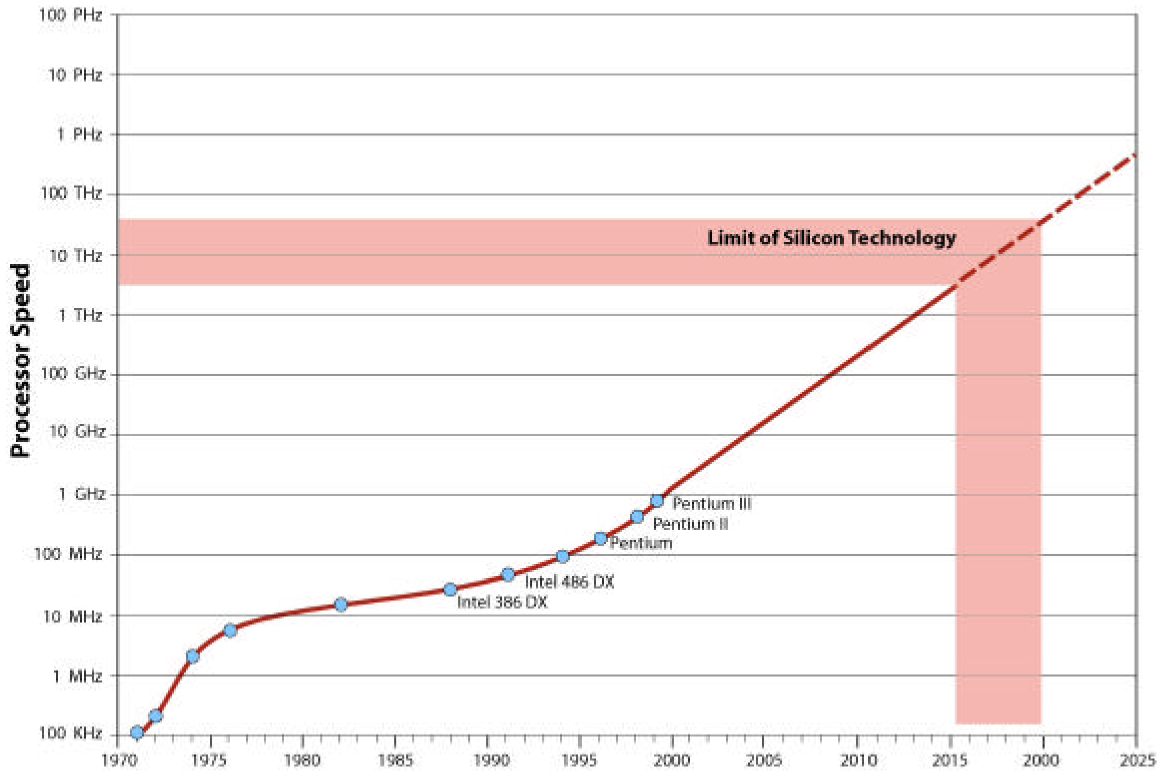

FIGURE 4.4-3: PROCESSOR SPEED TREND.

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. By one example, the equipment for a microchip manufacturing line that cost $12,000 in 1968 cost $12,000,000 in 2000 for the same microchip output, and is climbing toward the billions. This is becoming known as Moore's Second Law, which recognizes that economic reality can and will constrain technical progress.

Three technology avenues for extending this 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 xrays 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 alternative technologies currently being researched are optical, biochemical, molecular, and quantum processing. Progress towards these silicon-alternative computers, relative to the evolution of silicon technology, is shown in the following table, with estimates for when the new technology will likely become commercially available given in italics.

TABLE 4.4.4-1: FUTURE PROCESSOR TECHNOLOGIES.

Processor Type:	Silicon	Optical	Biochemical	Molecular	Quantum
Concept:	1928 (patent)	1964 (Bell Labs)	1993 (Adleman)	1975 (Aviram/Ratner)	1981 (Feynman)
Demonstration:	1947 (transistor)	1990 (S-SEED)	1994 (DNA-based)	1998 (ethynylphenyl)	1988 (BRTT)
Production:	1958 (integrated circuit)	*2000-05*	*2005-15*	*2015-25*	*2025+*

Two assertions regarding UAVs and information processing towards the latter years of this roadmap seem reasonable: UAVs will "come of age" during this period of transition from silicon to some other based processing, and they will be assigned missions requiring the utmost in processing power. Therefore, UAVs will be an early, driving consumer for, and beneficiary of, these emerging processing technologies.

4.5 Current UAV Technologies Research

A recent survey (Table 4.5-1) of Defense research laboratories revealed nearly 70 funded research initiatives are developing UAV-supportive capabilities. In general, these research efforts are closely aligned with their respective Service's developmental UAV programs—UCAV for the Air Force, RQ-7/Shadow 200 for the Army, and VTUAV/Fire Scout for the Navy. Of the total research investment across all Services (some $1,241M), 62 percent was in platform-related enhancements and 33 percent in payloads. Four percent was invested in communications and one percent in information processing, reflecting the dominance of commercial influence in new developments in these two areas. Of the Air Force's $716M investment in various research efforts supporting UAVs, 23 percent focuses on UCAV development and 18 percent on Global Hawk. The Army's $104M total has 62 percent focused on TUAV/Shadow 200 support. The Navy's $125M total is 52 percent dedicated to VTUAV/Fire Scout. DARPA's $298M total supports both UCAVs (34 percent) and Global Hawk (36 percent).

TABLE 4.5-1: COMPARISON OF SERVICE LABORATORY INITIATIVES WITH CINC REQUIREMENTS.

Requirements	Laboratory Initiative	Service/Lab	Target UAV(s)	Funding*
Platforms				**767.2M**
Endurance	Future ISR Vehicle Technologies	USAF/AFRL	Generic	24.4M
	Joint Expendable Turbine Engine	USAF/AFRL	Generic	18.9M
	"	USN/ONR	Generic	23.0M
	VAATE Engine Affordability	USAF/AFRL	Generic	60.0M
	Advanced Propulsion Materials	USAF/AFRL	Generic	63.1M
Survivablity	Canard Rotor/Wing ATD	DARPA/TTO	Dragonfly	14.6M
EMI Environment				
Unadulterated Airflow				
High Altitude				
Anti-Ice				
Hardpoints	UAV Weapons Integration	USAF/AFRL	Generic	49.6M
Hover	A160 Hummingbird ATD	DARPA/TTO	Hummingbird	29.9M
Power Generation	More Electric Aircraft (MEA)	USAF/AFRL	Generic	38.2M
	High Power Materials & Processes	USAF/AFRL	Generic	4.0M
Large Antenna Array	Future ISR Vehicle Technologies	USAF/AFRL	Generic	24.4M
Other	UCAV ATD	USAF/AFRL	UCAV-AF	62.0M
	"	DARPA/TTO	X-45/UCAV	34.0M
	Naval UCAV ATD	DARPA/TTO	UCAV-N	68.0M
	Reliable Autonomous Control	USAF/AFRL	Generic	29.1M
	Low Cost Airframe Structures	USAF/AFRL	UCAV	13.8M
	Affordable Composite Structures	USAF/AFRL	UCAV/RQ-4	51.1M
	Future ISR Vehicle Technologies	USAF/AFRL	Generic	24.4M
	UCAV Operator Interface	USAF/AFRL	UCAV	1.9M
	Multi-Sensory Interfaces	USAF/AFRL	RQ-1/UCAV	7.6M
	UAV/UCAV Training Research	USAF/AFRL	UCAV/RQ-1	0.6M
	C2 Operator Interfaces	USAF/AFRL	UCAV	5.2M
	UAV/UCAV Maintenance Support	USAF/AFRL	UCAV	15.7M
	Mini UAV (MUAV)	USA/NVESD	Backpack Mini	7.0M
	ALTAIRIS Mission Planning	USN/PMA263	VTUAV	0.3M
	Shipboard Touchdown Prediction	USN/PMA263	VTUAV	0.6M
	UAV Autonomy	USN/PMA263	VTUAV	61.1M
	See And Avoid System (SAAS)	USN/PMA263	Generic	0.4M
	Autonomy Development Efforts	USN/ONR-35	Generic	15.8M
	Dragon Eye Mini UAV	USN/NRL	Dragon Eye	4.0M
	Extender Deployable UAV	USN/NRL	Extender	2.8M
	Micro Air Vehicle	USN/NRL	Mite	3.0M
	Micro Air Vehicles	DARPA/TTO	MAV	8.7M
Payloads				**417.8M**
Imagery Intelligence	SHARP Moving Target ATR	USAF/AFRL	RQ-4	2.1M
	IR Sensors Materials & Processes	USAF/AFRL	Generic	8.5M
	Multi-Mode Tactical Radar ATD	USA/CECOM	RQ-7/VTUAV	7.2M
	HyLITE HSI & IR	USA/NVESD	RQ-1/RQ-4	6.3M
	LWG Light Weight Gimbal	USA/NVESD	RQ-7/RQ-1	0.7M
	Multi-Mission Modular EO/IR	USA/NVESD	RQ-7	4.7M
Signals Intelligence	Multifunction SIGINT Payload	USA/CECOM	RQ-7	5.2M
MASINT (CW/BW)	Remote Biological Detection	ASD(C3I)	RQ-7	1.3M
	Standoff Chemical Detection	ASD(C3I)	RQ-7	15.1M
	FINDER (CP2 ACTD)	DTRA	RQ-1/Finder	6.5M
MASINT (CC&D)	SPIRITT ATD (HSI)	USAF/AFRL	RQ-4/U-2	27.1M
	FOPEN ATD (SAR)	USAF/AFRL	RQ-4	73.5M

Requirements	Laboratory Initiative	Service/Lab	Target UAV(s)	Funding
	"	DARPA/SPO	RQ-4	54.0M
	LAMD MSI Minefield Detection	USA/NVESD	RQ-7	13.4M
	RTIS HSI Sensor	USA/NVESD	RQ-7	0.4M
Communications Relay	VTUAV Communications Payload	USN/ONR	VTUAV	0.2M
	Airborne Communications Node	DARPA/ATO	Generic	53.0M
ECM/ESM				
Leaflet Dispensing				
Hardened/Buried Targets				
Meteorological				
Other	Advanced SEAD Targeting	USAF/AFRL	UCAV	38.6M
	UAV Weapons Integration	USAF/AFRL	Generic	49.6M
	UAV Repetition Rated HPM	USAF/AFRL	Generic	22.9M
	Remote Nuclear Detection	USA/SBCCOM	RQ-7	1.3M
	Time Critical Precision Targeting	USN/PMA263	Generic	0.6M
	Future Navy VTUAV Payloads	USN/PMA263	VTUAV	0.4M
	Plug & Play MMP Capability	USN/PMA263	VTUAV	2.2M
	Airborne GPS Pseudo-Satellite	DARPA/SPO	Generic	23.0M
Communications				**43.2M**
Bandwidth	Advanced TCDL for UAVs	USA/CECOM	RQ-7	9.1M
	MLAS Multi Link Antenna ACTD	USN/PMA263	Generic	10.2M
Encryption				
LPI Techniques				
Coalition Compatible				
Other	Communications Fusion	USA/CECOM	RQ-7	23.9M
Information Processing				**13.0M**
Processor Speed				
Pattern Recognition	Airborne Video Surveillance	DARPA/SPO	Generic	13.0M

Total: **1,241.2M**

*Funding reflects Presidential Budget 01 for FY00 and out.

5.0 Operations

5.1 Operations Requirements

In addition to the technology-driven components of a UAV system, innovations in the way these systems are employed can also enhance warfighter capabilities. The IPL analysis used for identifying technical requirements also revealed operations-related shortfalls that could be addressed by UAVs--insufficient aircrews, uncertain satellite availability, and a desire for forward operating locations (FOLs).

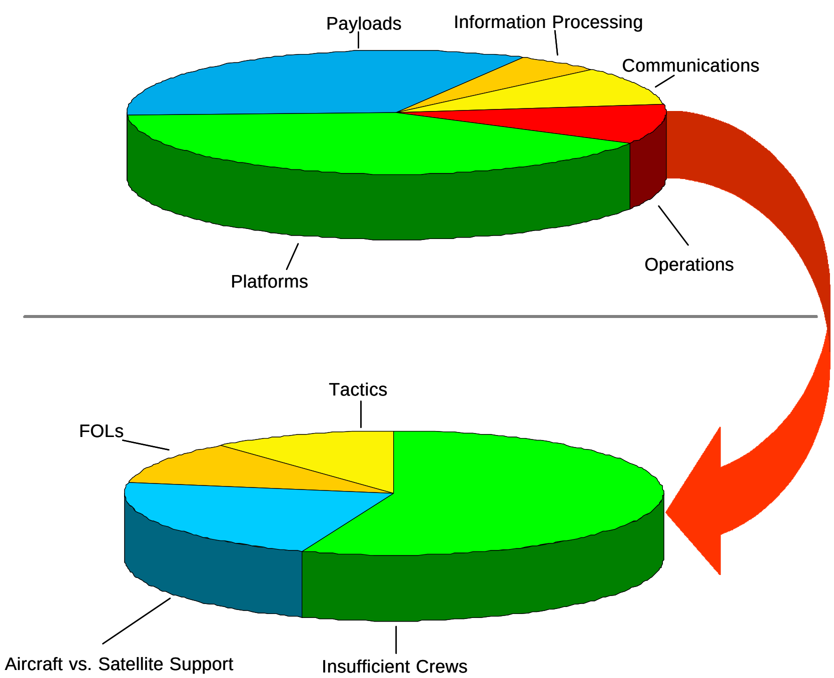

FIGURE 5.1-1: UAV OPERATIONS REQUIREMENTS.

5.1.1 Insufficient Aircrews

Aviation physiology regulations have evolved over the better part of a century and incorporate hard-learned lessons, but the logic underpinning them may not apply, in full or in part, to UAV operations and indeed may impede them unnecessarily. Their underlying assumption is that the flying environment imposes unique stresses (noise, temperature, reduced air pressure, confinement) on the human body, which requires limits to flight duration, recovery time between flights, and restriction for certain medical conditions. Obviously, UAV crews do not operate in this environment, opening the need to reexamine the absolute applicability of these regulations and offering the potential for a new paradigm in aircrew management.

Of the currently fielded UAV ground control stations (GCS), only one (Predator) incorporates a stick and rudder pedals which translate the pilot's (or Air Vehicle Operator's - AVO's) inputs into aircraft maneuvers. The trend in GCSs is to provide the

AVO with a mouse and keyboard with which to type in changes to route, altitude, etc. Even the external pilot functions for the Pioneer and the Hunter are being automated in the Fire Scout and the Shadow 200. Both the old and new GCSs require "airmanship," that familiarity with the flying environment (radio calls, weather evaluation, time and distance judgment, alternatives, etc.) and its requirement for thinking in three dimensions while moving, but only the stick and rudder pedal-based GCSs require the unique skill (foot, hand, eye coordination) of a pilot. For all future GCSs, the mission planning (and inflight replanning) and airmanship skills of rated non-pilots more closely match the requisite skills for a UAV operator/mission commander. Their use would widen the pool of Service resources from which to draw future UAV operators.

Even manned aircraft with augmented crews have limits to their duty day, thereby defining the aircraft's endurance. In contrast, a UAV operation should be able to rotate fresh aircrew members into their positions on a shift basis for as long as the aircraft can remain airborne. At typical overseas detachments of ISR aircraft (U-2s, RC-135s), three to five crews fly four to five 6-12 hour sorties per week. If the same number of UAV crews were used, using 6 to 8 hour shifts, they should be capable of conducting 7x24 operations for the same period or longer, a significant increase in crew availability. In the mid term, the paradigm of one crew, one aircraft should also give way to a concept (and a capability) of one crew, multiple aircraft, further multiplying the availability ratio.

The aircrew aspect of the low density/high demand problem for certain missions may be mitigated by examining current crew duty day, crew qualification, and medical restrictions for relevance to a ground-based flying environment.

5.1.2 Aircraft vs. Satellite Support

The trade offs between aircraft and satellites are most apparent in the CINCs' command, control, and communications (C^3) requirements. The satellite is accessible over a wide area, is relatively secure, and is logistics-free. However, transponders are not always available when needed (18 month waits per transponder are typical), and when they are, they can be congested and costly to lease (on average $5 million per year per transponder). A high altitude, endurance aircraft acting as a pseudo-satellite provides an alternative in return for surrendering some of the satellite's footprint area and reduced vulnerability advantages. In return, it offers a number of advantages:

- The opportunity to upgrade old or install new capabilities on a "between missions" basis, compared to SATCOMs, which may be using 10 to 20-year-old technology by the end of their life.

- By orbiting at 10 nm altitude instead of 22,000 nm, the airborne communications node is far less vulnerable to jamming and better able to receive weak or low power transmissions by a factor of 40 dB when 100 nm away to 60 dB when overhead.

- For coalition warfare considerations, aircraft-collected intelligence has historically been more readily downgraded for release than intelligence originating from satellites.

5.1.3 Forward Operation Locations

CINC-expressed desires to negotiate access to forward operating locations in their theaters underlie their desire for being able to react more immediately to local situations. Endurance aircraft have demonstrated the capability to provide this access by traversing oceans and performing missions before returning to their CONUS base; Aerosonde spanned the Atlantic nonstop in August 1998 and Global Hawk flew a round trip mission from Florida to Portugal in May 2000. Both successfully coordinated their flights with multiple national authorities on both sides and transited international airspace shared by civilian airliners without incident. As such capability becomes operationalized, endurance UAVs can offer an alternative to dependence on FOLs, with their attendant negotiations, lease costs, and security risks. The mechanics of unmanned overflight, such as obtaining civil aviation authority approval, are being built now with experiences like those above, though much work remains to be done. The politics of overflight, manned or unmanned, will remain a situational issue, occasionally requiring endurance aircraft to sacrifice some of their time on station for a more circuitous routing when permission is denied.

5.2 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 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.

5.2.1 Air Force

The Air Force established its UAV Battlelab 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 Air Force 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.

5.2.2 Navy & Marine Corps

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 DragonDrone UAVs into its recent series of Limited Objective Experiments (LOEs) supporting Capable Warrior, MCWL has funded development of three new UAVs (described in section 2.3.2), 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 has 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 2000, NSAWC was selected to initiate the feasibility phase of a joint test and evaluation program addressing the use of UAVs in time sensitive operations.

The Naval Warfare Development Command's Maritime Battle Center (MBC), established at Newport, RI, in 1996, typically conducts two Fleet Battle Experiments (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) and FBE-Hotel (Pioneer and Dakota II in 2000). In the latter, both UAVs attempted to positively identify time critical targets within a 110 nm^2 area.

5.2.3 Army

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. Most notable have been the application, in concert with the MCWL, of UAVs (Camcopter in November 1997) and micro air vehicles in urban warfare scenarios supporting the Military Operations in Urban Terrain (MOUT) ACTD at the Dismounted Battle Space Battle Lab at Ft. Benning, GA. The Mounted Maneuver Battle Lab at Ft Knox, KY, which focuses on brigade-level-and-below, has an extensive resume of UAV 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

5.2.4 Joint

OASD (C^3I)'s 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 Tactical Control System (TCS) and the Multiple Unified Simulation Environment (MUSE). MUSE is being used to explore operational concepts and train for the Army's Tactical UAV.

JFCOM is in the process of establishing the Joint Operational Test Bed System (JOTBS) to explore UAV and C4I interoperability concepts and procedures that benefit the joint warfighter.

