Civil UAV Capability Assessment

Draft Version

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Randal T. Albertson (NASA)……………………………………………Section 4.4

Jay Levine (Analytical Sciences & Materials, Inc)…………………Section 2.1

Executive Summary

This document presents the findings of a NASA led capabilities assessment of Uninhabited Aerial Vehicles (UAVs) for civil use. The intent of the report, which is intended to complement the Office of the Secretary of Defense UAV Roadmap, is four-fold:

- To determine and document potential future civil missions for all UAVs based on user-defined needs
- To determine and document the technologies necessary to support those future missions
- To discuss the present state of the platform capabilities and required technologies; identifying those in progress, those planned, and those for which no current plans exist.
- Provide the foundations for development of a comprehensive civil UAV roadmap

It is expected that the content of this report will continue to be used to assess the feasibility of future missions and to help influence funding decisions to develop those technologies that are considered enabling or necessary but are not contained within approved funding plans.

Discussed within section 2 of the report is a brief summary of current UAV platforms, both in the civil and military arena. The role of UAVs in enhancing warfighting capability has long been recognized by DOD, and current plans emphasize significant capability growth for UAVs within the next 10 years. Although this report does not focus on the military sector, it is recognized that a great deal of military UAV technology will be applicable to civil UAVs. Also discussed is an overview of market forecasts for civil use of UAV platforms. Tremendous potential for market growth exists, but some limiting factors preventing this growth create a high degree of uncertainty on the forecasts.

Section 3 of the report summarizes the documentation of several civil missions used for analysis. For this first edition, a total of thirty five missions were documented and analyzed. These missions came from various government and private sector agencies for both science and public benefit under the broad categories of (see Figure 1):

Homeland Security
Earth Science
Commercial
Land Management

From these 35 missions, most of which fall under the earth science category, 21 capabilities and technologies are identified as required to support the missions. Specific capabilities include such items as access to the National Air Space, long range/endurance, Over-the-Horizon communication, and formation flight. A complete list of capabilities allocated to the various missions is shown in Table II.

An assessment of civil UAV use is addressed in section 4 of the report. Several aspects of one of the primary obstacles to UAV use - cost - are discussed, including the role that safety, reliability, and operability of UAV's has in cost reduction. Also included is a general description and status for each of the capabilities and technologies identified in section 3. Over-the-Horizon communication and 'file and fly' access to the national air space are two capabilities which are seen as critical to expanding the civil use of UAVs. Another area of technology development which is required, particularly for earth science applications, is sensor development in terms of autonomy and size. Finally, a general schedule shows when some of the capabilities and technologies might be available.

While Department of Defense (DOD) missions are not considered as part of this report, it is recognized that many of the enabling technologies developed for military UAVs will be similar or identical to those required for civil UAVs. As a result, this effort will require close and continuing coordination between NASA and DOD in order to utilize and include, where possible, those military technologies that support civil missions.

This goal of fostering the capabilities of UAVs can most easily be accomplished by removing the technical and regulatory barriers to civil UAV flight. This means that NASA must endeavor to develop technologies from the low technology readiness levels to ones that can be readily developed in the commercial sense; then cost will become a lesser impact to market development. It also means developing technology and policies that facilitate flight in the National Air Space. When these occur, innovation and entrepreneurship will drive down the cost of UAV flights and drive up the safety, reliability, and operability of UAVs. As the costs go down and access to the airspace becomes routine, the market for UAV is expected to expand rapidly based on various market forecasts.

1 Introduction

In 1944 (60 years ago), Clarence "Kelly" Johnson, the legendary founder of Lockheed's Skunk Works and designer of the SR-71 and U-2 aircraft, predicted that the future of military aviation would belong to Uninhabited Aerial Vehicles (UAVs[1]). Judging by the increased roles for UAVs, it appears that Johnson's foresight is coming to fruition. Currently, the Air Force, Army, Marine Corps, and Navy possess and operate some type of UAV for ISR and combat support. Recent literature indicates that the military UAV application is maturing in a technology sense. On the civil side, National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Association (NOAA), and Department of Homeland Security (DHS), and others are examples of agencies with UAV interests other than for combat support. It would be interesting to know whether Johnson predicted the civil role for UAVs, as well.

1.1 Purpose

This document provides an assessment of the civil uninhabited aerial vehicle (UAV) missions and technologies and is intended to parallel the Office of the Secretary of Defense UAV Roadmap. The intent of this document is four-fold:

1. Determine and document desired future missions of all civil UAVs based on user defined needs
2. Determine and document the technologies necessary to support those missions
3. Discuss the present state of the platform capabilities and required technologies identifying those in progress, those planned, and those for which no current plans exist.
4. Provide the foundations for development of a comprehensive civil UAV roadmap to complement the DOD effort.

Two aspects of the President's Management Agenda are supported by this undertaking. First, it is one that will engage multiple Agencies in the effort as

[1] The term UAV is representative of a class of air vehicles known by different names: uninhabited aerial vehicle, unmanned aerial vehicle, remotely operated aircraft (ROA), and remotely piloted vehicle (RPV). For the purposes of this document, the term UAV will use a definition consistent with the Department of Defense, to wit: "A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles." The above definition would rule out unmanned dirigibles or airships. For the purpose of this report, these will considered if they are both powered and controllable. Another definition is found in the AIAA Committee of Standards, "Lexicon of UAV/ROA Terminology". It defines a UAV to be "An aircraft which is designed or modified, not to carry a human pilot and is operated through electronic input initiated by the flight controller or by an onboard autonomous flight management control system that does not require flight controller intervention." Either definition is appropriate for the subject of this report.

stakeholders and benefactors of the systems. In that sense, the market will be driven by the user requirements and applications. The second aspect is one of supporting economic development in the commercial sector. Market forecasts for the civil use of UAVs have indicated an infant market stage at present with a sustained forecasted growth. There is some difficulty in quantifying the value of the market since the typical estimate excludes system components other than the aerial platforms. (Section 2.4.1 addresses the civil UAV market forecast.) One point that can be drawn from these forecasts is that all show a sustained growth for the duration of the long-term.

1.2 Scope

The analysis of the proposed missions for this effort is limited to the civil UAV sector. The scope will address various government and private sector missions. For the initial investigation, missions were classified under the categories shown in Figure 1.