5.3 Reliability & Sustainability

A recent Israeli study of its UAV mishaps after having accumulated 80,000 hours of operations (the U.S. fleet is at the 50,000 hour mark) showed the following breakout of responsibilities for their mishaps.

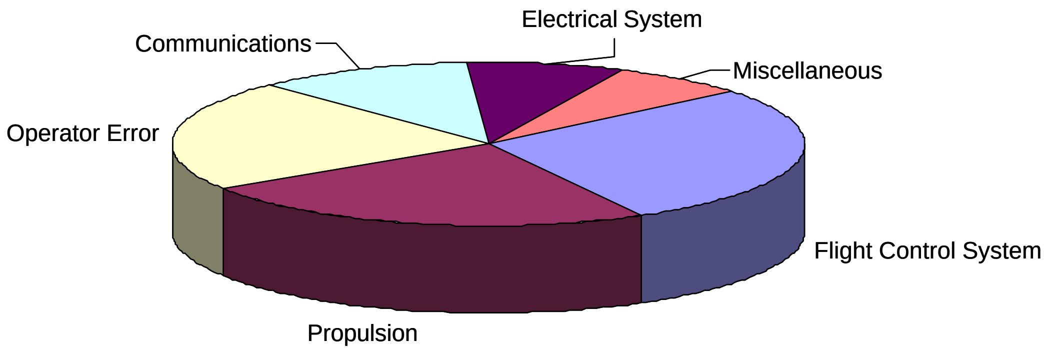

FIGURE 5.3-1: ISRAELI UAV MISHAP CAUSES.

By instituting reliability improvements in three of the above areas (flight control systems, propulsion, and operator training), which have historically accounted for 75 percent of UAV mishaps, the overall mishap rate for UAVs could be significantly reduced, resulting in appreciable savings in attrition aircraft acquisition costs. Further savings could result from decreased line maintenance due to advancing technologies, which will negate the need for hydraulic systems, analog sensors, and internal combustion engines. The challenge is to make tradeoffs so the recurring savings of a reliability enhancement exceeds the nonrecurring investment, and potentially decreased performance, required to make the enhancement. **The potential savings from improvements in these three areas make a strong case for identifying and incorporating such reliability enhancements in existing and all future UAV designs.**

5.4 Training

The training implications of UAVs are potentially great. Today's manned aircraft are flown over 95% (50% for ISR aircraft) of the time for peacetime training of aircrews, with the attendant operations and maintenance cost, because aircrews must practice in their environment to maintain their flying proficiency. Remove the aircrew and today's costly training paradigm requires reexamination. UAV operators 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 air vehicle operators would help mitigate today's low-density/high-demand operational tempo problem. Lower sortie rates could also lead to related reductions in certain support personnel, with their associated training and sustainment costs.

While the potential for savings in training is generally acknowledged, the extent of such savings have not yet been demonstrated (see DARPA effort below). 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 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, initial training, mission qualification, and proficiency training could be conducted largely in simulators, while most of the aircraft remain in ready boxes for months or years at a time. DARPA is exploring this concept by requiring its UCAV to be storable for up to 10 years from production delivery to first flight in specially designed containers optimized for airlift. These hermetically-sealed containers will incorporate monitors and access ports to enable maintenance personnel to check the aircraft's status without unboxing it.

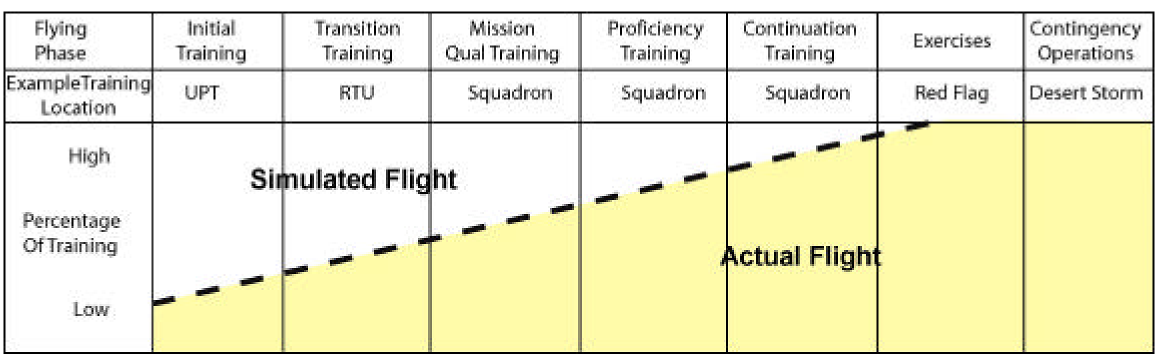

FIGURE 5.4-1: RELATIVE DEMAND IN ACTUAL VS. SIMULATED FLIGHT TRAINING.

While such a "build, box, 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.

5.5 Communication Infrastructure

The shortage in long haul, wideband other-the-horizon communications will be exacerbated as future ISR platforms, manned and unmanned, are fielded, as described in section 4.2.5. This shortage takes two forms, insufficient bandwidth and lack of coverage in some geographic areas, which can directly constrict global UAV deployment. This infrastructure needs to be increased as these platforms, including UAVs, are fielded.

5.6 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 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. Such cooperation will enable survivable penetration of defended airspace and permit time compressed coordinated target attacks. 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.

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 Figure 6.2-1). The key question addressed in this section is: *When will the technologies required to enable the CINCs' desired capabilities become available?*

6.1 Operational Metrics

To relate the priorities expressed by the CINCs in section 3 to the technologies coming available within the next 25 years (section 4), a number of *operational metrics* (see Table 6.1-1) were devised for this Roadmap. To use the road atlas analogy again, the CINCs' desired capabilities represent destinations, the technologies possible routes to them, and these metrics mileposts to indicate progress toward the requirements. They identify specific opportunities for future capabilities to satisfy the warfighters' needs. All references to years are for dates when these capabilities are expected to become available for fielding. 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	Operational Metrics	Availability Timeframe
Platforms	Endurance	1. Achieve 20% increased time-on-station with same fuel load	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. Distinguish armed from unarmed individuals from 4 nm	2002
		6. Distinguish facial features (identify individuals) from 4 nm	2005
		7. Achieve 12 in SAR resolution over a 10 nm wide swath	2000
		8. Achieve 6 in SAR resolution over a 10 nm wide swath	2002
		9. Achieve 3 in SAR resolution over a 10 nm wide swath	2005
		10. Achieve 3 in SAR resolution over a 20 nm wide swath	2010
Data Links	Data Rate	11. Relay entire COMINT spectrum in real time	2005
		12. Relay entire ELINT spectrum in real time	2025+
		13. Relay 10-band multi-spectral imagery in real time	2000
		14. Relay 100-band hyper-spectral imagery in real time	2010
		15. Relay 1000-band ultra-spectral imagery in real time	2025+
Information Processing	Processor Speed	16. Map surf zone sea mines in near real time	2002
		17. Map surf zone sea mines in real time	2016
		18. Reduce DTED level 5 data in near real time	2009
		19. Reduce DTED level 5 data in real time	2022

Metrics for endurance and signature reduction were defined to show how future UAV platform performance could be enhanced to meet the CINCs priorities. The endurance metrics seek to provide 20-, 30-, and 40-percent increases in flight endurance by equivalent improvements in specific fuel consumption (SFC) for a given engine type and constant fuel weight. Figure 4.1.2-1 predicts these increases should be attainable, due to such efforts as the AFRL's Versatile, Affordable, Advanced Turbine Engine (VAATE) program, by 2005, 2010, and 2015 respectively. These percentages equate to 20-, 30-, and 40-percent more time on station for the same number of deployed aircraft used today, helping address the coverage shortfall identified by the majority of the CINCs. The signature metric, driven by the CINCs' priorities for enhancing force protection, is to provide a UAV that is inaudible from 1000 ft, and ideally from 500 ft, slant range to preclude detection by base intruders. Figure 4.1.2-2 anticipates the mass specific power of fuel cell-powered engines will equal or exceed that of noisy internal combustion engines by 2004, enabling their use in fielding a silent airborne sentry.

To illustrate future payload opportunities, resolution metrics for EO/IR sensors and SARs were developed. Based on a recurring scenario in many theaters—an embassy or non-combatant evacuation from a foreign city—CINCs need a standoff sensor to avoid both further inciting the local populace and/or being downed by MANPADs (e.g., SA-7/14) with maximum ranges of up to 4 nm. Such sensors should be capable of distinguishing armed from unarmed persons, and, ideally, identifying specific individuals. The former capability requires video imagery with a GRD of 4-8 in, NIIRS 8, and an instantaneous field of view of 0.014 mrad; the latter requires a 2-4 in GRD, NIIRS 9, and a 0.007 mrad IFOV. Figure 4.2.2-1 predicts that improved focal plane arrays could enable today's gimbaled EO/IR sensor turrets to reach these levels of resolution by 2002 and 2005, respectively. For area searches, today's best SARs can image the equivalent of a 10 nm wide swath at 12 in resolution. The metrics chosen are to halve this resolution (6 in), then halve it again (3 in) for the same swath width, then to double the swath width covered to 20 nm and again achieve 6 and 3 in resolution. Figure 4.2.2-2 forecasts these capabilities being fielded by 2001 (6 in), and 2005 (3 in) for 10 nm wide swaths, and by 2010 (3 in) for 20 nm wide swaths.

Advances in UAV data links were measured in terms of data rate-based metrics needed for relaying unprocessed SIGINT and uncompressed multi-spectral imagery in real time. Such capabilities would contribute strongly to ensuring CINCs receive ISR information inside their opponents' decision cycles. For SIGINT, the capability to relay the entire COMINT spectrum or the entire ELINT spectrum was chosen. Figure 4.3-2 forecasts the communications technology for these opportunities could be fielded by 2005 and 2025+, respectively. For IMINT, the ability to relay successive 10-band multi-spectral (MSI) at 0.16 Gb/image, 100-band hyper-spectral (HSI) at 1.6 Gb, and 1000-band ultra-spectral imagery (USI) at 16 Gb, all at 1 sec intervals was chosen. These levels should be reached by 2000, 2010, and 2025+, respectively. Of course any decision to increase reliance on lasercoms would potentially allow the necessary data rates to be achieved sooner.

Finally, metrics were developed for information processing based on CINC prioritization of, and emerging technology in, counter mine warfare. The technology is that of ONR's Airborne Remote Optical Spotlight System (AROSS), which currently employs 500 MHz processing over 48 hrs to extract images of broaching sea mines from Predator UAV Skyball video. After optimizing AROSS' software, this process will still require an hour between imaging and results being available for dissemination. Using faster processors in the future, this time could be reduced to near real time (20 min) using 1.5 GHz processing, or to real time (1 sec) with 1800 GHz processing speeds. Moore's Law, as shown in Figure 4.4-1, predicts such levels of processing speed should become available in 2002 and 2016, respectively, but the latter date is within the period during which the limits of silicon-based processing will reach its limits, so real time mapping of sea mines may have to depend on alternative forms of computing. The same limit is encountered to reduce IFSAR data to DTED level 5 maps of a 150 x 150 nm area in near real time (2009) and real time (2022). Both examples illustrate an important caveat of the trends developed in section 4 and applied to operational tasks here, that of recognizing the limits to a given technology's growth.

The upper half of Figure 6.2-1 plots the predicted appearance of these 19 metrics over the next 25 years, with the date of each centered within a 5-year window of estimated initial availability for fielding.

6.2 UAV Roadmap for 2000-2025

By bringing together a plot of the predicted appearance of the listed metrics with a timeline of current/planned DoD UAV programs (Fig. 2.4-1), a roadmap of opportunities for applying emerging capabilities to forthcoming UAVs is created. This roadmap (Fig. 6.2-1) displays 19 such opportunities over the next 25 years.

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 operations & 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 (e.g., Shadow 200), (2) defense acquisition (milestone) programs (e.g., the Aquila UAV), and (3) Advanced Concept Technology Demonstrations, or ACTDs (ex: Predator). 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 a new design airborne is driven more by aerodynamics and propulsion than by human factors and avionics.

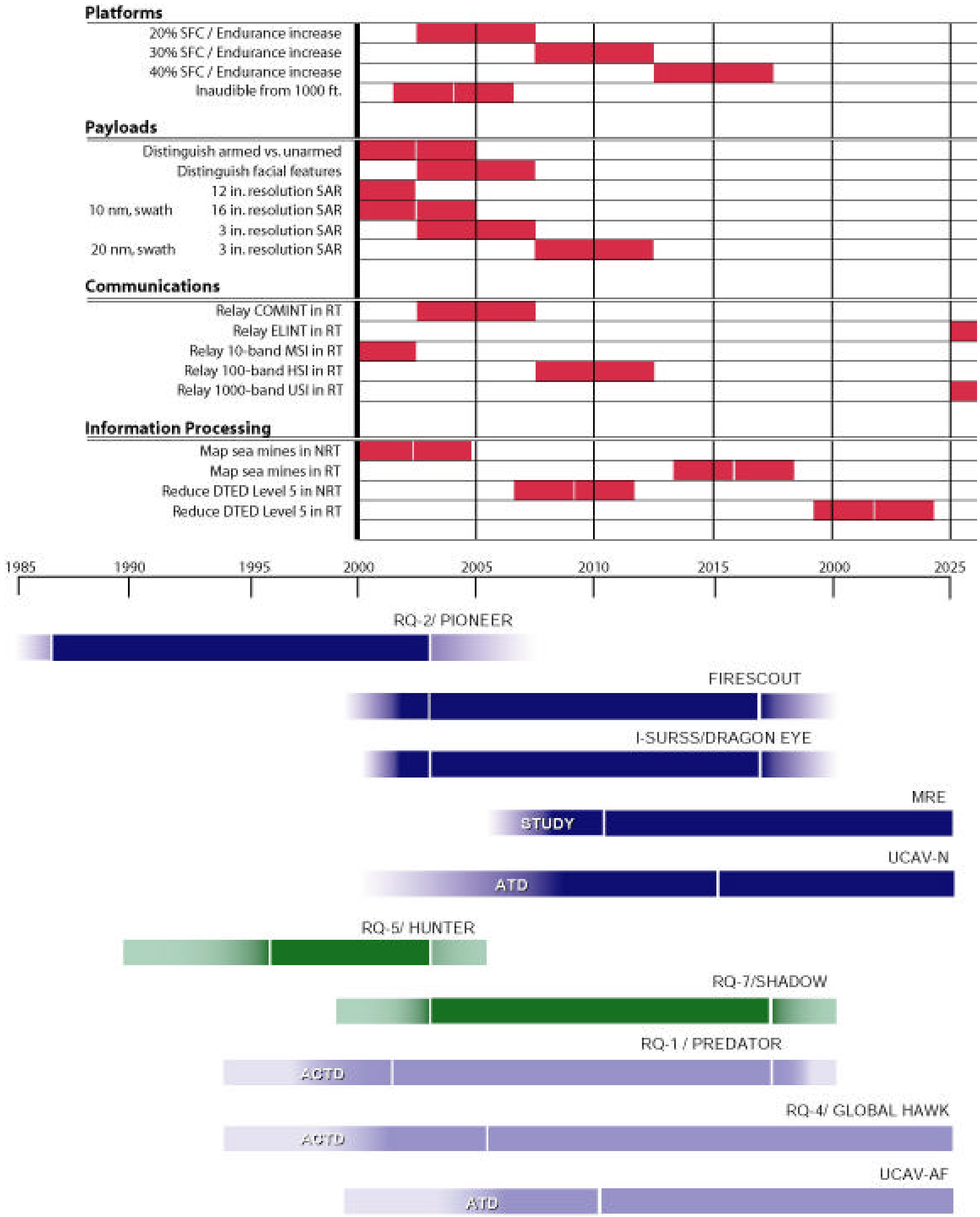

FIGURE 6.2-1: UAV ROADMAP, 2000-2025.

TABLE 6.3.1-1: 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*/USAF	$103M
X-45/UCAV	Apr 98	*Mar 01*	*35*	ATD/DARPA	$*102M*
Reconnaissance, Penetrating					
SR-71	Aug 59	Apr 62	32	SAP/CIA	$915M
D-21	Mar 63	Feb 65	23	SAP/USAF	$174M
Stealth					
XST/Have Blue (F-117)	Apr 76	Dec 77	20	SAP/USAF	$103M
RQ-3/DarkStar	Jun 94	Mar 96	21	ACTD/DARPA	$134M

*SAP = Special Access Program; DAB = Defense Acquisition Board (Milestone Process)

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 Joint Strike Fighter (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 "ground cockpit" of the UAV aircrew. Conversely, this ground control station can be capable of simultaneously flying multiple UAVs, somewhat restoring the advantage in cost to the unmanned system. Additionally, the GCS is a one time procurement cost regardless of the number of UAVs fielded during the life cycle of any particular system.

To illustrate this trade-off in procurement costs, compare a number of single seat F-16s at $30 million each with the cost of a "de-manned" F-16 ($25 million by subtracting out 3000 lb at $1500/lb) having a GCS of equal cost, then with DARPA's UCAV counterpart costing $10 million each and a GCS cost equal to that of two UCAVs ($20 million):

TABLE 6.3.2-1: MANNED VS. UNMANNED PROCUREMENT COSTS.

No. of Aircraft	F-16 Cost	Demanned F-16 Cost +GCS	Potential Savings	UCAV Cost+GCS	Potential Savings
1	$30 million	$50 million	-$20 million	$30 million	+ $0 million
2	$60	$75	-$15	$40	+ $20
3	$90	$100	-$10	$50	+ $40
4	$120	$125	-$ 5	$60	+ $60
5	$150	$150	0	$70	+ $80
6	$180	$175	+$ 5	$80	+ $100

The outcomes illustrated here are that (1) acquiring a de-manned version of a manned aircraft requires its GCS to be able to control a large number of simultaneous sorties (in this case six) to achieve a relatively small savings, compared to (2) acquiring a "clean sheet design" UAV, which offers a greater potential for procurement savings, in this case two flights (four aircraft each) of the comparable UCAV system for the same cost as one four-ship flight of F-16s.

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 objective of the DARPA/Boeing UCAV to deliver two 1000-lb JDAMs over a 650 nm radius to using today's F-16 for that mission. The weapon delivery performance for the two (i.e., 1.3 million lb-nm) is essentially the same, but the cost of the 7500-lb UCAV is to be half or less than that of the 19,000-lb F-16. The UCAV is to have a design life of 5,000 hrs, half of which could be spent in combat operations under a form of build, box, fly CONOPS. The 8,000-hour F-16 will spend 95 percent of its inflight 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 one twelfth (six times the hours at half the initial investment) that of the F-16 in this example, implying UCAVs could suffer 12 times the combat loss rate of F-16s and still be cost effective by the standards applied to today's manned fighters.

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. Three 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's Armstrong Lab, 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, with such simulators, the level of actual flying done by UAVs can be reduced, resulting in 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.

6.4 Key Issues

Any list of issues on an evolving topic such as UAV assimilation into our armed forces reflects the controversy surrounding it and therefore becomes controversial itself for what is and is not included. The four issues discussed below were chosen to address the technical (architecture), regulatory (airspace), political (treaty implications), and organizational dimensions of this controversy.