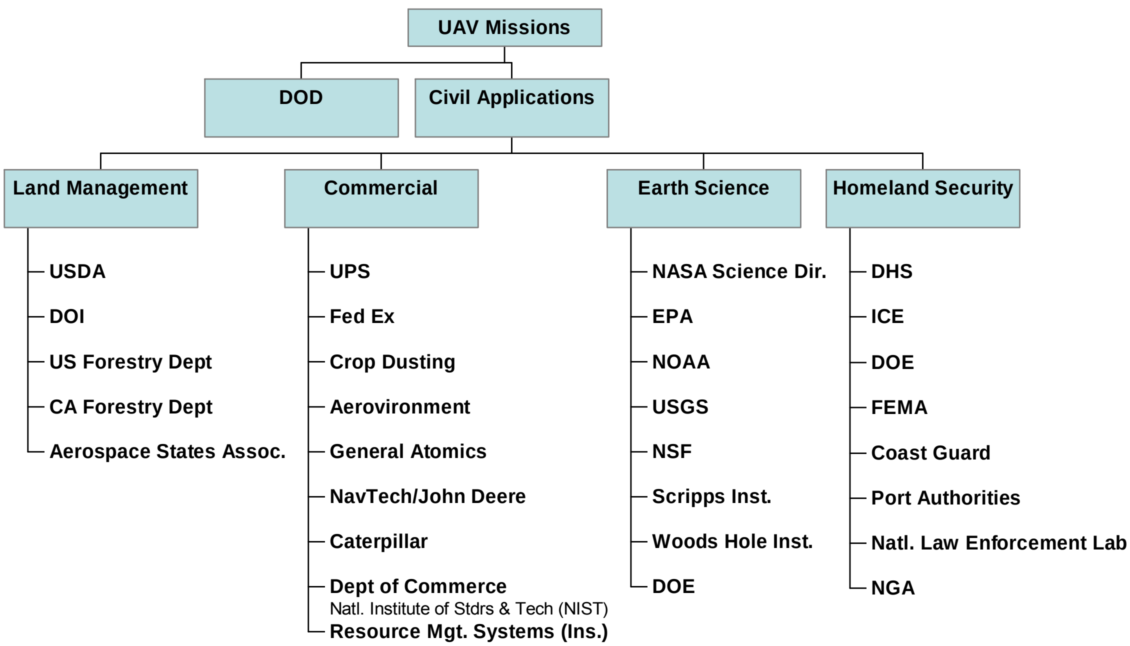


Figure 1. Classification of UAV Users

These categories indicate the current private and public sector organizations that have shown interest as potential users of UAVs. While DOD missions will not be considered as part of this report, it is recognized that many of the enabling technologies developed for military UAVs will be similar or identical to those required for civil UAVs. As a result, coordination between NASA and DOD will help to utilize and include, where possible, military technologies that support civil missions. It is expected that the content of this report will continue to be used to assess the feasibility of future missions and to direct funding to develop those technologies that are considered necessary but are not contained within funding plans.

Although the basic UAV technologies for both the DOD (DARPA and the uniformed services) effort and this NASA project are similar, there are large economic and philosophical differences between the programs. First, the DOD UAV has a specific combat role to fulfill. The vehicle must be combat equipped (including armor shielding, sensor suites and munitions). In this role, the completion of the mission without harm to personnel is supra to the economics of the vehicle. The basic objective of the NASA effort is to further develop the core technologies to reduce cost of acquisition and operation and to increase flight safety in order to help develop commercial applications for these vehicles. It is expected that many of the technological advancements made by NASA will be utilized by DOD in its UAV fleets.

This report is the initial version of the Civil UAV Capabilities Assessment and, because of time constraints, is heavily weighted toward the Earth Science missions. Additional workshops and interviews will be conducted to fuel a major update and scope expansion to this document scheduled for completion in March 2006. The March 2006 release will contain suggested paths to a greater UAV capability. Thereafter, minor updates will be made annually with a major update made in 2009. The schedule for these updates is shown in Figure 2.

	FY04	**FY05**	**FY06**	**FY07**	**FY08**	**FY09**	**FY10**
Initial Version	▲						
Major Updates			▲			▲	
Minor Updates			▲	▲	▲		▲

Figure 2. Civil UAV Capability Assessment Schedule

1.3 Approach

This document contains the “Draft” version (sometimes call the “strawman”) of the Civil UAV Capabilities Assessment (sometimes called the “roadmap”). This first version looks at a limited scope of UAV missions and identifies the technologies required to accomplish those missions. Over the next year, the scope will be expanded, additional technologies may be identified, and the status of those technologies (and their developmental projects) will be improved and updated. Feedback will be sought from the UAV users regarding the accurate capture of missions and technologies. The schedule for accomplishing this is shown below.