6.4.1 Architecture

The most fundamental, technology-driven decision facing UAV planners early in the 2000-2025 timeframe is whether to migrate towards an air-centric (processor based) or a ground-centric (communications based) architecture. In the case of the former, relatively autonomous UAVs with minimal ground infrastructure and direct downlinks to users will be the norm. For the latter, UAVs will be remoted “dumb” sensors feeding a variety of sensory data into a centralized ground node which builds a detailed, integrated picture for the users. Hybrid architectures, in which processing is begun on the aircraft and completed on the ground and transmission requirements are reduced by using recorders and/or data compression techniques, are used by today’s reconnaissance aircraft. This architecture exists because the capabilities of current processors and data links are inadequate by themselves to handle the amount of data generated by today’s sensor suites. Data compression techniques are the most prevalent workaround for insufficient onboard processing speed and data link data rate constraints.

At some future point, sufficient onboard processing power for the worst case information processing requirement, such as streaming video of ultra spectral imaging (thousands of spectral bands), will be reached. At that point the answer, vice the data that provided it, will become the driver for the data link’s capacity, downsizing its requirement drastically. As an illustration, a future UAV system searching for “tanks under trees” (TUT) with a hyper-spectral imaging sensor would process and exploit its imagery onboard in real time, then relay the coordinates and certainty of identification of all tank suspects found over a 9.6 kbps link, simultaneously with the UAV’s health and status. This becomes an air-centric (processor driven) architecture, in which UAVs become highly autonomous extensions of man, drawing their own conclusions onboard and distributing their answers directly to users.

Alternatively, data link capacities, having far outdistanced the worst case data rate requirement, reach the theoretical saturation of the RF and optical spectrums. At this point, transmitting the unprocessed TUT data off-board and deriving the answer on the ground becomes the more timely process. The UAV in effect becomes a pair of unthinking eyes attached to a bent pipe, passing what its sensors see to the ground without impeding the flow with any onboard processing. This becomes a ground-centric architecture, in which UAVs become highly dependent extensions of man, routing their data to a central node before further distribution.

These two extremes in architecture assume that, ultimately, there is a limit to how much information needs to be collected to satisfy the operator's requirements. As a gauge, the entire Encyclopedia Britannica consists of 1.3 Gb, a 100-band HSI image 1.6 Gb, and a 1000-band USI image 16 Gb; USI video, at 30 frames a second, would generate 480 Gbps as a data rate. As shown in section 4.3.4, such transmission rates could potentially be achieved by optical communications in the 2020 timeframe, but probably not ever by RF systems.

6.4.2 Airspace Integration

The most recognized contemporary issue concerning UAVs (Remotely Operated Aircraft, or ROAs, in FAA terminology) is how to safely integrate unmanned flight into the National Airspace System (NAS), which since its inception has been geared for manned flight. Standards must be established to allow UAVs to operate flexibly within the NAS, even for high altitude missions involving flight above all civil traffic, because UAVs reach such altitudes only after climbing through potentially crowded airspace. Such transits through the NAS while enroute from CONUS bases to overseas operating areas, like that performed recently by Global Hawk (Florida to Portugal for NATO's Linked Seas exercise in May 2000), will become increasingly common. Emergency/weather diversions through the NAS into alternate enroute airfields will eventually occur. Smaller tactical UAVs are also growing users of the NAS, participating in border patrol, counterdrug, and joint exercises requiring their flight within the NAS. Precedents set with the FAA for the NAS then need to be applied to the ICAO for governing UAV flights in international airspace. Such integration into civilian, peacetime airspace is above and beyond that required for integrating UAVs into the Air Tasking Order for a war zone, as discussed in section 5.5.

Establishing these standards is the responsibility of the FAA, whose overarching goal is to ensure safe air operations. The Services, through such organizations as the Air Force Flight Standards Agency (AFFSA), ensure military aircraft operations comply with the FAA standards and thus share responsibility for safe airspace integration. Airworthiness standards ensure aircraft are constructed for safe and reliable operation. Air operation standards ensure pilots and mechanics are trained and proficient to a common level. Air traffic standards ensure aircraft are channeled in time, altitude, and geography to reduce the risk of midair collisions. In the United States (as well as elsewhere in the world), specific versions of these standards have been developed for air carriers (passenger and freight airlines), general aviation, helicopters, homebuilt aircraft, gliders, and lighter-than-air craft, but not for UAVs. FAA Order 7610.4, a standard for military (not civil) UAV operations and aircrew qualifications, went into effect on 1 May 1999; the civil version(s) of this standard awaits the manifestation of a need, i.e., a commercial market developing. This order requires military users to obtain a Certificate of Authorization (COA), good for 1 year, up to 60 days prior to flight, thereby treating UAV flights as extraordinary, vice routine, events. Draft Advisory Circulars, which are official FAA documents that define issues and recommend solutions, but are not regulatory in nature, addressing these three areas for civil/commercial UAVs, were prepared in 1996. The current state of FAA and NATO regulations governing UAVs is shown below:

TABLE 6.4.2-1: STATUS OF FAA AND NATO UAV FLIGHT REGULATIONS.

User	Air Worthiness	Aircrew Qualification	Air Traffic/Operations
FAA Civil Status	Advisory Circular Draft	Advisory Circular Draft	Advisory Circular Draft
FAA Military Status	Not applicable	Order 7610.4 In effect, May 99	Order 7610.4 In effect, May 99
NATO Status	AC/92-D/967 Working paper	AC/92-D967 Working paper	AC/92-D967 Working paper

The FAA is on the verge of changing its entire approach to managing air traffic, and, as with any paradigm shift, an opportunity exists to piggyback change on change—in this case by also introducing a new paradigm for UAV flying. **The vision for future UAV operations *should be* one in which the UAV pilot can check the sky, decide to fly, file a flight plan, and be airborne, all within the same day**. The coming paradigm for manned air traffic is "free flight," a shift from ground-centric to air-centric air traffic control, to be implemented with the introduction of Global Air Traffic Management (GATM) by 2010. GATM offers savings in fuel and time by flying shorter, more direct routes and more efficient and safe use of increasingly congested airspace. GATM relies on implementing Automatic Dependent Surveillance-Broadcast (ADS-B), which employs a combination of Traffic Collision Avoidance System (TCAS), transponders, and GPS aboard each aircraft broadcasting its location to a bubble of airspace around it. When bubbles approach one another, each system automatically diverts its aircraft from possible collision; if one fails, the remaining one is sufficient to ensure collision avoidance. See and avoid becomes automated and independent of visibility in environments where all traffic is participating (i.e., GATM compliant). In such an environment, the manned and the unmanned become equally responsible users of the NAS, and the need for separate standards largely disappears.

6.4.3 Treaty Considerations

Initiatives to modify existing reconnaissance UAVs to deliver ordnance or to develop new unmanned combat aerial vehicles (UCAVs) for flight testing or deployment as a weapon—that is any mechanism or device, which, when directed against any target, is designed to damage or destroy it—must be reviewed in accordance with DoD Directive 2060.1 for compliance with all applicable treaties. Examples of treaties that may be considered include: 1) the 1987 Intermediate-range Nuclear Forces (INF) Treaty, 2) the 1990 Conventional Armed Forces in Europe (CFE) Treaty, and 3) the 1991 Strategic

Arms Reduction Treaty (START). As is the practice for all programs, determinations will be made on a case-by-case basis with regard to treaty compliance of armed UAVs or UCAVs.

6.4.4 Organizational Responsibilities

Although no single focal point for managing Defense Department UAV efforts exists, cross-Service oversight responsibilities for UAV development have been divided among the following organizations:

- USD(AT&L) – acquisition and technology oversight
- ASD(C^3I) – policy, interoperability standards, and ISR systems oversight
- JCS/JROC – CINC priorities evaluation and requirements formulation

The Defense Airborne Reconnaissance Office (DARO) served as this focal point from 1993-98. Created by Congress to oversee all airborne reconnaissance matters (manned and unmanned), its notable UAV accomplishments included flight testing of four new UAV designs (Predator, DarkStar, Global Hawk, and Outrider) via ACTDs, two of which emerged from the process with recommendations to go to production, establishing the Common Imagery Ground Support System (CIGSS) imagery standard, and prioritizing payload development efforts based on CINC mission requirements. DARO was disestablished in 1998.

Within each service, UAV cognizance generally resides in multiple staff elements, generally aligned by functional responsibility—acquisition, requirements, and operations. One element is responsible for representing its Service's interests on the Joint Requirements Oversight Committee's (JROC's) UAV Special Study Group. These elements and their span of responsibilities are:

TABLE 6.4.4-1: UAV RESPONSIBLE OFFICES OF SERVICES.

		Responsibilities	
Service	Acquisition	Requirements	Tactics/CONOPS
Army	SAAL-SA	DAPR-FDI*	TRADOC/TSM UAV
Navy	ASN(RDA)	N754*, N78	NWDC/NSAWC/Units
Marines	ASN(RDA)	DCS/APW*	MCCDC
Air Force	SAF/AQIJ	AF/XORR*	ACC

*Service representative to the JROC's UAV SSG.

In addition, the Navy has internally established a multi-level set of steering groups under the auspices of the Naval UAV Executive Steering Group, chaired by N75, which oversees Navy/Marine Corps UAV interests and includes representation from the naval acquisition, requirements, and tactics/CONOPS organizations identified above.

While there are a number of organizations involved, responsibility for the following broad recurring UAV-related functions and issues is not clearly defined within the current structure:

- Establishing interoperability standards, as has already been done for data links (CDL), for mission planning and control software, sensor product formats, etc.
- Identifying common equipment for cost effective procurement and maintenance.
- Prioritizing funding for promising technologies with cross-service applicability.
- Ensuring UAVs are fully considered as an option in new system Analyses of Alternatives.
- Representing DoD UAV interests in non-DoD and departmental-level forums (Congress, Intelligence Community, NASA, etc.).
- Participating in UAV system export decisions with the State and Commerce Departments.

6.5 Conclusions

The following conclusions address perceived gaps, overlaps, and potential advances in DoD UAV capabilities, programs, and organizations identified in this study.

6.5.1 Technologies

1. Fuel cells may have equal or better mass specific power than that of internal combustion engines as early as 2005 (section 4.1.2) and become suitable for propulsion systems on tactical-size UAVs.

2. Flight control system failures have historically been the largest single contributor to UAV mishaps (section 5.3).

3. DARPA's micro air vehicles may be ready for field trials and joint military utility assessment (MUA) by 1QFY02 (section 2.3).

4. Long term (12-20 years) research programs focused on improving turbine engine efficiencies have demonstrated their ability to deliver significantly improved performance (section 4.1.2). Improving turbine engine efficiency would be beneficial for endurance UAVs.

5. COTS/GOTS payloads could address CINC requirements for an interim SIGINT capability if integrated on endurance UAVs (section 4.2.3).

6. IFSAR holds significant potential to benefit targeteers by providing Level 5 DTED (section 4.2.2). High altitude endurance UAVs may be a suitable platform for this sensor technology.

7. Preliminary flight tests of NRL's multiple quantum well retro-reflector data link demonstrated a 400 Kbps data rate, with the potential to achieve 1-10 Mbps

covert transmissions (section 4.3). This optical data link may prove suitable for rotary and fixed wing UAVs and MAVs.

6.5.2 Operations

1. UAVs offer the potential to relieve the impact of low-density/high-demand aircraft missions (such as those of the RC-135, EP-3, E-3, E-8, etc.) on their aircrews (sections 5.1.1, 5.4, and 6.3.3).

2. Meteorology data, useful to a wide audience of interservice users, is readily collectable by UAVs but goes unreported because of not being included in the telemetry downlink information (section 4.2.1).

3. Reexamining Service training paradigms for UAVs may significantly reduce training time and costs for UAV personnel (section 6.3.3).

4. Each service currently reports its UAV mishaps under different criteria, making it difficult to detect UAV fleet-wide reliability and mishap trends (section 5.3).

5. The shortage in long haul, wideband, over-the-horizon communications will be exacerbated as future ISR platforms, both manned and unmanned, are fielded (sections 4.2.5 and 5.5).

6. Flights by UAVs into the National Airspace System (NAS) are currently treated as mission-specific events by the FAA, constraining their military utility (section 6.4.2). UAVs should become able to conduct flights within the NAS by filing a same-day flight plan in the future.

6.5.3 Organizations

1. Organizational responsibilities for a number of broad recurring UAV-related functions, especially cross-Service functions, are not clearly defined within the current DoD structure (section 6.4.4).

Appendix

Service Research Laboratories' UAV-Related Initiatives

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TABLE A-1: DATA CALL FOR S & T EFFORTS FOR UAV PAYLOADS/SENSORS/SUPPORT TECHNOLOGIES

PLATFORM TECHNOLOGIES	
UAV to meet NASA Science Mission Reqmts. (Predator B)	NASA/DFRC
A160 Hummingbird long endurance/range UAV helicopter	DARPA/TTO
Canard Rotor/Wing (CRW) ATD high-speed VTOL	DARPA/TTO / Boeing / Navy
UCAV ATD	DARPA/TTO / USAF
UCAV-N ATD	DARPA/TTO / Navy
Autonomous Ground Ops. & Collision Avoidance for UCAV ATD	NASA Dryden
Weapons Integration for UAVs (PDAM, SSBREX, LOCAAS, SMD)	AFRL/MN
Directed Energy: Repetition Rated High Power Microwave Technologies	AFRL/DE
Directed Energy & Radar: Matls. & Processes for High Power Applications	AFRL/ML
Reliable Autonomous Control (at reduced size, wt, and cost)	AFRL/VA
Low Cost Airframe Structures (reduced parts)	AFRL/VA
Affordable Composite Structures (matls. & mfg.)	AFRL/ML
Vehicle Technologies for future ISR reqmts.	AFRL/VA
Mini UAV	Army CECOM/Night Vision & Elec. Sensors
Micro AV	NRL / ONR
Micro Air Vehicles (MAV)	DARPA/TTO
Multiple 6.1 Autonomy Development Efforts	ONR-35
UAV Autonomy technologies for capability gaps (details not available)	ONR/NAVAIR
Automated/Assisted Maneuvering (details not available)	ONR/NAVAIR
Autonomous Ops. FNC (sit. awareness, multi-vehicle network, & intelligent autonomy)	Navy PEO(W)/PMA 263
Altairis for UAV autonomy (VTUAV Mission Ctrl. Software)	Navy PEO(W)/PMA263
Shipboard Touchdown Prediction Landing Aid	Navy PEO(W)/PMA263

See & Avoid System (SAAS)	Navy PEO(W)/PMA263
Multiple Link Antenna System (MLAS)	Navy PEO(W)/PMA263
Dragon Warrior (Battalion VTOL)	MCWL
Broad-Area Unmanned Responsive Resupply Ops. (BURRO)	MCWL
Dragon Drone testbed	MCWL
Dragon Eye Backpack UAV	MCWL/ONR/NRL
Extender air-drop deployed UAV for EW	ONR
PROPULSION TECHNOLOGIES	
Autonomous Op. FNC: Propulsion Tech. Program	ONR
Joint Expendable Turbine Engine Concepts (JETEC)	AFRL/PR
Versatile Affordable Advanced Turbine Engine (VAATE)	AFRL/PR
Advanced Propulsion Materials and Processes	AFRL/ML
More Electric Aircraft (MEA)	AFRL/PR
Helios Prototype – Solar Powered Aircraft for long duration (6 months)	NASA Dryden
HUMAN EFFECTIVENESS TECHNOLOGIES	
DARPA/USAF UCAV Operator Vehicle Interface (control of multiple UCAVs by a single operator)	AFRL/HE
Multi-Sensory Interfaces/Visualization Techniques	AFRL/HE
UAV/UCAV Training Research	AFRL/HE
C2 Operator Interfaces for manned and unmanned	AFRL/HE
UAV/UCAV Predictive Failure and Diagnostics	AFRL/HE
Flight Control Predictive Diagnostics	ONR/NAVAIR

SENSOR TECHNOLOGIES	
Airborne GPS Pseudo-Satellites for countering GPS jammers	DARPA/SPO
Airborne Comms. Node (ACN) for wide freq. and SIGINT	DARPA/ATO
FOPEN SAR ATD	DARPA/SPO / AFRL / Army
Airborne Video Surveillance (AVS) for targeting and monitoring	DARPA/AVS
VTUAV Comms. Relay (details not available)	SPAWAR (SD, CA)

VTUAV Comms. Payload: Info. Dist. FNC	ONR
Time Critical Precision Targeting (TCPT)	Navy PEO(W)/PMA263
Future Navy VTUAV Payload study	Navy PEO(W)/PMA263
True Plug & Play MMP	Navy PEO(W)/PMA263
Advanced TCDL	Army CECOM/Intel. & IW,
Fusion of Communications	Army CECOM/Space & Terrestrial Comms.,
Hyperspectral Longwave Imaging for the Tactical Environment (HyLITE)	Army CECOM NVESD
Multi-Mode Tactical Radar (with MTI, SAR)	Army CECOM/Intel. & IW,
Remote Tactical Imaging Spectrometer (RTIS)(day-time hyper-spectral)	Army CECOM/Night Vision & Elec. Sensors
Lightweight Airborne Multispectral Minefield Detection (LAMD)	Army CECOM/Night Vision & Elec. Sensors
Multi-Mission Command Modular Adv. EO/IR for TUAV	Army CECOM/Night Vision & Elec. Sensors
Multifunction SIGINT (MFSP)	Army Comms.-Elecs. Command/Intel. & IW,
Light Weight Gimbal (LWG)	Army CECOM/Night Vision & Elec. Sensors
Remote Nuclear Detection	SBCCOM
Remote Biological Detection	SBCCOM
Standoff Chem. Detection (JSAFEGUARD)	SBCCOM
FINDER (CW strike sampler)	DTRA CP2 ACTD / NRL
Advanced SEAD Targeting	AFRL/SN
System High Range Resolution Air-to-Grd Recognition Program(SHARP)	AFRL/SN
Spectral Infrared Remote Imaging Transition Testbed (SPIRITT)	AFRL/SN
Materials and Processes for IR Sensors	AFRL/ML

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A160 HUMMINGBIRD UAV HELICOPTER

Lead agency: DARPA/TTO, (703) 696-7502

Objective/Description: The A160 Hummingbird Helicopter Advanced Technology Demonstration (ATD) is a DARPA program developing a long endurance long range UAV helicopter. This vehicle utilizes low disk loading and a patented variable speed rotor to vary the rotor flight characteristics to optimize flight performance, and utilizes a hingeless rigid rotor to allow precision vehicle control. The efficient rotor operation and propulsion, along with high fuel fraction, gives the vehicle 3000+ nm max range and 40+ hours max flight endurance.

The base vehicle technology is being developed to demonstrate a low vibration environment for payload operation, including EO/IR, and to demonstrate remote payload deployment capability, including Unmanned Ground Vehicles. Vehicle signatures and high lift options will be investigated and assessed. A laptop control station will be developed for forward pass vehicle control. Studies will be carried out on potential scaling of the technology to other size vehicle.

The FCS variant of the A160 is being pursued to develop/demo an all weather/all environment operations capability for potential FCS applications. This includes adverse weather/environment precision high reliability flight systems, SAR/GMTI radar integration, and remote resupply systems. Studies will be carried out on potential SATCOM data link options and survivability enhancement options.