Develop list of "customers"	Jun 2004 thru Mar 2005
Develop website and coordinate workshops	Nov 2004 thru Feb 2005
Interview customers and conduct workshops	Jul 2004 thru Sep 2005
Develop list of missions	Jul 2004 thru Sep 2005
Develop prioritized list of technologies	Aug 2004 thru July 2005
Develop schedule for technology development	Nov 2004 thru Sep 2005
Identify gaps (unsupported technology development)	Apr 2005 thru Sep 2005
Submit document back to customers for ratification	Sep 2005
Update document based on customer comments	Oct 2005 thru Feb 2006
Final Signed Copy	Mar 2006

Information for this first effort was gathered primarily from two sources: a workshop held in Arlington, VA in July, 2004, and a series of personal interviews with subject matter experts. The initial step was to develop a "customer list" – defined as a group of individuals who were either knowledgeable about specific mission requirements for UAVs or had interests in utilizing UAVs for potential missions. These users represent a variety of different organizations with a broad range of potential applications. The current customer list is provided in Appendix A. Inclusion in the customer list does not imply support for or concurrence with the findings of this report.

Once the customer list was developed, some participants were interviewed at workshops or individually. For this initial version of the capability assessment, not all those on the customer list were interviewed. To ensure a mix of different types of applications, missions were classified under the general categories shown in Figure 1, and customers were selected from each of the civil categories (with the exception of the Commercial). Much of the information for the Earth Science category was obtained from the "Suborbital Science Missions of the Future" workshop held in July 2004. Information for other categories was gathered from personal interviews. A sample interview questionnaire is shown in Appendix B.

While the authors of this report will attempt to contact many members of the "customer list", we do not claim the list to be all-inclusive. If readers have a desire to be part of this effort, or desire to have missions included, we would invite them to contact the authors through the following email address:

uav.cap.access@dfrc.nasa.gov

The project also hopes to develop a website for the dissemination of information and announcement of scheduled workshops and conferences. When the website is established, members of the customer list with e-mail addresses will be notified of the URL.

Other sources of information to be considered during the first major update are:

1. The Revolutionary Aerospace Systems Concepts Science Workshop, June 2002
2. The UAV National Task Force results
3. The Office of the Secretary of Defense UAV Roadmap

1.4 Acronyms and Definitions

Acronyms used in this document are contained in Appendix C. Where appropriate, a short definition has been included to help define the acronym.

2 UAV Programs

2.1 Historical

Since the first automatically controlled flight of an aircraft in 1916, military planners have imagined the value of an uninhabited air vehicle (UAV) that could spy on the enemy, or even deliver munitions to a target without endangering a human pilot.

In 1916 Lawrence and Elmer Sperry combined the stabilizing gyro and a steering gyro to make an automatic pilot system they called the aerial torpedo. That aircraft flew for more than 30 miles with Lawrence Sperry as a passenger. It is generally considered the first automatic steering of an aircraft. However, the technology was not yet mature and the military later was forced to abandon the aerial torpedo.

Although the notion of using UAVs, in one form or another, has been around since World War I, the US did not begin experimenting seriously with unmanned reconnaissance drones until the late 1950s. The idea of being able to carry out airborne missions behind enemy lines without harm to a pilot intrigued war strategists. Although the initial efforts proved unsuccessful, the Vietnam War and the Cold War spurred a variety of development programs, which led to several reconnaissance drones, such as the Firebee and Lightning Bug.

Although those early UAVs were sometimes difficult to operate and maintain, the Air Force deployed them for a variety of missions, including gathering signals intelligence and collecting high- and low-altitude imagery both during the day and at night. By the end of the Vietnam War, concern about casualties meant that only two aircraft were allowed to fly reconnaissance missions over North Vietnam: the Lightning Bug UAV and the SR-71, a high-altitude, manned reconnaissance plane. The urgent need for unmanned aerial vehicles ended with the Vietnam War, but the services remained interested in exploring the capabilities that those aircraft had to offer.

The modern UAV era originated in the early 1970s. Designers in the United States and Israel started experimenting with smaller, slower, cheaper UAVs. These UAVs resembled large model airplanes, powered by motorbike or snowmobile engines. Their most important feature was that they used new, small video cameras that could send pictures to the operator in real time.

The US Army began developing a tactical UAV called Aquila in 1979. It suffered many growing pains (developmental problems, cost overruns, changes in requirements) and was finally canceled in 1987. During that time, the Israelis used very simple and cheap drones to good effect to destroy Syrian air defenses in Lebanon’s Bekaa Valley in 1982. Their success inspired then Secretary of the Navy John Lehman to push for his service to acquire UAVs, primarily to support targeting by, and conduct battle-damage assessment for U.S. battleships. The UAV efforts by the Navy led to newer systems developed by the Air Force that were used successfully for combat operations during the 1991 and 2003 middle east conflicts. The military use for UAVs was reinforced by these operations.

On the civil side, NASA programs such as the PA-30 in 1969 looked at automatically controlling an aircraft, but a pilot was in the cockpit to take over if the research didn't go as expected. NASA engaged in several other successful programs to help develop data bases for future UAV researchers such as the F-15 Spin Research Vehicle, a 3/8 scale aircraft; Drones for Aerodynamic and Structural Testing (DAST); and the Highly Maneuverable Aircraft Technology (HiMAT) program.

The need for technologies to assist a fledgling UAV market led to a key 1990s NASA-led program that, initiated with industry partners, brought the potential of a commercial UAV market into focus. Continuing work developed from that effort seeks resolution of major technological and policy impediments that yet dam up the waters of potential. The nine-year long NASA program called Environmental Research Aircraft and Sensor Technology (ERAST) helped to redefine UAV technology with research on engines, sensors and integrated vehicles that would conquer the barriers to high altitude, long-endurance (HALE) aircraft. Products resulting from the ERAST partnership include Pathfinder, Helios, Altus, and Perseus B, and potentially could result in vehicles with altitude ceilings above 100,000 feet and endurances up to 6 months.

2.2 Civil UAVs

The following sections describe the characteristics of some of the more prominent UAVs applicable to civilian missions. The aircraft listed here, chosen primarily for previous roles in science missions, serves as a sampling of civil UAV systems and is not intended to be complete and exhaustive. A more complete listing of UAV's may be found in the following reference:

Aviation Week and Space Technology, "2005 Aerospace Source Book". January 17, 2005.

2.2.1 Operational Civil UAVs

The following sections discuss a few of the civilian UAV that are considered to be operational

2.2.1.1 Aerosonde

The Aerosonde UAV was developed by Aerosonde Pty, Ltd. of Australia. It was originally designed for meteorological reconnaissance and

environmental monitoring although it has found additional missions. It has a gross take-off weight of 33 lbs (15 kg) and a payload weight ranging from 4.5 to 11 lb (2 to 5 kg) depending on the desired endurance. For intermediate weights, the Aerosonde has a ceiling of 23,000 ft (7 km). It has an endurance of 10 to 30 hours and a range of 1100 to 1600 nm (2000 to 3000 km), depending on the payload weight. Aerosondes are currently being operated by NASA Goddard Space Flight Center for earth science missions.

2.2.1.2 Altair

Altair was built by General Atomics Aeronautical Systems Incorporated as a high altitude version of the Predator B aircraft. Designed for increased reliability, it has a fault-tolerant flight control system and triplex avionics. It is capable of payloads of 660 lbs (300 kg) internally and up to 3000 lbs (1361 kg) on external wing stations. Altair has a ceiling of 52,000 feet (15.2 km) and an endurance of 30 hours. It is operated by General Atomics although NASA Dryden Flight Research Center maintains an arrangement to conduct Altair flights.

NASA Dryden Flight Research Center Photo Collection
NASA Photo: EC03-0154-3 Date: June 9, 2003 Photo By: Tom Tschida
The remotely-piloted Altair unmanned aerial vehicle (UAV) took to the air on its first checkout flight on June 9, 2003 at El Mirage, California.