Timeline: Base Technology Development

Base Tech	FY00-01:	A160 ground and flight tests, Low vibration rotor design review
	FY02:	Low vibration rotor demo, EO/IR demo, UGV Deployment Demo, Compound helicopter development
FCS Tech	FY01:	Adverse environment systems design review
	FY02:	SAR/GMTI Demo, SATCOM data link report

Current Funding Levels:

	FY00	FY01	FY02
Vehicle Tech Development	$5.445	$3.00	$7.00
FCS Development	$0.00	$6.80	$7.70

Desirable unfunded follow-on activity, with estimated cost:

Triply Redundant Autonomous UAV Flight Management System: $5M

Lightweight Heavy Fuel Engine $20M

ADVANCED PROPULSION MATERIALS AND PROCESSES

Lead Agency: AFRL/ML, (937) 255-1305

Objective/Description: Develop affordable, low-density, high-strength, high-temperature materials and manufacturing technologies for all classes of future and derivative military engines, including UAVs. These technologies are critical elements for the development of affordable future propulsion systems. These programs are developing, testing, and transitioning the technologies needed to double range or payload capacity by decreasing fuel consumption and doubling of turbine engine thrust-to-weight ratio. Technical challenges include developing high temperature materials with low density, balanced engineering properties, long-life environmental durability and oxidation resistance at very high temperatures, affordable manufacturing techniques, improved life prediction methodologies, and improved material testing capabilities. Manufacturing technologies include lower cost more durable castings and forgings, more affordable surface treatments for increased fatigue life, and lean depot refurbishment processes.

Timeline:

FY01-04: Develop and mature enabling materials technologies such as gamma titanium aluminides, refractory intermetallic alloys, ceramic matrix composites, higher-temperature polymer matrix composites, damage tolerance methodologies for preventing high cycle fatigue failure, and affordable metals manufacturing.

FY03: Complete turbofan/jet demonstration of 60% improvement in engine thrust-to-weight, a 200°F increase in compressor exit temperature, and a 600°F increase in turbine inlet temperature.

FY05: Demonstrate 100% improvement in engine thrust-to-weight and a 40% fuel savings for turbofan/jet engines using advanced materials, which include 1500°F gamma TiAl for compressor disks and blades, 2200°F refractory intermetallic alloys (Nb or Mo) for turbine rear frame leading edges and high-pressure turbine blades, and 2400°F CMCs for combustors and turbine vanes.

Current Funding Levels:

	FY00	FY01	FY02	FY03	FY04
AFRL S&T	$8.9M	$8.0M	$9.0M	$10.0M	$9.0M
(Non-S&T) Manufacturing Technologies	$7.6M	$8.1M	$2.0M	$0.5M	

ADVANCED SEAD TARGETING

Lead Agency: AFRL/SN, (937) 255-4794 ext 4314

Objective/Description: The AST program is a jointly-funded DARPA/AFRL science and technology effort aimed at developing and demonstrating cost-effective multi-ship targeting technology for the lethal suppression of enemy air defenses (SEAD) mission. The technology will permit multiple platforms to use existing data links and common precision timing to quickly and cooperatively determine a target's GPS coordinates. The program will enable the use of generic precision guided weapons, non-dedicated SEAD platforms, and new CONOPs for the lethal SEAD mission. It is envisioned that this system could be deployed on multiple non-dedicated platforms to include strike aircraft, UAVs, and other available theater targeting assets. AST is on the UCAV Roadmap as an enabling technology.

Timeline:
FY01: Data Link Ground Test Completion
FY01: Lab Experiments & Calibration Completion
FY02: Ground Experiments & Calibration Completion
FY02: T-39 Flight Testing at the Western Test Range Completion
FY03: Technology Availability Date

Current Funding Levels:

	FY00	FY01	FY02	FY03
DARPA	$7.4M	$12.3M	$9.8M	$2.5M
AFRL	$0.5M	$4.0M	$2.1M	
TOTAL	$7.9M	$16.3M	$11.9M	$2.5M

- Ready to begin system integration: FY03

ADVANCED TACTICAL COMMON DATA LINK FOR UAVS

Lead Agency: US Army CECOM/Intelligence and Information Warfare Directorate/ C. Lucas/732-427-5692

Program Description: CECOM I2WD is pursuing the development of a reduced size, full-capability Tactical Common Data Link (TCDL) for use with planned SIGINT and Multi-INT UAV platforms such as Prophet and Aerial Common Sensor. Data transport techniques and architectures will be developed to compliment sensor control and cross-platform operations developments to maximize the Intelligence operational capabilities.

Program Objective: The short-term objective is to develop fully JASA compliant, open-architecture, data transport mechanisms and capability in a reduced SWAP configuration for the Shadow 200 –series UAV. The long-term objective is to develop multiple networking capabilities on a single platform. The airborne wide-area networking communications capability provided by multiple data links would both enable the development of a Multi-INT system architecture with multi-platform, networked connectivity and facilitate a scaleable, wide-area data transport capability for multi-platform Imagery and Signals Intelligence operations.
Technical Objective: The short-term technical objective is to reduce the size, weight and power of available systems, allowing the full complement of TCDL cards to fit in a two-wingbox assembly on the Army's Shadow 200 UAV. The long-term technical objective is to further reduce full TCDL communications networking capability into a single-box assembly, enabling dual data link capabilities and robust, wideband ISR communications networking.

Program Status:
Program award 4QFY00 and is in Requirements Definition Phase.

Program Funding:

	FY00 Funded	FY01 Unfunded	FY02 Unfunded	FY03 Unfunded
Engineering Development	$1,100 K	$ 4,000 K	$ 2,000 K	
Prototyping			$ 1,000 K	
Integration/Flight Demo				$ 1,000

AFFORDABLE COMPOSITE STRUCTURES

Lead Agency: AFRL/ML, (937) 904-4597

Objective/Description: Affordable Composite Structures involves several programs across the AFRL Materials and Manufacturing Directorate. The objective this effort is to develop the tools and technologies that will enable an order of magnitude cost reduction for composite structures. A parallel goal is to demonstrate and transition these technologies to current and future platforms. The focus of this effort is to reliably and repeatably produce large integrated and bonded structures thereby reducing costs related to part count, fasteners, tooling, labor hours, etc. Planned demonstrations include a small UCAV demonstration in FY01, and further UCAV demonstrations from FY01-03 and Global Hawk UAV structural demonstrations from FY01-03. The Global Hawk will demonstrate a 30% cost reduction for the outer wing and the UCAV will demonstrate a 25% cost reduction for the entire airframe (including skins) and an attendant 20% (40 lb.) weight reduction. The program offices will be integrally involved in these developments and demonstrations.

Timeline:

FY03: The Global Hawk UAV and UCAV will complete the fabrication, structural testing and cost verification of these demonstrations.

Current Funding Levels:

Funding represented includes technology development, maturation, demonstration and validation of affordable composite structures for fighters, UAVs and other systems.

	FY00	FY01	FY02	FY03	FY04	FY05
AFRL S&T	$1.150M	$2.588M	$2.813M	$3.813M	$2.313M	$3.375M
(Non-S&T) Manufacturing Technologies	$5.060M	$3.600M	$7.500M	$6.800M	$5.800M	$6.500M

AIRBORNE COMMUNICATIONS NODE (ACN)

Lead Agency: DARPA/ATO, 703-696-7495

Objective/Description: The Airborne Communications Node (ACN) is a DARPA effort focusing on developing a multi-mission, multi-function scaleable payload capable of communications over a wide frequency spectrum (2Mhz-40GHz). The system is designed to interface differing legacy radio systems, data links and imagery transmission links through ACN to facilitate electronic control of the battlefield. Additionally, ACN is designed to provide a payload capable of performing a broad spectrum Signals Intelligence (SIGINT) mission. Technologies being developed as part of the ACN Program will allow near simultaneous communications and SIGINT functioning at extremely close frequencies. ACN will be scalable to fit a wide variety of platforms (Air, Surface (ground and naval) and Subsurface) and to meet varying user needs for these capabilities. ACN will be dynamically re-configurable in terms of connectivity and capacity. The candidate air platforms for demonstrating the ACN capabilities are the Air Force Global Hawk HAE UAV, Air Force Predator MAE UAV, US Army Shadow 200 CRTUAV, and US Navy VTUAV.

Timeline:

FY00	Technology Development
FY01	Technology Development
FY02	Complete design though CDR level
FY03	Transition to Services for demonstration and evaluation

Current Funding Levels

FY 00	FY 01	FY 02
$30.4M	$12.6M	$10.0M

Desired unfunded follow-on activity with estimated cost: None

AIRBORNE GPS PSEUDO-SATELLITES

Lead Agency: DARPA/SPO, 703-248-1547

Objective/Description: The Global Positioning Experiment (GPX) program will demonstrate the ability to use airborne pseudo-satellites (pseudolites) on UAVs to combat enemy jamming of Global Positioning System (GPS) signals. The airborne pseudolite (APL) approach puts high power GPS-like transmitters on aircraft, which are much closer to the battlefield than the satellites are. The high power and shorter range allow the pseudolites to burn through the jamming and provide precise location data to GPS users with minimal modification to their GPS receivers. Demonstrations have occurred on Hunter UAV and commercial jets. Future demonstrations will include more Hunters, and possibly a Predator, Global Hawk, or Shadow.

Timeline:

FY00: APL on Hunter UAV burns through jamming in field demo
FY01: Demonstration of APL self-navigation in jamming
FY02: Demonstration of two APLs on UAVs and captive precision weapons
FY03: Demonstration of full APL system (4 UAVs) with live precision weapons drop

Current Funding Levels:

FY00	FY01	FY02	FY03
$4M	$4M	$5M	$10M

Ready for system integration: FY04
Anticipated operational availability: FY06

Desirable unfunded follow-on activities, with estimated cost:

Unfunded: Service (JPO) funding for follow-on integration.

AIRBORNE VIDEO SURVEILLANCE (AVS)

Lead Agency: DARPA/SPO, (703) 248-1543

Objective/Description: The AVS Program is developing and evaluating video processing technologies to enable real-time targeting and automated activity monitoring from video sensors onboard manned or unmanned aerial vehicles (UAV). The real-time targeting effort ingests streaming airborne video imagery, with geolocation accuracies on the order of 50-100's of meters, and registers the video to high-precision reference imagery to provide geolocation accuracies in the 1-15 meter range (dependent on reference imagery used – DPPDB offers PGM accuracy). This is done at near real-time rates (1 to 5 seconds per frame) to allow precise, real-time, precision targeting. The automated activity monitoring technology detects specific human and vehicle activity in airborne video streams.

Timeline:
FY98-99: Video geolocation (Ft. AP Hill) was performed at 1/10 Hz, 2-10m accuracy relative to reference imagery created. Activity monitoring for specific human and human vehicle events (Ft AP Hill, vehicle removal scenario).

FY 00: Video geolocation was extended/evaluated on varied terrains (Camp Lejeune, Fallon NAS, Ft. Drum). Activity monitoring-based index keys were developed for the USAF UAV experimental Predator digital video archive. Provide video geolocation technical transfer support for ARL, USA TUAV. Activity monitoring experiments will be performed for force perimeter security.

Past/Current Funding Levels:

FY 98-99	FY 00	FY 01
$12M	$13M	$0M

Unfunded: Service funding for integration, including engineering analysis, program planning, engineering design and field testing for each UAV effort (USA TUAV, USN VTOL, USAF Predator) to insert AVS technology.

ALTAIRIS FOR UAV AUTONOMY

Lead Agency: NAVY PEO(W)/PMA263, (301)- 757-5848

Objective/Description: Altairis has greatly simplified mission development for VTUAV by separating mission extensions from core of common software. The core software is compiled code that is common to all command and control projects. Mission extensions primarily consist of Finite State Models, scripts, and display definition files developed in data, not code, by the system end user rather than programmers.

Timeline:
FY00: Work completed on Altairis Mission Control Software for VTUAV

Current Funding Levels:

FY00
$256,667

Desired unfunded follow-on activity, with estimated cost:

Altiris UAV autonomy: $ 685,000

AUTONOMOUS GROUND OPERATIONS AND COLLISION AVOIDANCE TECHNOLOGIES FOR UAVS

Lead Agency: NASA Dryden Flight Research Center

Objective/Description: The NASA Dryden Flight Research Center has been under an agreement with The Boeing Company and the Defense Advanced Research Projects Agency (DARPA) for providing the flight test site support for the UCAV-ATD Program. In addition to flight test facilities and range support, DFRC also has several engineering and research tasks in the areas of autonomous ground operations, collision avoidance, and contingency planning/management for the UCAV. This work, being performed under the agreement, is being augmented by Flight Research R&T Program funds to expand and further refine to a TRL of 6 or 7 the autonomous algorithms that will result from the effort. DFRC, with the Flight Research Program funding, is developing two mobile vans to house computer hardware and software that will demonstrate these autonomous control algorithms in an actual airfield environment, with driver-override capability for safety. DFRC will incorporate into these algorithms the commercially-available TCAS system for ground collision avoidance.

Timeline:
FY01-FY02: Autonomous control algorithms will be developed for the UCAV Program and delivered to Boeing for integration and demonstration on the UCAV air vehicles.

FY02-FY04: Autonomous control algorithms with imbedded collision detection and avoidance capability will be further refined and demonstrated in an actual airfield environment via the DFRC surrogate vehicle vans.

Current Funding Levels: FY00: $200K, FY01: $200K, FY02: $200K

Ready for demonstration on UCAV air vehicles: FY01
Ready for operational demonstration using surrogate vans: FY03-04

Desirable Unfunded Follow-On Activity, with estimated cost:
Incorporate autonomous control and collision avoidance algorithms into Military aircraft (F/A-18, F-15) simulation: $250K
Demonstrate selected technologies on military aircraft in flight: $1M to 2M

BROAD-AREA UNMANNED RESPONSIVE RESUPPLY OPERATIONS (BURRO)

Lead Agency: MCWL, (703) 784-3208 Maj McKinney

Objective/Description: The BURRO is a 5,000 lbs K-Max helicopter, built by Kaman Aerospace, that is capable of carrying a 6,000 lbs external load. MCWL is doing the research, development, and experimentation to turn this, currently single pilot vehicle, into an unmanned aerial vehicle. Experimentation will be conducted with BURRO to determine whether or not it is capable of conducting sea-based autonomous resupply in support of the Marine Corps' Operational Maneuver From The Sea (OMFTS) Warfighting Concept, and the enabling concept, Ship To Objective Maneuver (STOM). Experimentation within OMFTS would hypothetically be conducted from a small and fast "SLICE like" vehicle that was carrying supplies that maneuvered 15-20 nautical miles off shore. Initial proof of concept experimentation will be conducted at Twentynine Palms, CA.

Timeline:
FY00-01: Autonomous flight demonstration in November 00 at Twentynine Palms, CA.
FY02: TBD

Current Funding Levels:

FY00	FY01	FY02
$4.5M	$500K	TBD

Estimated unit cost of each BURRO helicopter $4M.
Ready to begin system integration: FY03
Anticipated operational availability: FY04+

Desirable unfunded follow-on activity, with estimated cost:
There are no unfunded requirements in the BURRO program at this time.

C^2 Operator Interfaces for Manned/Unmanned Systems

Lead Agency: AFRL/HE, (937) 255-5779

Objective/Description: Two AFRL/HE projects support improved command and control operator interfaces for manned and unmanned systems. The *Virtual Air Commander* Project Arrangement, under the US/Australian Co-Operative and Collaborative Research Development and Engineering Agreement (CCRDE), supports a joint exploratory and advanced demonstration program pursuing the design, development, and evaluation of a class of crew station concepts common to Airborne Early Warning and Control (AEWC) aircraft, air-to-ground strike aircraft, and ground-based Unmanned Combat Air Vehicle (UCAV) control stations. The products of this effort will include: (1) Quantification of potential benefits arising from the application of advanced control and display technologies to the AWACS platform, (2) advanced virtual crew system demonstrators for AEWC aircraft, ground-based UCAV applications, and air-to-ground strike aircraft, and (3) risk reduction for the acquisition community concerning the utilization and requirements for virtual control and display devices used within AWACS, UCAV, and Common Space Interfaces. A key focus area is seamless, integrated control of manned and unmanned assets. A separate research effort, *Variable Autonomy Control System for UAVs,* is a AFRL/HE sponsored SBIR Phase 2 project to provide an operator with selectable levels of control over a UAV system, from full manual control to full autonomous control. This effort will culminate in the flight test demonstration of the variable control effort. A Phase 3 is planned, in which this technology will be integrated into a command and control workstation and flight demonstrated in a command and control scenario.

Current Funding Levels:

	FY00	FY01	FY02	FY03
AFRL	$1.675M	$2.00M	$0.70M	$0.77M

Canard Rotor / Wing (CRW)

Lead Agency: DARPA/TTO, (703) 696-2362

Objective/Description: The CRW Advanced Technology Demonstration (ATD) is a 50/50 jointly funded DARPA/Boeing program that is being conducted with collaboration and support from the Navy. The CRW is a revolutionary new technology for high Speed VTOL, which combines the low disk loading hover efficiency, and low-speed flight characteristics of a helicopter with the high - subsonic cruise speed of a fixed wing aircraft. In rotary wing mode, hot exhaust gas from a conventional turbofan engine is ducted through the mast stem to reaction drive nozzles at the wing tips. During conversion, the canard and horizontal tail surfaces provide sufficient lift to unload the rotor, allowing it to be stopped and locked into a fixed position for survivable, high-speed cruise (>375kts). This proof of concept demonstration program will explore the revolutionary flight potential of the CRW high-speed VTOL concept through the design, fabrication and flight test of two unmanned CRW demonstrator aircraft. Conversion from rotary wing to fixed wing and vice-versa will be validated over a range of flight conditions.

Timeline:

FY00: Completed detailed designs and initiated fabrication of two unmanned air vehicles.
FY01: Complete fabrication and assembly, and begin flight-testing.
FY02: Complete flight tests.

Current Funding Levels: (Combined DARPA/Boeing)

FY00	FY01	FY02
$5.88M	$4.82M	$3.91M

Desired Follow-On Activities and ROM Estimated Costs:

ACTD of Operational Unmanned CRW System, $50M-$100M
ACTD of Operational Manned CRW System, $100M-$150M

DIRECTED ENERGY: MATERIALS AND PROCESSES FOR HIGH POWER APPLICATIONS

Lead Agency: AFRL/ML, (937) 255-2227 ext 3498

Objective/Description: Develop materials and process technologies for ultra-lightweight , ultra-high power aircraft applications. These applications include radar and lethal and non-lethal directed energy weapons. Wide bandgap semiconductor materials, like silicon carbide and gallium nitride, have critical fields that are >5x that of silicon or gallium arsenide. This translates into a >25x higher power density, which reduces the size and weight of any airborne high power microwave system. The technology improvement would allow the ability to put such devices in fighter/UAV sized aircraft. The Air Force is working to develop the basic materials and processes needed for wide frequency band, high power, fast pulse, and multi-pulsed operation at VHF through Ku-band and higher frequencies.

Timeline:
FY00-01: Conductive bulk 2” silicon carbide wafers developed, 3” wafers demonstrated and epitaxial silicon carbide thin films for power distribution developed for 2” wafers and demonstrated for 3” wafers. Initiate bulk growth of nitride wafers. Initiate

development of multiple 3” epitaxial reactors for thin film growth of wide bandgap semiconductors.

FY02: Conductive bulk 3” wafers developed with 4” wafer demonstration. Demonstration of 2” diameter nitride wafer.

Current Funding Levels:

	FY00	FY01	FY02	FY03	FY04	FY05
AFRL	$0.706M	$0.685M	$0.250M	$0.862M	$0.750M	$0.750M

Conductive Silicon Carbide 3” diameter wafers will be commercially available by end of FY02.

DIRECTED ENERGY: REPETITION (REP) RATED HPM TECHNOLOGIES

Lead Agency: AFRL/DE, (505) 846-4040

Objective/Description: Investigate High Power Microwave (HPM) technologies best suited to support advanced tactical applications such as aircraft self-protection, made practical based on increased power available on future aircraft. This is a direct result of the Directed Energy Airborne Tactical Air Combat (DE ATAC) study, and will focus the research on developing the technologies necessary to proceed with the top-rated concepts. The applications component activity will focus on performing the initial research to determine weapon system feasibility.

Timeline:
FY00: Initiated UCAV technology requirements & design study
FY01: Demo rep-rated experiment on HPM sources, pulsed power, multi-Gigawatt (MG) antennas
FY02: Down-select rep-pulsed MG technologies
FY03: Demonstrate Improved Virtual Wide Band System

Current Funding Levels:

	FY00	FY01	FY02	FY03	FY04
AFRL	$5.61M	$3.72M	$4.30M	$4.57M	$4.72M

- Ready to begin system integration: FY04
- Anticipated operational availability: FY06

DRAGON DRONE UAV

Lead Agency: MCWL, (703) 784-3208 (Maj McKinney)

Objective/Description: The Dragon Drone fixed wing UAV has been MCWL's UAV testbed since 1997. It will conclude experimentation at the end of FY00.

Timeline:
FY00-01: Dragon Drone will provide UAV coverage during the Millennium Challenge Joint experiment in Gulfport, MS during September 00.
FY02: N/A

Current Funding Levels:

FY00	FY01	FY02
$1.5M	0	0

DRAGON EYE BACKPACK UAV

Lead Agency: ONR/MCWL/NRL, (202)404-1213

Objective/Description: The Naval Research Laboratory (NRL) in collaboration with the Marine Corps Warfighting Laboratory (MCWL) is developing an affordable, expendable airborne sensor platform, Dragon Eye, to demonstrate Small Unit reconnaissance and threat detection capabilities. Dragon Eye will consist of a man-portable, multi-role, 4 lb, hand-launched air vehicle, and a wearable Ground Control Station (GCS) to provide control of, and receive intelligence from, the air vehicle. The vehicle characteristics will enable an operational capability in adverse weather conditions. Dragon Eye will feature autonomous flight capability to allow one-person operation, with recovery via an autopilot-commanded deep stall terminal descent. The endurance goal is 30 min at 35 kt airspeed, with an electric propulsion system. Interchangeable 1 lb modular commercial off-the-shelf components payloads for Dragon Eye will include daylight, low light, and infrared imaging systems and robust communication links. For GCS development, the Dragon Eye Program is enhancing MCWL and ONR-sponsored End User Terminal (EUT+) effort currently being executed at NRL. The EUT+ is a ruggedized wearable computer configured on a Modular Lightweight Load-Carrying Equipment vest.

Timeline:
FY00: Dragon Eye 70%: semi-autonomous vehicle flight, w/ visible camera payload.
FY01: Dragon Eye 90%: autonomous vehicle flight, w/ IR payload and wearable ground station.
FY02: Dragon Eye transition: full system integration, w/ residual systems for warfighter testing.

Current Funding Levels:

FY00	FY01	FY02
$1.5M	$1.5M	$1.0M

Estimated unit cost of each production full-up Dragon Eye air vehicle: $5K

Desirable unfunded follow-on activity, with estimated cost:

Development of on-board imagery mosaicing and storage: $ 0.5M
Development of data fusion (vis with IR): $ 0.5M
Development of fuel cells for Dragon Eye: $ 2.5M

POCs:

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DRAGON WARRIOR

Lead Agency: MCWL, (703) 784-3208, Maj McKinney

Objective/Description: Dragon Warrior is a close range VTOL UAV that will support at the Battalion level and below. It will have a range of 50 kilometers with a loiter time of 1.5 hours. It can carry either an electro-optical or Infrared sensor with built in laser range finder in order to provide precision targeting. It has removable wings and a shrouded rotor system in order to reconnaissance, surveillance, and target acquisitions in an urban battlespace. It has a maximum forward airspeed of 125 knots, and a payload capacity of 25-35 lbs, depending on fuel load.

Timeline:

FY00-01: First flight scheduled for September 00. Fully autonomous flight during an MCWL operational experiment, January 01.

FY02: Additional prototypes built with product improvements implemented resulting from experimentation.

Current Funding Levels:

FY00	FY01	FY02
$5.0M	$500K	TBD

Estimated unit cost of each UAV system with sensor $250K.
Ready to begin system integration: FY03
Anticipated operational availability: FY04+

Desirable unfunded follow-on activity, with estimated cost:
- Additional Ground Control Stations: $500K
- Additional Air Vehicles: $1.0M
- Chem/Bio sensor: $2M
- LADAR mapping and targeting sensor: $3M
- Field-testing: $1.0M for FY01 experimentation

EXTENDER

Lead Agency: ONR, (703) 696-0114

Objective/Description: Extender is an air-drop deployable UAV for Electronic Warfare missions. Extender folds for storage into a 32” x 32” x 20” enclosure. For deployment, the Extender enclosure is simply pushed out of the door of any helicopter, transport, or patrol aircraft. Upon being air-dropped, a parachute is deployed, the enclosure is shed, and the wings unfold and lock into position. Next the parachute is released and the electric motor is switched on. Extender has a 2.3 hour endurance, cruising at 45 mph, powered by LiSO2 batteries. Extender can perform an entirely autonomous mission using GPS navigation, or utilize a spread spectrum RF link for realtime operator directed command and control. Gross weight is 31 lbs, including a 7 lb payload capacity. Currently under development, Extender has flown conventional runway takeoffs, demonstrated autonomous navigation, and demonstrated air-drop deployment of the folded wings in a vertical wind tunnel simulating descent under the parachute. Air-drop testing from a helicopter is currently scheduled for October 2000. Extender is funded by ONR as 6.2 R&D project. Follow-on funding is anticipated for mission specific development.

Timeline:
FY98-00: FINDER airframe and subsystem development and flight testing
FY01: (Anticipated) Transition to application sponsor for mission specific development
FY02: (Anticipated) Field trials

Current Funding Levels:

FY98	FY99	FY00	FY01	FY02
$250K	$250K	$800K	$1M anticipated	$1M anticipated

Estimated unit cost of each Extender: $35K in qty 100 production

Desirable unfunded follow-on activity, with estimated cost:
- Flight safety approvals and integration with Navy EP-3: $1M
- Mission specific development of operational capabilities: $2M

POC: Richard Foch, NRL Code 5712, richard.foch@nrl.navy.mil, (202) 404-7623

FLIGHT INSERTED EXPENDABLE FOR RECONNAISSANCE (FINDER)

Lead Agency: DTRA, (703) 325-2050

Objective/Description: FINDER's mission is to fly through the smoke plume shortly after a bomb or missile strike against a suspected chemical warfare (CW) weapons storage or manufacturing site. Onboard sensors sample the plume to provide a realtime detection capability. Samples are also collected and stored for later laboratory analysis. FINDER is carried to the operational area with wings folded, mounted under the wing of a Predator UAV. The nominal FINDER mission is to fly 50 miles ingress to the target after deployment from Predator, loiter in the target vicinity for up to 2 hours performing the CW detection and collection, and accompany Predator during egress for up to 600 miles before autonomously landing at a designated location such as an open field. FINDER command and control messages are relayed via Predator to/from the Predator GCS. FINDER development is sponsored by DTRA under the CP2 ACTD.

Timeline:

FY00: FINDER airframe, payload, and subsystem development and integration
FY01: System integration and testing; first air-drop deployment from Predator
FY02: Developmental system testing
FY03: Program mission demonstration

Current Funding Levels:

FY00	FY01	FY02	FY03
$2.5M	$1.8M	$1.2M	$1.0M

Estimated unit cost of each FINDER (including deployment pylon):

$100K at current low production rate for developmental test program
$60K for follow-on operational production

Desirable unfunded follow-on activity, with estimated cost:

Development of a Biological Agent detection capability: $1.0M

POC: Alvin Cross, NRL Code 5712, alvin.cross@nrl.navy.mil, (202) 767-4475

FOLIAGE PENETRATION (FOPEN) RADAR

Lead Agency: DARPA/SPO, (703) 248-1514

Objective / Description: The FOPEN Synthetic Aperture Radar (SAR) Advanced Technology Demonstration (ATD) is a DARPA Program that is being conducted jointly with the Army and the Air Force. The radar operates simultaneously in the VHF and UHF bands to detect stationary targets under foliage and camouflage. The ATD will be demonstrated on an Army RC-12D aircraft; however, it is more than 85% compatible with the Air Force's Global Hawk High Altitude UAV. The radar and its ground station will be capable of real-time target detection and cueing.

Timeline:
- FY00-01: ATD concept will be tested to demonstrate that it meets DARPA's technical goals.
- FY02: Air Force Tanks Under Trees (TUT) and other user demonstrations of the system.

Current Funding Levels:

FY00	FY01	FY02
27M	16M	11M

Estimated unit cost of each FOPEN SAR system $5.5M.
Ready to begin system integration: FY02
Anticipated operational availability: FY04+

Unfunded: Service funding for system integration into other appropriate platforms.

FUSION OF COMMUNICATIONS FOR UAVS

Lead Agency: US Army CECOM, Space and Terrestrial Communications Directorate

Program Description: CECOM S&TCD is pursuing efforts to combine all UAV communications functions within the TUAV aircraft. This effort will aid in multi service interoperability as well as payload(s) weight and volume reduction.

Program Objective: To expand the Fort Gordon BCBL CRP CEP efforts, by combining Tactical Common Data Link (TCDL) with Identification Friend or Foe (IFF) and combining CRP requirements with aircraft C2 (Air Traffic Control) requirements. The objective is to develop a software re-programmable communications package fully JTRS/JASA compliant.

Technical Objective: By combing functions and capabilities this will reduce the total communications payloads volume, size, weight and power. Long term objective is to develop and integrate hardware and software.

Program Status:

Program is in Requirements Definition Phase.

Program Funding Requirements:

	FY00 Funded	FY01 Unfunded	FY02 Unfunded	FY03 Unfunded
Engineering Development		**$ 4.6 M**	**$ 3.2 M**	
Prototyping			**$ 4.3 M**	**$ 3.4 M**
Integration/Flight Demo				**$ 800 K**
CRP CEP	$ 367 K			

FUTURE NAVY VTUAV PAYLOAD STUDY

Lead Agency: NAVY PEO(W)/PMA263, (301)-757-5848

Objective/Description: A study to provide a quick look into evolving sensor technologies that have application as a P^3I for the VTUAV. This study will investigate future UAV technologies, missions and operational requirements, system trade studies, C4ISR&T architectures/CONOPS formulation, UAV simulation capability, UAV assessments, and field demonstration recommendations.

Timeline:
FY00: Phase I of the study completed by August 2000

Current Funding Levels:

FY00
$400,000

Desired unfunded follow-on activity, with estimated cost:

- Phase II of Future Navy VTUAV Payload Study: $750,000

HELIOS PROTOTYPE – SOLAR POWERED AIRCRAFT

Lead Agency: NASA (Dryden Flight Research Center), (661) 276-3704

Objective/Description: The Helios Prototype Project is a NASA Office of Aero-Space Technology activity being conducted under the Environment Research Aircraft and Sensor Technology (ERAST) Project. The principal objective is to develop solar powered UAV and energy storage technology which will open the door to low cost ultra-long duration (up to 6 months) high altitude flight for applications such as earth monitoring, communications, emergency services, law enforcement and the DoD. The principal contractor in this effort is AeroVironment, Inc.

Timeline:
FY00-01: Install solar array and demonstrate UAV flight to 100,000ft; develop prototype high density energy storage system (ESS) based on PEM fuel cell technology for Helios Prototype and begin testing.
FY02-03: Complete development and testing of a lightweight ESS based on PEM fuel cell technology; integrate ESS onto the Helios Prototype UAV and conduct a 96 hour demonstration flight.

Current Funding Levels:

FY00	FY01	FY02	FY03
$13.9M	$15.6M	$11.5M	$9.7M

Estimated unit cost of "production" Helios Aircraft: $3M to $5M.
Anticipated operational availability: FY04+

Desirable unfunded follow-on activity, with estimated cost:
Extend maximum altitude of Helios Prototype up to 120,000ft: $20M
Extend maximum flight duration of Helios Prototype to 6 months: $30M
Extend operational capability of Helios Prototype to ±35° latitude: $50M

HYPERSPECTRAL LONGWAVE IMAGING FOR THE TACTICAL ENVIRONMENT (HYLITE) TACTICAL DEMONSTRATION SYSTEM

Lead Agency: CECOM NVESD, (703) 704-1314

Objective/Description: The HyLITE system concept makes use of a hyperspectral imaging sensor for day and night operations, real-time spectral anomaly algorithms to detect CC&D and other difficult targets, and a high-resolution imaging sensor for confirmation of targets. The HyLITE design incorporates a longwave infrared spectral sensor integrated with a high resolution midwave infrared imager in a tactical, closed cycle cooled, stabilized package. The Spectral detections cue the high-resolution camera to provide an image for review by an image analyst. The HyLITE design is compatible with Predator, and a high altitude preliminary design for Global Hawk is complete. A reduced performance Tactical Demonstration System (HyLITE-TDS) being developed for demonstration is a non-stabilized pushbroom version based on the original closed cycle cooled HyLITE design. The TDS integrated on the test and demonstration airborne platform will provide real-time CC&D target detection and cueing for day only operations.

Timeline:
FY00-01: TDS development and fabrication.
FY01-02: TDS integration and user demonstrations on demonstration aircraft.

Current Funding Levels:

FY00	FY01	FY02
$4M	$2M	$2M

Estimated unit cost of each HyLITE system is $1.85M.
Ready to begin system integration: FY01
Anticipated operational availability: FY03+

Desirable unfunded follow-on activity, with estimated cost:

Integrate RISTA-II imager on HARP for TDS night operations: $1.5M
Develop and integrate MWIR imager in HyLITE TDS package: $4.5M
Develop and integrate stabilization and scanning in HyLITE TDS package: $6M
Develop processor and algorithms for real-time target detection: $3.3M

JOINT EXPENDABLE TURBINE ENGINE CONCEPTS

Lead Agency: AFRL/PR, (937) 255-2767

Objective/Description: The Joint Expendable Turbine Engine Concepts (JETEC) program validates advanced, innovative, high payoff missile/Uninhabited Air Vehicle (UAV) turbine engine technologies necessary for future Air Force, Navy, and Army systems. The UAV portion of this program is driven by the requirement to provide a propulsion technology base of proven high payoff components that are aimed at new or upgrade/derivative, limited life UAV engines. The XTL-57 demonstrator uses the Joint Turbine Advanced Gas Generator (JTAGG) XTC-56 as the engine core for this medium altitude demonstrator. The XTL-87 uses the part of the engine core from NASA's general aviation program (GAP) for this high altitude demonstrator. Improvements for UAV engines relative to program baselines include a 40% decrease in specific fuel consumption, and a 60% reduction in engine cost. This effort will integrate advanced engine technologies into an engine demonstrator in order to acquire the test and design data necessary to accurately define integrated performance, overall engine stability, mechanical limitations, and costs for use in risk assessment.

Timeline:
FY98-02: Design and manufacture JETEC XTL-57 engine demonstrator
FY01: XTC-56 engine core available
FY01: NASA GAP engine core available
FY02: XTL-57 goal demonstration test
FY99-03: Design and manufacture JETEC XTL-87 engine demonstrator
FY03: XTL-87 goal demonstration test

Current Funding Levels:

	FY00	FY01	FY02	FY03
AFRL	$4.0M	$4.7M	$5.5M	$3.7M
Navy	$0.4M	$1.5M	$1.5M	$0.2M
Total	$4.4M	$6.2M	$7.0M	$3.9M

Money includes funding from Air Force and Navy for XTL-57 and XTL-87 only

LIGHTWEIGHT AIRBORNE MULTISPECTRAL MINEFIELD DETECTION (LAMD)

Lead Agency: CECOM, Night Vision and Electronic Sensors Directorate (POC: Tom Smith 703-704-1219)

Objective/Description:
The LAMD Science and Technology Objective program is investigating and developing technology to support the detection of surface and buried minefields from the Tactical Unmanned Aerial Vehicle (TUAV) platform. The technology is being developed to support the United States Army Engineer School's (USAES) Airborne Standoff Minefield Detection System Operation Requirements (ASTAMIDS). The STO initially focused on phenomenology investigations and technology trade-studies to support the specification of the technology to be applied/developed to support the minefield detection requirements with a TUAV compatible package. Current efforts are focused on the investigation and demonstration of two approaches/objectives.

One objective is to evaluate the surface and buried minefield detection capability of a modified Advanced TUAV EO/IR ATD sensor. A TUAV EO/IR sensor modified with a filterwheel on the 3-5 micron camera will be procured, aided minefield detection algorithms will be applied/developed and a field performance evaluation will be conducted. This approach is expected to provide a good detection capability under favorable environmental conditions.

The second objective is to develop and demonstrate a minefield detection system based on an active laser polarization sensor combined with an imaging 8-12 micron IR system. A prototype sensor will be designed and fabricated, aided target detection algorithms will be applied/developed and a field performance evaluation will be conducted. This approach is expected to provide very good surface minefield detection capability under most environmental conditions and good buried minefield detection under favorable environmental conditions.

Timeline:
FY00: Detailed design of Advanced TUAV EO/IR sensor filterwheel modification. Developed system specification and initiated preliminary design of active laser / LWIR system.

FY01: Detailed design and fabrication of active laser / LWIR component hardware and data processing system. Fabrication and delivery of modified advance TUAV EO/IR sensor and initial system test.
FY02: Conduct field performance evaluation of the modified TUAV EO/IR sensor and ATR system. Complete fabrication, initial test and delivery of the laser / LWIR sensor and ATR system.
FY03: Conduct field performance evaluation of the laser / LWIR sensor and ATR. Conduct MSI and transition to PM-MCD PDRR program

Current Funding Levels

FY 00	FY 01	FY 02	FY 03
$ 14608	$ 13916	$ 8964	$ 3566

Ready to begin system integration: FY04
Initial Production: FY08

Desirable unfunded follow-on activity, with estimated cost:
Both of the approaches being investigated under the LAMD STO will use Aided Target Recognition (ATR) systems to support the minefield detection process. Under the LAMD STO, the ATR system will process recorded data at speeds less than 1/4 the sensor data output rate (4 seconds to process 1 seond of sensor data). The objective system will require real time processing and reporting. Due to high data rates and limited data link bandwidth, on board real time processing will be required. It is desirable to develop a lightweight processor based on COTS technology, which can implement the minefield detection algorithms in real time for UAV applications. As noted in the advanced TUAV EO/IR sensor paper, a program to support the build and preliminary field testing would cost 4M$.

A broadband 8-12micon sensor will be used during the LAMD STO. There is data which supports that a multiband LWIR sensor may provide enhanced buried minefield detection. It is desirable to integrate and test a multicolor LWIR sensor with the laser sensor. The cost of this effort is estimated at 700k$.