2.2.1.3 Altus I / Altus II

The Altus aircraft were developed by General Atomics Aeronautical Systems Incorporated, San Diego, CA, as a civil variant of the U.S. Air Force Predator. Although similar in appearance, the ALTUS has a slightly longer wingspan and is designed to carry atmospheric sampling and other instruments for civilian scientific research missions in place of the military reconnaissance equipment carried by the Predators. It can carry up to 330 lb of sensors and other scientific instruments in a nose-mounted payload compartment, a location designed to allow air being sampled by the sensors to be undisturbed by heat or pollutants from engine exhaust. Altus II has a ceiling of about 65,000 ft (19.8 km) and an endurance of about 24 hours.

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: EC98-44684-1 Date: 29 Jun 1998 Photo by: General Atomics
Altus II aircraft flying over southern California desert

General Atomics has built two Altus aircraft to date: the Altus I, equipped with a single-stage turbocharger, for the Naval Postgraduate School (see Section 2.2.1.4 on CIRPAS), and the Altus II, with a two-stage turbocharger, currently at NASA Dryden Flight Research Center.

2.2.1.4 CIRPAS

The Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) is a research center at the Naval Postgraduate School. The Office of Naval Research established CIRPAS in the spring of 1996. CIRPAS provides measurements from an array of airborne and ground-based meteorological, aerosol and cloud particle sensors, radiation and remote sensors to the scientific community. The data are reduced at the facility and provided to the user groups as coherent data sets. The measurements are supported by a ground based calibration facility. CIRPAS conducts payload integration, reviews flight safety and provides logistical planning and support as a part of its research and test projects around the world. The center operates a variety of manned aircraft and unmanned aerial vehicles. Its aircraft include the UV-18A ‘Twin Otter’, the Pelican, the Altus ST UAV, the Predator UAV, and the GNAT-750 UAV. CIRPAS is also a National Research Facility of the University National Oceanographic Laboratory System.

The facility provides unique flight operation and scientific measurement services by:

- Providing access to manned aircraft, UAVs and support equipment, as well as to scientific instruments, to spare users the cost of ownership, guaranteeing equal access by all interested parties on a first-come, first-served basis.
- Instrumenting and operating aircraft to meet the requirements of a variety of individual research and test programs.
- Developing new instrumentation to meet increasing challenges for improvements in meteorological and oceanographic measurements.
- Calibrating, maintaining, and operating the facility’s airborne instruments in accordance with individual mission specifications.
- Integrating auxiliary payloads as required and handling flight safety and logistics tasks, allowing the user to concentrate on his specific mission goals.

2.2.1.5 RMAX

The Yamaha RMAX helicopter has been around since about 1983. It has been used for

both surveillance and crop dusting, and other agricultural purposes. It has a payload of about 65 lbs (30 kg), a flight time of about 90 minutes, and range of about 5.5 nm (10 km).

2.2.2 UAV Technology Development Programs

NASA is currently leading a series of efforts that will impact the capabilities of future UAVs. A few of these are mentioned here; a more complete discussion (of both NASA and other agencies) will be completed in the next update.

2.2.2.1 Autonomous Robust Avionics (AuRA)

The AuRA project is focused on developing and maturing the technology which will enable aircraft to fly with reduced or no human intervention, to optimize flight over multiple regimes, and to provide maintenance on demand. Three main components of AuRA are Intelligent Mission Management (IMM), Integrated Systems Vehicle Management, and Adaptive Flight Controls.

2.2.2.2 Earth Sciences Capability Demonstration (ESCD)

Sponsored jointly by the Science and Aeronautics Research Mission Directorates, ESCD is oriented toward developing component systems to make UAV's more functional for science missions.

2.2.2.3 High Altitude Long Endurance Remotely Operated Aircraft (HALE ROA)

HALE ROA aircraft goals are to redefine duration and payload capabilities of high altitude UAVs. Duration goals are in the weeks-to-months time frame.

2.2.2.4 Integrated Tailored Aero Structures (ITAS)

The objective of ITAS is to improve structural capabilities for aircraft intended for high altitude and long endurance.