The baseline advanced TUAV EO/IR sensor is configured with a 3-5micron camera and a RGB camera. The USMC has demonstrated successful daytime surface minefield detection with a multi-spectral UV-NIR camera. The USMC results and phenomenology investigation support that a NIR band (790nm) can enhance target to background contrast. It is desirable to investigate the fabrication, integration and test of a modified three-color camera to enhance surface minefield detection. The cost of such an effort is estimated to be $900k.

LIGHT WEIGHT GIMBAL (LWG)

Lead Agency: CECOM, Night Vision and Electronic Sensors Directorate (POC: Richard Wright 703-704-1329)

Objective/Description:

The LWG is a lightweight, compact and low cost gimbal system capable of achieving 5 micro radian stabilization on UAV and other fixed wing application. The LWP program is in the second phase of an SBIR that will provide a proof of concept prototype gimbal that can achieve 5 micro radian stabilization in a fixed wing dynamic environment. The stabilization will allow target location accuracy as well as day and night recognition and ID to more than double in range over even the most advanced payloads in the same weight and size category today. This approach is simpler than current designs and is anticipated to be half the cost of comparable payloads today. It will be a modular payload compatible with the TUAV and Predator interfaces thus affordable for those systems.

Timeline:

FY00: Detail design of the gimbal structure, control electronics and motor drive system.

FY01: Fabrication and assembly of the turret and daylight sensor.

FY02: Evaluation of gimbal jitter, stability, and pointing accuracy using a representative cross section of Army fixed and rotary wing aircraft vibration inputs.

Current Funding Levels

FY 00	FY 01	FY 02	FY 03
$ 370K	$ 375K	0	0

Estimated per payload cost:
350K

Desirable unfunded follow-on activity, with estimated cost:

FY03-FY04: Build a complete payload with very long-range tactical optics as a prototype for TUAV and SRUAV with EO and IR sensors. 8M$

FY04-FY05: Integrate and evaluate payload performance on Fixed, Rotary Wing and UAV Aircraft. 3M$

LOW COST STRUCTURES FOR UAV AIRFRAMES

Lead Agency: AFRL/VA, (937) 656-6337

Objective/Description: The Low Cost Structures for UAV Airframes thrust is developing a new generation of more unitized structure specifically designed for UAVs. The structural concepts being developed will reduce manufacturing cost and increase system readiness without weight or supportability penalties. The approach is to identify, develop, and transition new structural design concepts and manufacturing methods for both metals and composites that place emphasis on reducing both part count and the number of structural joints and fasteners. Technologies in development include probabilistic design methods and for more reliable bonded joints, low cost composite manufacturing processes from the automotive and general aviation industries. Design concepts are centered on more effective integration of unitized advanced composite and metal structures. Design methods and criteria development are focused on predicting failure for these non-traditional materials and manufacturing methods.

Timeline:

FY00-02: Demonstration of innovative structural concepts and appropriate failure criteria for limited life UAV structures

FY00-01: Low Cost composite fuselage structure for UCAV

FY01-03: Development of unitized design/manufacturing methods for metal structures

FY01-04: Low cost UAV composite engine inlet duct and wing structures for UAV

FY05-07: Demonstration of reliable, unitized UAV structure

Current Funding Levels:

	FY00	FY01	FY02	FY03	FY04
AFRL	$3.133M	$3.537M	$2.857M	$2.662M	$1.552M

MATERIALS & PROCESSES FOR INFRARED SENSORS

Lead Agency: AFRL/ML, (937) 255-4474 ext 3220

Objective/Description: The Materials Directorate has a strong program in materials and processes for very high performance infrared sensors and related technologies. The requirements are military specific and cover all infrared wavelengths. The current program focus is on materials for Long Wave Infrared (LWIR) sensors, on materials technologies for multispectral and hyperspectral infrared applications, and on high payoff IR transparency technologies. The sensor materials being developed will provide better resolution at longer ranges, enhanced target discrimination, and expanded sensor field of regard. Aluminum Oxynitride (ALON) is being developed for IR transparencies to supplant current expensive, easily damaged, heavy materials for UAV IR systems; ALON will reduce transparency cost, will reduce weight by 50%, and will not require periodic replacement.

Timeline:

FY01: Develop growth and doping techniques for materials for three-color infrared detection. Demonstrate reproducible growth of processable wafers for 14 micron cutoff at 40-65 degrees K operating temperature.

FY02-03: Transition reproducible growth technology for 14 micron cutoff/40 degree operating temperature IR sensor material to industrial fabrication lines, making affordable high performance focal planes available for system integration. Demonstrate three color material for high target discrimination and high definition imaging for battlespace characterization. Demonstrate large size (one piece) ALON transparencies.

Current Funding Levels:

	FY01	FY02	FY03
AFRL	$2.5M	$2.8M	$3.2M

MICRO AIR VEHICLES (NRL)

Lead Agency: NRL/ONR, (202)-404-1213

Objective/Description: The focus of the 6.2 Navy (Office of Naval Research/ Naval Research Laboratory) Micro Air Vehicle (MAV) effort is to develop and refine technologies that enable valuable Navy missions with the smallest practical unmanned fixed-wing MAVs. This effort includes the development and integration of sensors, avionics, advanced autopilots for flight control, aerodynamics technology and a payload. The final objective is to demonstrate a flying MAV with a 6 to 18 inch wingspan capable of placing a jamming system on a radio frequency (RF) target. The FY02 MAV wingspan will be determined by the weight of the various onboard subsystems. In addition to enabling new missions specifically suited to MAVs, the miniaturized avionics and sensors developed for this effort are more broadly applicable to larger unmanned aerial vehicles (UAVs), increasing either their useful payload or their endurance.

Timeline:
FY00: Fabricate MAVs and conduct flight tests with 6 to 18 inch flight test airframes.
FY01: Integrate subsystems for flight demonstrations; fabricate and flight test baseline MAV.
FY02: Complete subsystem integration; conduct mission payload final demonstration.

Current Funding Levels:

FY00	FY01	FY02
$1.2M	$1.0	$0.8M

Estimated unit cost of each MAVwith COTS camera payload: $1K

Desirable unfunded follow-on activity, with estimated cost:
Development/ configuration of a miniature autopilot with GPS: $ 0.9M
Development of micro-batteries for subsystems power: $ 1.5M
Development of conformal GPS antenna for MAV skin: $ 0.75M

POC:
Dr. Jill P. Dahlburg
NRL Code 5703
Dahlburg@lcp.nrl.navy.mil
(202) 404-1213

MICRO AIR VEHICLES (DARPA/TTO)

Lead Agency: DARPA/TTO, (703) 696-2310

Objective/Description: The MAV program will develop the technologies needed for an air vehicle system that shall be very small (threshold less than 1 foot, goal about 6 inches) and capable of autonomous operation as part of a military force. The MAV shall be capable of conducting military operations anytime of the day or night, in all weather conditions under tactical conditions that include dust created by movement of neighboring vehicles and use of smoke obscurants by friendly and enemy forces. The MAV shall be capable of operating on the battlefield with "maneuver forces," including armored vehicles and performing operations of up to one-hour duration without requiring re-supply or significant intervention by operators or support personnel. The MAV system shall be designed and developed to conduct "close in" reconnaissance to allow the small unit leader to know literally what is over the next hill or around the next corner.

Timeline: FY00 the separate critical technologies will be demonstrated at an industry week.

Current Funding Levels:

FY00
$8.7M

Desirable unfunded follow-on activity, with estimated cost:
Back packable electric vehicle for small unit operations $12M
Under the Canopy Surveillance for Future Combat System $37M

MINI UNMANNED AIR VEHICLE (MUAV)

Lead Agency: CECOM, Night Vision and Electronic Sensors Directorate (POC: Richard Wright 703-704-1329)

Objective/Description: The MUAV is a lightweight autonomous air vehicle system capable of providing day and night over the hill surveillance operations at the lowest echelon. The MUAV consists of an air vehicle with 36" wingspan, multiple interchangeable payloads, data link and ground terminal. The inexpensive/attritable air vehicle and payload will be capable of operations of greater than one hour at altitudes of 1000 feet AGL. The modular payload approach will allow for selection of TV, thermal, acoustic, near infrared and chemical sensors. Major advancements in uncooled thermal technology meeting required performances have enabled the inclusion of combined EO/IR technology into a MUAV. NVESD is also technical oversight for Congressional program to develop a back pack portable autonomous MUAV system with Mitex Corp.

Timeline:

FY00: Evaluate Field of View Vs MUAV dynamics and flight profiles using Pointer MUAV and off the shelf TV and Bolometer FLIR sensors.

Demonstration/evaluation of MUAV prototype from Mitex

FY01: Purchase of Pointer and Dragon Warrior MUAVs, evaluate Acoustics to find targets in tree lines, and determine performance requirements and design constraints for sensors.

FY02: Custom sensor purchase and initial User Evaluation of sensor imagery at Ft. AP Hill

FY03: Integration of Mini UAV into overall information network of Mobile, Local Hostile STO.

FY04: Participate in Mobile Local Hostile STO Demonstrations.

Current Funding Levels

FY 00		FY 01	FY 02	FY 03
In house	$ 500K	$ 1000K	$ 875K	$ 1481K
Congressional	$ 1000K	0	0	0

Estimated per system cost: 40K (aircraft and laptop ground station)

Desirable unfunded follow-on activity, with estimated cost:

FY01-FY02: Custom light weight Bolometer FLIR sensors. 200K

FY01-FY02: Development of 2 oz roll stabilized pan and tilt system. 500K

FY01-FY03 evaluation of autonomous flight, payload and stability other candidate platforms (250K per vender x 6 vendors) 1,500K

FY01-FY03: Integration of acoustic cueing and automated search 500k

FY01-FY03: Incorporation of AVS image mosaicing and georegistration into a prototype laptop ground station for improved situational awareness and target location accuracy. 750K

FY01-FY04: Purchase of Mini UAV aircraft and ground stations for initial user evaluation and CONOPS development. 50-100K per system (aircraft and hand held ground station).

MORE ELECTRIC AIRCRAFT

Lead Agency: AFRL/PR, (937) 255-6226

Objective/Description: The MEA program develops power generation, conversion, energy storage and distribution systems including advanced electrical power component and subsystem technologies. Power components are developed for aircraft and flight line equipment to increase reliability, maintainability, commonality, and supportability. These electrical power technologies are necessary to meet the 10-20 year, long-term storage requirements of Air Force unmanned combat aerial vehicles (UCAVs). Aircraft and system-level payoffs for the power technology improvements demonstrated include a 20% reduction in deployment requirements for combat aircraft due to reduced ground support equipment; a 15% reduction in maintenance manpower; two-level maintenance instead of three-level; a 15% increase in sortie generation rate; an 8-9% reduction in combat aircraft life-cycle cost; an 8% reduction in takeoff gross weight for a

Joint Strike Fighter-type platform; a 4X increase in power system reliability; and a 15% reduction in vulnerability for combat aircraft.

Timeline:
FY01: Direct drive starter/generator with turbomachine demonstrator
FY02: Integrate internal integral starter/generator into turbine engine core
FY02: Magnetic bearing health prognostics demonstration for integrated power unit
FY02: Complete fabrication of Motor Drive with 50% improvement in power density

Current Funding Levels:

	FY00	FY01	FY02
AFRL	$19.1M	$8.7M	$10.4M

MULTIFUNCTION SIGNALS INTELLIGENCE PAYLOAD (MFSP) FOR UAVS

Lead Agency: US Army Communications-Electronics Command, Intelligence and Information Warfare Directorate, (732)427-6520

Objective/Description: The MFSP program is being conducted jointly by CECOM I2WD and the Army PEO IEW&S, Project Manager Signals Warfare. The objective is to develop a single payload capable of conducting both Communications and Electronic Intelligence (COMINT/ELINT) from 20 MHz to 40 GHz on a Tactical Unmanned Aerial Vehicle. The program's short-term objective is to demonstration its capabilities in the VHF frequency band aboard a Hunter UAV. The long-term objective is to expand its frequency range and capabilities using the DARPA Advanced Digital Receiver. Complementary antenna development research is being conducted by Small Business Innovative Research (SBIR) programs.

Timeline:
FY01: The prototype unit will be flight demonstrated in December 2000 against VHF signals.
FY01-02: Payload development will be continued expanding the frequency range and signal type capabilities with a flight demonstration at the end of FY02.

Current Funding Levels:

FY99	FY00	FY01
$0.8M	$3.9M	$0.5M

Estimated Unit Cost of each MFSP: $0.75M
Ready to begin system integration (initial capability): FY00
Ready to begin system integration (full capability): FY02
Anticipated operational availability (full capability): FY04

Desirable unfunded follow-on activity, with estimated cost:
Expansion of signal types: $2.5M
Expansion of frequency range: $1M
Field testing/flight demonstration: $2.5M

MULTI-MODE TACTICAL UAV RADAR FOR UAVS

Lead Agency: CECOM, Intelligence & Information Warfare Directorate(732)427-5719

Objective/Description: The Multi-Mode Tactical UAV Radar is part of an ongoing Multi-Mission Common Modular UAV Payloads Advanced Technology Demonstration program. This radar provides a Moving Target Indicator (MTI) mode for the detection and location of moving targets and a high resolution Synthetic Aperture Radar (SAR) for the location and imaging of stationery targets in Strip Map and Spot-light modes. The SAR mode provides target location with accuracy suitable for targeting of non line-of-sight weapons. The ATD program advances radar technology from the 175 lb. TESAR system flown on Predator to a 63 lb. Radar. The Army selected Tactical UAV presents additional volume challenges for integration of the radar which must be overcome through additional development.

Timeline:
FY01: Integrate radar on a Hunter surrogate Tactical UAV and demonstrate achievement of ATD Exit Criteria. Available for IBCT.
FY02-03: Expect to initiate integration of TUAVR for the Navy's Vertical TUAV

Current Funding Levels:

FY00	FY01
$ 4.0 M	$ 3.2 M

Estimated unit cost per radar in production: $475k

Desirable unfunded follow-on activity, with estimated cost:
Exercise contract option for 5 additional radars for IBCT: $4M FY02, $1M FY03
Redesign of radar for TUAV volume constraints: $4M FY02, $4M FY03
Implementation of DARPA RF Tags: $1.5M FY02

MULTIPLE 6.1 AUTONOMY DEVELOPMENT EFFORTS

Lead Agency: **ONR-35, Dr. Allen Moshfegh, (703) 696-7954**

Dist. continual plng. & exec
Internet in the sky

Dist. autonomous agent networks
Intelligent autonomous AVs
Interconnectivity & Control Policy for AV clusters enabling fault-tolerant comms
Fault-tolerant adaptive ctrl.
Aggressive path plng. for multiple autonomous AVs
Exponentially unstable UAVs with Saturating Actuators
Hybrid & Intelligent ctrl. architectures
Nonlinear active ctrl. of external fluid flows
Dist. Multisensor Fusion Algorithms for Tracking
Intelligent architectures
Adaptive Control
Passive Sensor-Based Ctrl. of Nonlinear systems
A theory of hierarchical dist. systems
Data Provisioning for Mobile Agent organization
Adaptive Comm. System
Data transfer over changing networks
Learning and knowledge acq.
Adaptation & Control Strategies
Reactive Ctrl. for Dist. UCAV Networks
Applied Bayesian & Dempster-Shafer Inference
Design methodologies dvmt.
Multi-Agent Decision Makinging and Comm.
Nonlinear Ctrl. Design for Stability & Performance
Network of Networks for Multi-Scale Computing

Current Funding Levels:

FY 98	FY 99	FY 00	FY 01	FY 02
$1.332M	$3.573M	$6.976M	$6.210M	$2.561M

MULTIPLE LINK ANTENNA SYSTEM (MLAS)

Lead Agency: NAVY / PEO(W)/PMA263, (301) 757-6403

Objective/Description: The MLAS Advanced Concept Technology Demonstration (ACTD) is an FY00 new-start program intended to assess military utility of an electronically steered active aperture phased array antenna based on the Multifunction Self-Aligned Gate Monolithic Microwave Integrated Circuit (MSAG MMIC) technology. It will provide two-way Ku-band communications with four different platforms simultaneously while on the move and meet the increasing demand for high data rate video, voice and data links applicable for land, sea, and air platform adaptation. The electronically-steered phased array antenna has no moving parts or mechanical interference. It has a much smaller footprint and is more reliable than the equivalent number of mechanically-steered antennas.

Timeline:

FY00: Completed initial RF component design, lab tests and confirmed capability to handle four simultaneous full duplex links at high CDL data rates.

FY01: Complete design and initiate fabrication of interim demonstration antenna system. Initiate design of final demonstration antenna system.

FY02: Assemble, test and initiate MLAS demonstrations in lab and field environments with interim antenna system. Initiate fabrication and integration of final demonstration antenna system.

FY03: Complete design, fabrication, and integration of final demonstration antenna system. Conduct military utility and operational assessments; deliver residuals.

Current Funding Levels:

S&T Funding

FY00	FY01	FY02	FY03
$1.2M	$1.5M	$1.5M	$1.0

Non-S&T Funding

FY00	FY01	FY02	FY03
$3.5M	$.5M	$.5M	$.5

Anticipate transition decision: FY04
If transitioned, first production article: FY05

Desired unfunded follow-on activity, with estimated cost:

OSD-approved ACTD – potential Navy Lead
Activity included in scope, but unfunded

FY01	FY02	FY03
$10.5M	$1.5M	$0

In FY01 -- $7M from Approp Bill

MULTI MISSION COMMON MODULAR ADVANCED EO/IR SENSOR FOR TUAV

Lead Agency: CECOM, Night Vision and Electronic Sensors Directorate (POC: Richard Wright 703-704-1329)

Objective/Description: The Advanced EO/IR payload is a part of the Multi-Mission Common Modular Sensor suite supporting the TUAV Block II improvement for FCS. The ATD will demonstrate affordable rapidly interchangeable EO/IR and lightweight MTI/SAR payloads for the FCS tactical UAVs with applications to UGVs and ground tactical vehcles. The EO/IR Common modular payload will be form/fit/interface compatible and share common electronics, data link, and data compression. The EO/IR payload leverages results of the ASSI program and utilizes a progressive scan color TV and high quantum efficiency 3-5 micron staring array for an all digital imaging system. The sensors will interface with the Tactical Common Data Link (TCDL), and the Tactical Control Station (TCS) to deliver IMINT products to Army Users. The sensor has been designed to accommodate Aided Target Recognition (ATR) algorithms and processing as well as Airborne Video Surveillance (AVS) mosaic and geo registration requirements. As a PrePlanned Product improvement (P3I), the Advanced EO/IR payload can include a laser designator for the directing off board weapons. This advance sensor payload will provide enhanced reconnaissance, surveillance, battle damage assessment, and target cueing for non-line of sight weapons.

Timeline:
FY00: Detailed Design and Fabrication of Component Hardware
1Q FY01: Delivery of Payload #1, Initial flight testing on Surrogate Twin Otter Aircraft
2Q FY01: Delivery of Payload #2 with laser range finder, initial testing on Twin Otter Aircraft
3Q FY01: Demonstration flight on Hunter UAV.
4Q FY01: Begin transition to PM TESAR for production.
FY02-FY03: Short EMD, transition to LRIP
4QFY03: Anticipated delivery of First Production Units

Current Funding Levels

FY 00	FY 01	FY 02	FY 03
$ 5200	$ 1928	0	0

Estimated Unit Cost: <200K by 33rd Unit.

Desirable unfunded follow-on activity, with estimated cost:

The contract currently has an unfunded option for a diode based Laser Rangefinder/Designator which provides 50M CEP and Hellfire designation at 4Km from an airborne UAV. Technology provides for needed target location accuracy for GPS guided and area munitions, illumination of targets for unambiguous target handoff, and forward lasing of targets for Apache and Comanche to increase their survivability. Cost to build EMD prototype is 2.5M$ and would require 18-24 months to execute once option is exercised.

The Advanced EO/IR payload has been design to use technology being developed under a DARPA program called Airborne Video Surveillance. AVS technology can, among other functions, mosaic and geo-locate imagery for very high location accuracy. The real-time demonstration of AVS and the Advanced EO/IR payload is currently unfunded. The demonstration would include real-time mosaicing and geo-location of imagery from the Advanced EO/IR sensor from a UAV (Hunter). Cost for the demonstration is 1.5M$ if done in conjunction with 3Q FY 01 Hunter EO/IR demonstration. It will require 6 months of preparation and pre testing prior to demonstration.

There currently is no EMD program to incorporate AVS Technology into the Common Ground Station (CGS). A program is required to transition from DARPA the technology into a CGS compatible system. EMD cost is ?M$ and would require 24 months.

There is a TUAV objective ORD requirement to provide an Aided Target Recognition (ATR) system for the EO/IR sensor. This would give the UAV a wide area search capability with acceptable user workload. The development of the ATR system for this sensor is a joint Air Force/Army/OSD program. The Real-time-embedded Strike Surveillance Target Acquisition and Recognition (RsSTAR) program is a program to develop a common neural net based ATR algorithm leveraged from the Comanche ATR which can be used for Mid Wave and Long Wave FLIR sensors as well as SAR imagery. The program is funded at 1M$ per year through FY02. What is needed is development of the processor based on COTS technology, which can implement the algorithm in real time for UAV applications. An EMD program to do this would be required to start by 3Q FY02, require 18 months to build, do preliminary field testing and cost 4M$.

MULTI-SENSORY INTERFACES / VISUALIZATION TECHNIQUES

Lead Agency: AFRL/HE, (937) 255-5779

Objective/Description: This inter-service research program is investigating the role of multi-sensory interfaces as applied to the existing and future Unmanned Air Vehicle (UAV) control stations. In addition, this effort is determining the relative effectiveness of 2-D vs 3-D displays for UAV operations. The baseline for the near-term research is the USAF Predator Medium Altitude Endurance (MAE) UAV. Studies are empirically evaluating the effectiveness of haptic technology, 3-D audio, head-coupled/head-mounted display operations, and symbology improvements using a high fidelity UAV simulation testbed facility. In addition, an associated program (Speech Recognition) is exploring the effectiveness of speech recognition interfaces in the UAV and Unmanned Combat Air Vehicle (UCAV) domain. The results of this effort will be expanded to facilitate the design of multi-sensory interface concepts supporting single station control of multiple UCAVs. An additional research effort within AFRL/HE (Real-Time Human Engineering) is focused on the development of UCAV operator workload and situation awareness metrics that can be collected in real time. Specifically, real-time operator functional state assessment tools are being developed to assist with the implementation and control of UCAV automation. The objective will be to minimize required UCAV system manning, while ensuring that workload and performance remain within acceptable levels.

Timeline:

FY00-01: Demonstrate partial-immersive Predator UAV interface with identified improvements to crew performance.

FY01: Demonstrate reduced crew Predator UAV workstation.

FY02: Demonstration of real-time UCAV operator workload metric data collection.

FY03: Demonstrate multi-sensory concepts supporting multi-ship UCAV control.

Current Funding Levels:

	FY00	FY01	FY02	FY03
AFRL	$2.12M	$2.11M	$1.69M	$1.70M

- Ready to begin system integration: FY02
- Anticipated operational availability: FY02+

NAVAL UCAV ADVANCED TECHNOLOGY DEMONSTRATION (UCAV-N ATD)

Lead Agency: DARPA/TTO, (703) 696-2321

Objective/Description: The objective of the DARPA/DoN Naval Unmanned Combat Air Vehicle Advanced Technology Demonstration (UCAV-N ATD) is to design, develop, integrate, and demonstrate the critical technologies pertaining to an operational Naval UCAV system. The critical technology areas are command, control, and communications, human-systems interaction, targeting/weapons delivery, and most importantly, design and demonstration of an aircraft carrier capable air vehicle. The specific objectives of the UCAV-N ATD include: developing and demonstrating a low life-cycle cost, mission effective design for a SEAD/Strike unmanned air vehicle; developing and demonstrating a re-configurable control station for multi-ship operations; demonstrating robust/secure command, control and communications, including line-of-sight and over-the-horizon; exploring the full range of human-computer function allocation, dynamic mission planning and management approaches; evaluating off-board/on-board sensor integration, weapon targeting and loadouts. Another objective is to demonstrate human-in-the-loop: detection, identification, location, real-time targeting, weapons authorization, weapons delivery and target damage indication. Validating the

UCAV weapon system's potential to affordably perform Suppression of Enemy Air Defenses, Deep Strike, and Surveillance missions in the post 2010 timeframe is another key objective. Life cycle cost models will be developed which include verifiable estimates of acquisition and O&S costs. The critical affordability assumptions and technologies will be validated through concept and process demonstrations.

Timeline:
FY00: Begin conceptional design of a Naval UCAV Operational Air System (UOS-N)
FY01: Compete conceptional of the UOS-N and develop a critical technology demo plan
FY05: Complete demonstration phase.
FY10: Initial Operational Capability

Current Funding Levels*:

FY00	FY01	FY02	FY03	FY04
$3.0M	$3.0M	$15.0M	$25.0M	$25.0M

* Funding shows total burdened dollars (including management, overhead, etc.) from both the Navy and DARPA, currently budgeted for the program. DARPA has not yet completed budgetary planning for the program demonstration phase of the program; hence all funding shown for fiscal years 2002-2004 is Navy funding.

Desirable unfunded follow-on activity, with estimated cost: DARPA share if funding to initiate and complete the demonstration phase in fiscal years 01-04: approx. $75M.

RELIABLE AUTONOMOUS CONTROL FOR UAVS

Lead Agency: AFRL/VA, (937) 656-6337

Objective/Description: The Reliable Autonomous Control for Unmanned Air Vehicles (UAVs) thrust is targeted at providing the on-vehicle control capabilities to enable unmanned air vehicles to be as safe and mission effective as manned assets, but at significantly reduced size, weight and cost. The approach is to develop, integrate, and demonstrate the key capabilities for autonomous control: reliable, compact, light weight hardware; intelligent inner-loop control functions to compensate for failures and changing flight conditions; and self-adapting outer-loop (flight path and navigation) control to provide on-board capability to react to changing mission needs. Technologies in development include: photonic vehicle management systems, intelligent reconfigurable control, prognostic health management, multi-ship coordinated control, and automatic air collision avoidance. Coordination will be made with Navy, NASA, DARPA, and Army efforts in autonomous control and related technologies.

Timeline:

FY00-02: Demonstration of key implementation technologies (photonics, intelligent control, multi-ship coordinated control)

FY02: Baseline design of integrated reliable autonomous control system

FY03: Flight demonstration of automatic air collision avoidance

FY04-05: Simulation and ground test of integrated autonomous control system

Current Funding Levels:

	FY00	FY01	FY02	FY03	FY04	FY05
AFRL	$3.1M	$6.6M	$7.0M	$5.9M	$4.1M	$2.4M

- Ready to begin system integration: FY05.
- Anticipated operational availability: FY07.

REMOTE BIOLOGICAL DETECTION FOR UAVS

Lead Agency: SBCCOM

Objective/Description:

Concept of operation is being pursued on UGV and UAV to develop an operational / Tactical Biological Detection system. Will provide Potential Presumptive Identification at 0 - 300 feet AGL operation. The system will be able to provide Tips & Cues other Bio assets for confirmation. System specifications; Sensitivity (10 particles/liter for 2-10 m particles), Alarm response time (< 1 min.), False alarm rate (few per week) Compact, light weight, low power

Timeline:

FY 00 – 01 develop and integrate

FY 01 demonstrate on UAV and UGV

Current Funding Levels

FY 00	FY 01	FY 02	FY 03
$ 640 K	$ 640 K	0	0

Desirable unfunded follow-on activity, with estimated cost: Develop from existing BAWS system, an UAV Biological detection system to compliment ground systems.

FY 02 – Initiate design and development of an TUAV sensor $ 2.3 M

FY 03 – Integration and testing on TUAV $ 1 M

FY 04 – Transition to EMD/LRIP $ 1 M

REMOTE NUCLEAR DETECTION FOR UAVS

Lead Agency: SBCCOM

Objective/Description:

Concept of operation is being pursued on UGV and UAV for Theater / Operational / Tactical Radiation Detection system. Developing, integrating and demonstrating payload that detects Gamma & Neutron Radiation, Quantifies Radiation Exposure Rate at 0 - 10000 feet AGL operation and may drop in from higher altitudes.

System specifications; Ratemeter and integrated dose, measures dose rate from 0.1µGy/hr - 230 Gy/hr, measures total dose from 0.1µGy - 999 Gy, combined rate meter and tactical dosimeter, measures dose rate from 0.1-999cGy/hr, measures total dose from 0.1-999cGy .

Timeline:

FY 00 – 01 integration of existing ground equipment
FY 01 demonstrate on UAV and UGV

Current Funding Levels

FY 00	FY 01	FY 02	FY 03
$ 640 K	$ 640 K	0	0

Desirable unfunded follow-on activity, with estimated cost:

To design and develop an UAV radiation detection sensor complementary to ground equipment (VDR2/UDR13).

FY 02: Initiate design and development of TUAV sensor $ 1.3 M
FY 03: Integration and testing on TUAV $ 1 M
FY 04: Transition to EMD/LRIP $ 1 M

REMOTE TACTICAL IMAGING SPECTROMETER (RTIS) DEMONSTRATION SYSTEM

Lead Agency: CECOM NVESD, Tom Colandene (703) 704-1314

Objective/Description: The RTIS is a day time hyper-spectral sensor payload suitable for TUAV. It will provide real-time target search of CC&D targets for detection and cueing. The design incorporates a combined visible/near/short wave IR (VNIR/SWIR) spectral sensor with a high resolution midwave IR imager in a tactical, closed cycle cooled, roll stabilized package. The system concept makes use of real-time spectral anomaly algorithms to detect CC&D and other difficult to find targets. Spectral detections cue the high-resolution camera to provide an image which is transmitted via a data link to an image analyst on the ground. The RTIS is a roll stabilized, wiskbroom scanned, Offner spectrometer version of the Night Vision's Imaging Spectrometer (NVIS) sensor developed and demonstrated on NVESD's Hyperspectral Airborne Reconnaissance Platform (HARP). The RTIS design would be compatible with TUAV, Hunter, Predator and a high altitude aircraft such as Global Hawk .

Timeline:
FY00: Proof of Concept demonstration in JCF AWE using NVIS on manned aircraft.
FY01: Design and fabricate RTIS sensor.
FY02: Assemble, Integrate and Ground Test Sensor and processing.
FY03: Sensor Specific Algorithm modifications, Flight testing on Twin Otter Surrogate, Hunter Surrogate and TUAV.

Current Funding Levels:

FY00	FY01	FY02
$ 400K	0	0

Estimated unit cost of each RTIS system is 750K
Ready to begin system integration: FY02
Anticipated operational availability: FY04+

Desirable unfunded follow-on activity, with estimated cost:
RTIS System is currently unfunded except for Proof of Concept AWE participation
FY01: Design and fabricate RTIS sensor. 3.2M$
FY02: Assemble, Integrate and Ground Test Sensor and processing. 2.2M$
FY03: Sensor Specific Algorithm modifications, Flight testing on Twin Otter Surrogate, Hunter Surrogate and TUAV. 1.9M$

SEE AND AVOID SYSTEM

Lead Agency: NAVY PEO(W)/PMA263, (301)- 757-5848

Objective/Description: See and Avoid systems (SAAS) are a UAV Collision Avoidance option that consists of a multiple sensor system. One of the two systems is transponder-based which is a derivative of the BF Goodrich Skywatch. The second system is EO/IR and LADAR based system being built by Engineering 2000. A combination of both systems will provide a multiple sensor solution that will allow UAVs to fly in national airspace without a manned escort aircraft.

Timeline:
FY00: UAV Collision Avoidance Test
FY01: FAA certification of digital datalink data to ground control system Engineering 2000 (E2K) SAAS

FY00: Contract award and Preliminary Design Review
FY01: Critical Design Review, meetings, and Technical Manual

Current Funding Levels:

FY00	FY01
$220,000	$250,000

Desired unfunded follow-on activity, with estimated cost:

- Integration and Dimensional Reduction of Skywatch and E2K SAAS: $500,000
- Testing of Integrated System: $500,000
- FAA certification of integrated system: $750,000

SHIPBOARD TOUCHDOWN PREDICTION LANDING AID

Lead Agency: NAVY PEO(W)/PMA263, (301)-757-5848

Objective/Description: The shipboard touchdown prediction landing aid project is a PMA funded effort developed by Altair Aerospace Corporation using Finite State Models (computer code to control space satellites) and sophisticated non-linear prediction algorithms to predict ship motion and assist the landing evolution of Naval UAVs aboard ships at sea. The system will be deployed as Pre-Programmed Products Improvements (P^3I) to the US Navy Firescout VTUAV ground station and will allow prediction of quiescent periods of ship motion 20-30 seconds ahead of when they occur. The VTUAV can then be commanded to make an autonomous landing during this quiescent period.

Timeline:
FY00: Touchdown prediction landing aid will be delivered and demonstrated as a risk reduction effort for VTUAV.
FY01: EMD into VTUAV Ground station (if incorporated)
FY02: Operational testing (if Touchdown Prediction Landing Aid is incorporated into LRIP VTUAV ground station)
FY03: Incorporated into production of VTUAV ground station.

Current Funding Levels:

FY00
$632,000

Desired unfunded follow-on activity, with estimated cost:

- EMD into VTUAV ground station: $ 1M
- Operational testing: $500 K

SPECTRAL INFRARED REMOTE IMAGING TRANSITION TESTBED (SPIRITT)

Lead Agency: AFRL/SN, (927) 299-5922 ext 291

Objective/Description: The SPIRITT Advanced Technology Demonstration (ATD) will develop a day/night, high altitude, hyperspectral imaging (HSI) reconnaissance sensor testbed to address U-2/Global Hawk limitations in detecting and identifying camouflaged, concealed, and other difficult targets. The SPIRITT ATD will develop and demonstrate an HSI sensor system with an integrated high resolution day/night imaging system engineered to fit within both the U-2 Q-Bay and the Global Hawk E-O Bay. It will provide the critical demonstration for transitioning this AFRL technology to these two platforms. Operationally, this new EO/IR payload will be able to fly concurrently with other reconnaissance assets for an integrated multi-INT capability: the Signals Intelligence (SIGINT) payload and potentially either the Advanced Synthetic Aperture Radar System (ASARS) radar or the Senior Year Electro-Optical Reconnaissance System (SYERS) Pre-Planned Product Improvement (P3I) camera on the U-2, and the synthetic aperture radar on the Global Hawk UAV. In parallel with the SPIRITT ATD, the ASC/RA Airborne Targeting and Cross-Cueing System (ATACCS) EMD program will develop multi-INT cross-cueing and fusion capabilities capable of integrating the SPIRITT payload with the existing U-2 and Global Hawk reconnaissance systems. In both the U-2 and Global Hawk configurations, the sensor system will support a real-time on-board processing capability for rapid precision targeting. It will also support full data recording for longer term Measurement and Signature Intelligence (MASINT) exploitation for targets of interest to the Intelligence Community. The SPIRITT ATD will have two development phases supporting demonstration milestones at the end of FY03 and FY05. In Phase I, the baseline day only sensor system will be designed, developed, and tested on-board a high altitude manned aircraft. Phase II adds the day/night capability.

Timeline:
FY01-04: A day only hyperspectral sensor configuration will be developed and flight-tested on a manned high altitude aircraft.
FY03-06: The day/night modular upgrade configuration will be developed and tested.

Current Funding Levels ($M):

	FY00	FY01	FY02	FY03	FY04	FY05	FY06
AFRL	$1.2M	$0.6M	$2.0M	$3.3M	$2.5M	$4.3M	$2.5M

DIA/CMO	$0.9M	$2.0M	$1.2M	$0.6M			
ASC/RA				$2.0M	$3.0M	$1.0M	

- Ready to begin system integration of day system on manned test aircraft: FY03
- Anticipated operational availability on U-2: FY05+

STANDOFF CHEMICAL DETECTION (JSAFEGUARD) FOR UAVS

Lead Agency: SBCCOM

Objective/Description:
Primarily a Theater TMD Asset that Detects Chemical Vapors, Identifies Chemical Vapors, and Quantifies Chemical Vapors. The system will provide Tips & Cues to other NBC Assets and operate at 2000 - 10000 feet AGL, 3.5 Km Swath @ 10000 feet AGL.

The system Provides TM WMD event situational awareness, Enables battlespace NBC effects situation understanding, Extends battlespace geometry, Enables fighting force positional advantage, Prevents operational & tactical level force surprise and Full-dimension protection (individuals, fighting formations, and critical assets).

Timeline:
FY 00: Design and Development
FY 01: Integration
FY 02: Flight testing
FY 03: IOC
FY 04: Production

Current Funding Levels

FY 00	FY 01	FY 02	FY 03
$ 1.5M	$ 1.0M	$ 6.3M	$ 6.3M

Desirable unfunded follow-on activity, with estimated cost:
Leverage from current concept of operation efforts and develop remote chemical detection sensor, complementary to existing ground equipment (ACADA/ICAM).

FY 02 – Initiate design and development of a TUAV sensor that may or may not be dropped. $ 1.8 M
FY 03 – Integrate and test on TUAV $ 1.6 M
FY 04 – Transition to EMD/LRIP $ 1.3 M

SYSTEM HIGH RANGE RESOLUTION AIR-TO-GROUND RECOGNITION PROGRAM (SHARP)

Lead Agency: AFRL/SN, (937) 255-1105 ext 3434

Objective/Description: The Air Force has identified the requirements for moving target ATR. Current Moving Target Indicator (MTI) and Synthetic Aperture Radar (SAR) technology have limitations against moving targets which High Range Resolution (HRR) ATR is expected to overcome. Specifically, current MTI technology can detect moving targets over a wide search area but can not classify them while current SAR ATR technology can classify these targets but only if they are stationary. HRR ATR will complement the existing MTI and SAR technology by providing an ATR capability the warfighter currently does not have but needs, a wide area search and ATR classification capability against ground moving targets in all weather. This program will demonstrate cost effective robust ATR of moving ground targets using an HRR radar mode. Concept of operations, projected radar performance, and on board processing limitations will drive the technical approach. Operational constraints will be defined and documented. Under these operational constraints, existing HRR ATR algorithms will be evaluated for feasibility of transition to operational radar platforms, including U-2 and Global Hawk UAV.

Timeline:

FY98-00: Demonstrate air-to-ground HRR algorithm on 5-10 moving targets using radar testbed data.

FY01: Demonstrate fusion of Moving Target Indication and Track for HRR using reconnaissance platform data.