2.2.2.5 Low Emission Alternative Propulsion (LEAP)

The Low Emission Alternative Power (LEAP) project focuses on the development of non-conventional propulsion systems technologies which reduce emissions while dramatically increasing efficiency. The technologies under investigation are key to enabling high altitude long endurance aircraft platforms. Technical focus areas directed towards HALE ROA applications include an integrated ground test demonstration of a hydrogen/oxygen regenerative fuel cell system, materials for high temperature PEM fuel cells, solid oxide fuel cells, and lightweight hydrogen-based storage and feed systems. A component of the LEAP project is a flight demonstration of an unrefueled, multiple day hydrogen based fuel cell power system.

The focus of the LEAP project is to develop propulsion systems suitable for long duration missions.

2.2.2.6 Remotely Operated Aircraft in the National Airspace (ROA in the NAS)

NASA centers, the Federal Aviation Administration and other governmental agencies have united in an effort to develop recommendations to the FAA for certifications and procedures to incorporate UAVs into the national airspace. The assignment is a key impediment to development of the commercial UAV market.

2.3 Military UAVs

The DOD recognizes that UAV technology has the potential to transform the way in which warfighting is conducted. In recent military operations operational UAVs, such as Predator, Hunter, and Shadow; and developmental UAVs, such as Global Hawk, have demonstrated a significant force multiplier capability. As such the DOD is expanding the role of the UAV within military concepts of operation. Due to the large variety of military UAVs, a brief summary of the classes of UAVs in current operation or development follows, as well as a description of some current military technology development programs which will provide the capability for operational concepts using UAVs over the next 20 years. More specific information can be found in the DOD UAV roadmap (Unmanned Aerial Vehicles Roadmap, Office of the Secretary of Defense, December 2002). A general history of military UAV development is shown in Figure 3.