Current Funding Levels:

	FY00	FY01
AFRL	$0.70M	$0.76M
DARPA	$0.30M	$0.30M
TOTAL	$1.00M	$1.06M

- Estimated unit cost for Global Hawk radar modifications and software modifications $2M.
- Ready to begin System Integration: FY05
- Anticipated Operational Capability: FY07+

TIME CRITICAL PRECISION TARGETING

Lead Agency: NAVY PEO(W)/PMA263, (301)-757-5848

Objective/Description: The tasks addressed under TCPT will provide on-site engineering and technical assessment and advice regarding advancing technologies and developments in UAVs and UAV payloads. Tasks will include:

- Participation in designated Integrated Product Teams
- Technical assessment of UAV command and control systems
- UAV platform avionics improvements
- UAV image exploitation improvements
- Development of UAV targeting concept of operations (CONOPS)
- Field demonstrations of new/improved capabilities
- Prototyping of new concepts and systems
- Total ownership cost trades between levels of automation and levels of required training and manning.

Timeline:

FY00: On-site Engineering and Technical Assessments and UAV Platform Avionics Improvements

FY01: Engineering and Technical Assessment of C3 Systems and UAV Ground Systems Improvements

Current Funding Levels:

FY00	FY01
$370,000	$250,000

Desired unfunded follow-on activity, with estimated cost:

- UAV Image Exploitation Improvements: $120K
- UAV Targeting CONOPS: $30K
- Field Demonstrations of New Capabilities: $120K

TRUE PLUG AND PLAY MODULAR MISSION PAYLOAD CAPABILITY

Lead Agency: NAVY PEO(W)/PMA263, 301-757-5848

Objective/Description: The intent of the plug and play MMP is to have a VTUAV open architecture such that: "An MMP with the proper mechanical, electrical and software interface, and within the platform's physical constraints, shall be able to operate in the TCS-compliant UAV systems with nothing more that an automatic MMP driver load into TCS". In other words, the integration of a new MMP should not require recertification of the system.

Northrop Grumman Ryan Aeronautical Center conducted an architectural trade study to evaluate Network topologies that will provide a "plug and play" capability, and identify the efforts necessary to support implementation of this topology, and other relevant program impacts, especially on the airborne elements.

Timeline:

- FY00: Low-level studies such as Northrop Grumman Ryan Aeronautical Center's MMP interface Architecture Trade Study for the Firescout VTUAV
- FY01: Studies & Low Level Technology development & demonstrations
- FY02: EMD into TCS/VTUAV
- FY03: Integration and test support

Current Funding Levels:

FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07
$0	$200K	$200K	$200K	$400K	$400K	$400K	$400K

Desired unfunded follow-on activity, with estimated cost:
Technology development: $ 1.5M
Development of standard interface: $ 2.5M

UAV AUTONOMY: AUTONOMOUS OPERATIONS FNC

Lead Agency: NAVY PEO(W)/PMA263, (30)- 757-5848

Objective/Description: The UAV Autonomy project is a core program of the Autonomous Operations FNC in the Office of Naval Research (ONR). The project seeks to develop and demonstrate those core technologies needed to increase the autonomy of the future UAVs and, in particular, provide P^3I options to Firescout VTUAV and Tactical Control System programs. The UAV autonomy project will produce three major demonstrations, with technology transition opportunities after each:

Situational awareness demonstration (FY03)
Multi-Vehicle Networking Demonstration (FY05)
Intelligent Autonomy Demonstration (FY07)

Timeline:
FY00: Low-level planning

FY01: Detailed demonstration planning and technology roadmapping
FY02-FY07: Technology Development and Demonstrations

Current Funding Levels:

FY00	FY01	FY02	FY03-07
$100,000	$1M	$10M	$10M/Yr

Desired unfunded follow-on activity, with estimated cost:

- Joint Demonstration (with US Army, USAF): $ 1.5M
- Situational Awareness EMD to VTUAV: $2M
- Multi-vehicle Networking EMD to VTUAV: $2M
- Intelligent Autonomy EMD to VTUAV: $2M

UAV PROPULSION: AUTONOMOUS OPERATIONS FNC

Lead Agency: NAVY/ONR/, (703) - 696-7917

Objective/Description: The UAV propulsion project is a funded above-core program of the autonomous operations FNC in the Office of Naval Research (ONR). The project seeks to leverage those technologies developed by the Integrated High Performance Turbine Engine Technologies (IHPTET) program for future naval UAV/UCAV applications, and in a particular to press towards a flight worthy demonstrator engine. Major demonstrations are scheduled to be conducted FY05-07.

Timeline:
FY00: Low level planning
FY01: Detailed demonstration planning and technology roadmapping
FY02-07: Technology developmental demonstrations

Current Funding Levels:

FY00	FY01	FY02	FY03	FY04	FY05	FY06
$392,700	$500K	$2.9M	$4.2 M	$4.5 M	$5.0 M	$5.5 M

Desired unfunded follow-on activity, with estimated cost:

- Joint Demonstrations (with USAF): $ 1.5 M
- Final Development of Flight Worthy Demonstration Engine: $75 M
- In-Flight Demonstrations: $ 5 M

UAV TO MEET NASA SCIENCE MISSION REQUIREMENTS (PREDATOR B)

Lead Agency: NASA/DFRC

Objective/Description: This is a joint NASA/General Atomics-Aeronautical Systems Inc. (GA-ASI) effort to develop the Predator B. The project consists of three aircraft. The first two aircraft were part of GA-ASI's original effort to develop two versions of the Predator B for the US military. The first of these aircraft will fly for 25 hours over 40,000 feet. It will have a GTOW of 6,400 lbs, 94 foot wingspan, carry a payload of 700 lbs, and use a Honeywell (Allied Signal) TPE 331-10 turboprop engine. The second vehicle will be the same size and GTOW, but will fly up to 57,000 feet, have a maximum duration of 12 hours and will use the Williams FJ44-24 fanjet engine. The third vehicle will be built to meet NASA objectives. It's GTOW will 7,000 lbs, and a wingspan of 84 feet. IT will use the Honeywell turboprop engine and carry a maximum payload of 880 lbs. NASA plans to fly a series of science demonstration missions for 24 hours above 40,000 feet in the National Airspace System. NASA has to goals for the project. The first is to develop an uninhabited aircraft to fly between 40,000 feet and 65,000 feet and durations from 24 to 48 hours. The second goal is to fly over-the-horizon flights in the National Airspace to promote the development of regulation to support the use of UAVs for science missions.

Timeline:
FY00 Build and flight-test aircraft 001 (turboprop)
FY01 Build and flight-test aircraft 002 (turbofan)
FY02 Build and flight-test aircraft 003 (NASA enhanced turboprop)

Current Funding levels

	FY99	FY00	FY01	FY02
NASA	$0M	$2.4M	$4.7M	$3.7M
GA-ASI	$4.0M	$4.8M	$2.7M	$0.5M
Total	$4.0M	$7.2M	$7.4M	$4.2M

UAV/UCAV PREDICTIVE FAILURE AND DIAGNOSTICS

Lead Agency: AFRL/HE, (937) 656-4390

Objective/Description: The objective of the Predictive Failure and Diagnostics for Legacy Aircraft (PFAD) program is to reduce legacy aircraft downtime by enhancing the capability of maintainers to identify the causes of system failures through better diagnostics, and, where possible, identify imminent system failures (failure prognostics) so that replacements can be made before an actual failure occurs. This program has critical value in promoting the rapid turnaround of future UAVs and UCAVs for maximum sortie rate.

Timeline:
FY00: Sensors investigation (6.2) - Task Order
FY00: PFAD Prime Contract Award
FY01: Data Requirements, On vs Off-Board Diagnostics
FY02: Diagnostics Concept Design/Algorithm Development
FY03: Demonstrate Diagnostics Approach, Prognostics Concept Design
FY04: Prognostics Algorithm Development
FY05: Technology Demonstration, Technology Transition

Current Funding Levels:

	FY00	FY01	FY02	FY03	FY04	FY05
AFRL	$0.40M	$1.97M	$1.84M	$3.3M	$5.7M	$2.5M

Ready to begin system integration: FY05
Anticipated operational availability: FY05+

UAV/UCAV TRAINING RESEARCH

Lead Agency: AFRL/HE, (480) 988-6561 ext 111

Objective/Description: This program is developing a high fidelity control station using the Predator UAV (RQ-1) as the initial baseline system. In partnership with AC^2ISR/C^2U and TRSS Det 1, AFRL/HE is developing, fabricating, and delivering a PC-based training system which supports Predator UAV crew training and serves as a testbed to assess alternative training curricula and methods, automation levels, interface formats and design changes. To promote realistic testbed development, cognitive task analyses have been conducted that identify current UAV and future UCAV operator functional requirements. The testbed will provide a realistic, low cost synthetic environment that can be networked into larger synthetic exercises to support distributed mission training and to provide decision-aiding information. The synthetic environment and derived tasks, as well as the system hardware requirements and software, are available for use in UAV/UCAV research efforts. Using the software from the training system and some synthetic tasks derived from the cognitive task analysis, there is also an ongoing study designed to determine the amount and type (if any) of flying experience required to serve as an Air Vehicle Operator for the Predator.

Timeline:
FY00: High fidelity Predator simulation capability for training and research.
FY 01: Compete Flying Experience Study

FY03: UCAV training research capability demonstrated in distributed mission training.

Current Funding Levels:

	FY00	FY01
AFRL	$0.30M	$0.30M

UAV/UCAV MAINTENANCE/SUPPORT

Lead Agency: AFRL/HE, (937) 656-4390

Objective/Description: The objective of the Predictive Failure and Diagnostics for Legacy Aircraft (PFAD) program is to reduce legacy aircraft downtime by enhancing the capability of maintainers to identify the causes of system failures through better diagnostics, and, where possible, identify imminent system failures (failure prognostics) so that replacements can be made before an actual failure occurs. This program has critical value in promoting the rapid turnaround of future UAVs and UCAVs for maximum sortie rate.

Timeline:
FY00: Sensors investigation (6.2) - Task Order
FY00: PFAD Prime Contract Award
FY01: Data Requirements, On vs Off-Board Diagnostics
FY02: Diagnostics Concept Design/Algorithm Development
FY03: Demonstrate Diagnostics Approach, Prognostics Concept Design
FY04: Prognostics Algorithm Development
FY05: Technology Demonstration, Technology Transition

Current Funding Levels:

	FY00	FY01	FY02	FY03	FY04	FY05
AFRL	$0.40M	$1.97M	$1.84M	$3.3M	$5.7M	$2.5M

- Ready to begin system integration: FY05
- Anticipated operational availability: FY05+

UCAV OPERATOR VEHICLE INTERFACE RESEARCH

Lead Agency: AFRL/HE, (937) 255-5779

Objective/Description: This interface research directly supports Phase II of the DARPA/USAF Unmanned Combat Air Vehicle (UCAV) Advanced Technology Demonstration (ATD). The Operator Vehicle Interface program designs, develops and evaluates interface concepts supporting the control of multiple UCAVs by a single supervisory operator. This research effort works very closely with Boeing Human System Interface personnel to identify operator requirements and integrate interface solutions into the overall UCAV operator workstation.

Timeline:
FY00-02: Prototype interface concepts supporting UCAV software Builds 1.2, 1.3, and 2.1.

Current Funding Levels:

	FY00	FY01	FY02
AFRL	$0.65M	$0.67M	$0.57M

- Ready to begin system integration: Ongoing
- Anticipated operational availability: FY05+

UCAV ADVANCED TECHNOLOGY DEMONSTRATOR (UCAV ATD)

Lead Agency: DARPA/TTO, (703) 696-2369

Objective/Description: The objective of the DARPA/USAF Unmanned Combat Air Vehicle Advanced Technology Demonstrator (UCAV ATD) is to design, develop, integrate, and demonstrate the critical technologies pertaining to an operational UCAV system. The critical technology areas are command, control, and communications, human-systems interaction, targeting/weapons delivery, and air vehicle design. The specific objectives of the UCAV ATD include: developing and demonstrating a low life-cycle cost, mission effective design for a SEAD/Strike unmanned air vehicle; developing and demonstrating a re-configurable control station for multi-ship operations; demonstrating robust/secure command, control and communications, including line-of-sight and over-the-horizon; exploring the full range of human-computer function allocation, dynamic mission planning and management approaches; evaluating off-board/on-board sensor integration, weapon targeting and loadouts. Another objective is to demonstrate human-in-the-loop: detection, identification, location, real-time targeting, weapons authorization, weapons delivery and target damage indication. Validating a UCAV weapon system's potential to affordably perform SEAD/Strike missions in the post 2010 timeframe is another key objective. Life cycle cost models will be developed which include verifiable estimates of acquisition and O&S costs. The critical affordability assumptions and technologies will be validated through concept and process demonstrations.

Timeline:

FY01: Block 1 Flight Testing (1 vehicle, taxi and flight tests, handoff of control, etc.)

FY02: Block 2 Flight Testing (2 vehicles, dynamic retasking, weapon drop, etc.)

Current Funding Levels*:

FY98	FY99	FY00	FY01	FY02
$15.0M	$32.0M	$34.1M	$38.8M	$23.1M

Funding shows total burdened dollars (including management, overhead, etc.) from both the Air Force and DARPA, for Phase I and Phase II of the program. Total contract dollars for Phase II are $110M from the Government, with an additional $21M from Boeing. Projected UCAV Unit Recurring Flyaway (URF) Cost is less than 1/3 of JSF. Projected UCAV O&S Cost is less than 1/4 of F-16 HARM Targeting System squadron

Ready to begin system integration and initiate EMD: FY05
Anticipated Operational Availability: FY10

Desirable unfunded follow-on activity, with estimated cost:
Initiate Phase III in FY02: approx. $225M

- (Phase III includes intelligent multi-vehicle flight ops, ground ops, end-to-end demo, etc.)

VEHICLE TECHNOLOGIES FOR FUTURE ISR REQUIREMENTS

Lead Agency: AFRL/VA, (937) 656-6337

Objective/Description: The Vehicle Technologies for Future Intelligence, Surveillance, and Reconnaissance (ISR) Requirements thrust is developing a set of technologies that will enable a significantly more affordable ISR capability. The endurance capability for these air vehicles is critical for mission effectiveness and greatly impacted by vehicle weight and aerodynamic efficiency. This thrust is focused on adaptive structures and active flow control for maximizing aerodynamic efficiency, ultra-lightweight airframe concepts specific to high altitude airfoil geometry, and structural concepts that enable efficient integration of large antennae. Flexible structures, coupled with advanced actuation concepts, will enable aircraft geometry to adapt to changing flight conditions and increase aerodynamic efficiency throughout the mission profile. Application of advanced material product forms, advanced manufacturing and assembly processes, design optimization and criteria, hybridization of composite and metallic materials, and integration of structure and subsystem features will enable the structural weight reduction necessary for long endurance.

Timeline:

FY01-03: Exploratory development of adaptive airframes and flow control for aerodynamic efficiency improvement and broadband array integrated with load bearing structure.

FY02-04: Exploratory development of ultra-lightweight structural concepts.

FY02-04: Advanced development of structurally integrated antenna.

FY03-07: Advanced development of adaptive airframes, flow control, and lightweight structural concepts.

Current Funding Levels:

	FY01	FY02	FY03	FY04	FY05	FY06	FY07
AFRL	$0.656M	$1.431M	$3.229M	$4.682M	$6.105M	$4.884M	$3.330M

VERSATILE AFFORDABLE ADVANCED TURBINE ENGINE

Lead Agency: AFRL/PR, (937) 255-2767

Objective/Description: Develop and demonstrate affordable, advanced turbine engine system and engine/ airframe integration technologies for legacy, pipeline, and future military aircraft/rotorcraft, missiles, and unmanned air vehicles; and improve design and cost analysis methods to gain a fundamental understanding of the overall propulsion and power system affordability. The Versatile Affordable Advanced Turbine Engine (VAATE) goal is a revolutionary 10X improvement in turbine engine affordability (capability-to-cost ratio) by 2017 with interim goals of 4X by 2006 and 6X by 2010. [Propulsion capability includes engine thrust/weight and fuel consumption; and propulsion cost is the sum of development, production, and maintenance costs.] The focus is to combine advanced aerodynamics, materials, and structural concepts with emerging active control, health management, aircraft subsystem integration, and information technologies to create a revolutionary improvement in turbine engine affordability. When combined with advanced air vehicle technologies, VAATE technologies will allow a 100-200% range improvements of current and developmental combat and reconnaissance UAVs.

Timeline:

FY04-06: Small engine core design and manufacture

FY06: Engine core test

FY05-07: Design and manufacture of UAV engine demonstrator

FY07: Phase I UAV engine demonstrator test

Planned Funding Levels:

FY04	FY05	FY06	FY07	FY08
$5M	$15M	$18M	$16M	$6M

- Approximately 2/3 to 3/4 of the funding is from AFRL, with the balance being the Navy.

VTUAV Communications Payload: Information Distribution FNC

Lead Agency: NAVY/ONR, (703) 696-7917

Objective/Description: The VTUAV communications payload project is a funded above-core program of the Information distribution FNC in the Office of Naval Research (ONR). The project seeks to facilitate network centric warfare by developing and integrating a payload package for the Firescout VTUAV capable of wideband data relay via "internet in the sky" directional Tactical Common Data Link (TCDL). The needs of littoral forces will also be addressed. Major demonstrations of this technology are scheduled to be conducted in FY05-07.

Timeline:
FY00: Low level planning
FY01: Detailed demonstration planning and technology roadmapping
FY02-07: Technology development & demonstrations

Current Funding Levels:

FY00	FY01
$100,000	$100K

Desired unfunded follow-on activity, with estimated cost:

- Joint Demonstrations (with US Army, USAF): $ 1.5 M
- Development of fit Army TUAV: $ 2.0 M

Weapons Integration For UAVs

Lead Agency: AFRL/MN, (850) 882-5151

Objective/Description: Weapons Integration for Unmanned Air Vehicles (UAVs) is a collection of flight test munitions programs that are on the critical path (required for mission utility as an Unmanned Air Vehicle) for the weaponization of Unmanned Air Vehicles. The munitions programs include: Precision Direct Attack Munitions (PDAM), Small Smart Bomb Range Extension (SSBREX), Low Cost Autonomous Attack System (LOCAAS), and Small Munitions Dispenser (SMD). These programs will provide a UAV the capability to be small in size, low cost, have increase payload, and standoff while attacking fixed and mobile targets. PDAM, SSBREX, and

LOCAAS are precision guided weapons with increased accuracy to significantly improve kills/sortie. The SMD program will develop and demonstrate advanced technologies applicable to provide optimum carriage, electrical interface, and dispensing of smart miniature weapons.

Timeline:

FY00: Flight test of SSBREX will validate range extension predictions

FY01: Flight test of LOCAAS will validate safe separation and flight commands for a mobile target killer.

FY02: Flight test demonstration of optimum carriage, electrical interface, and dispensing of miniature weapons.

FY02: Critical design of Precision Direct Attack Munitions for increased target accuracy.

Transition Dates:

Small Smart Bomb Range Extension (SSBREX)	FY01
Low Cost Autonomous Attack System (LOCAAS)	FY02
Small Munitions Dispenser (SMD)	FY04
Precision Direct Attack Munitions (PDAM)	FY05

Current Funding Levels:

	FY00	FY01	FY02	FY03	FY04
AFRL	$10.53M	$9.46M	$12.6M	$10.62M	$6.41M