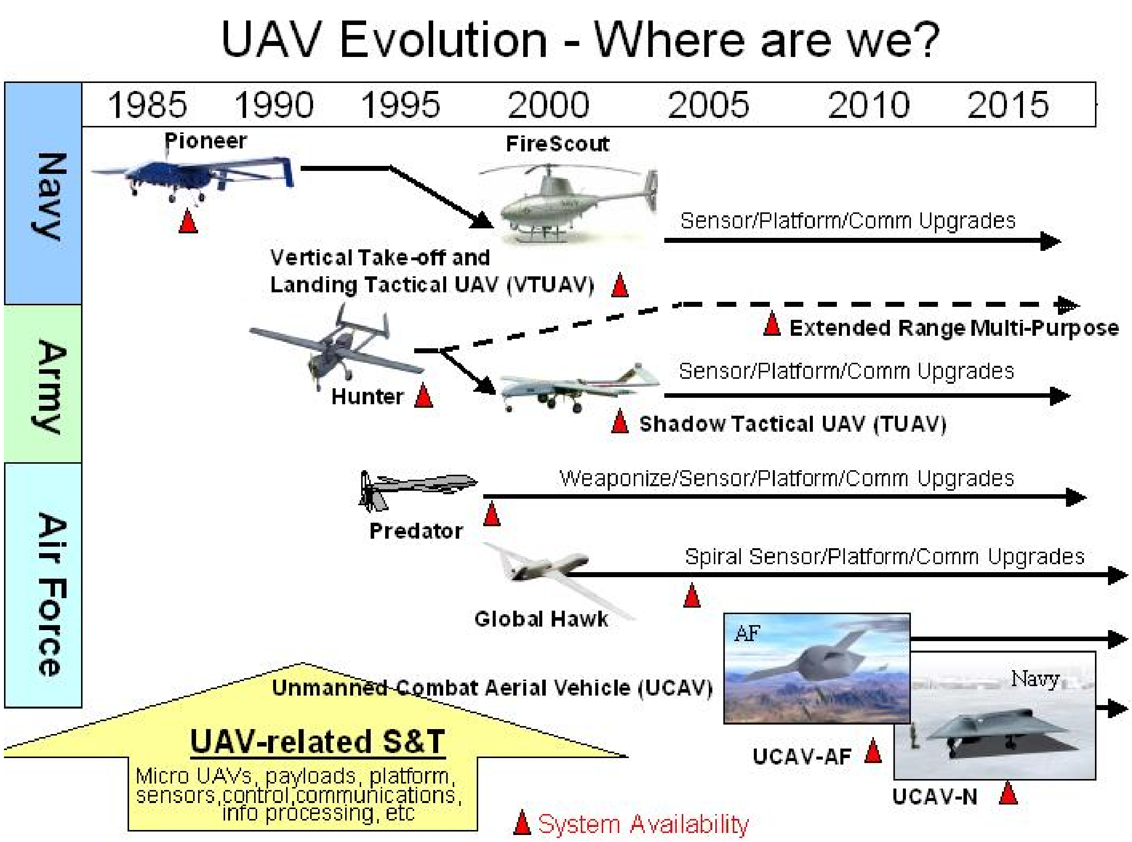


Figure 3. History of Military UAVs

2.3.1 Classes of Military UAVs

For the purposes of this report, UAVs are classified into 4 categories: micro-aerial vehicles, local area support vehicles, tactical area support vehicles, and theatre area support vehicles.

Micro-aerial vehicles are defined by their physical dimensions. They are no larger than 12 inches (.3 m) in any direction. Total weights of these vehicles range from .2 lbs (.1 kg) to a few pounds with payload weights on the order of fractions of pounds. They are easily transported and operated by one individual, through both autopilot and remotely piloted modes. The primary use is for reconnaissance support of the individual soldier or squad of soldiers. The payload is a miniaturized camera. Examples of these vehicles include the Black Widow, the 9" (.23 m) ducted fan iSTAR (intelligent Surveillance, Target acquisition, and Reconnaissance), and the Wasp.

Vehicle: Wasp
Manufacturer: AeroVironment
Weight: .4 lbs (.18 kg)
Payload weight: .01 lbs (.004 kg)
Length: 8 inches (.20 m)
Max speed: 35 knots (65 km/hr)
Endurance: 100 minutes

Local area support vehicles are designed to be carried in a backpack or on a ground transport vehicle to support squad or platoon level operations. They are operated by one or two individuals, generally through the use of waypoint guidance or autopilot interface and remotely piloted mode. Total weight for these vehicles can range from 5 to 50 pounds (2.3 to 23 kg), with payload weights from 1 to 5 pounds (.45 to 2.3 kg). Typical payloads are a suite of electro-optical (EO) cameras; sometimes infrared (IR) cameras are included. The mission is 'over-the-hill' type reconnaissance. Examples of these vehicles include the 29" (.74 m) ducted fan iSTAR, Pointer, Dragon Eye, and Raven.

Vehicle: Pointer
Manufacturer: AeroVironment
Weight: 8.3 lbs (3.7 kg)
Payload weight: 2 lbs (.9 kg)
Length: 6 ft (1.8 m)

Max speed: 43 knot (80 km/hr)
Endurance: 120 minutes

Tactical area support vehicles are operated by a crew in support of brigade, battalion, division, or corps level commanders. Total weights for these vehicles range from 300 lbs (136 kg) to about 2000 or 3000 lbs (907 or 1360 kg). Conventional take-off from a runway or catapult assisted launches are necessary for fixed wing aircraft. Rotary wing vehicles are also being developed in this class. Primary role of these vehicles is reconnaissance with increased ranges over previous classes, anywhere from 50 to 150 nm (92.5 to 278 km). Examples of these vehicles include Shadow, Hunter, and Dragon Warrior.

Vehicle: Hunter
Manufacturer: Northrop Grumman
Weight: 1600 lbs (725 kg)
Payload weight: 200 lbs (91 kg)
Length: 23 ft (7 m)
Endurance: 11.6 hr
Radius of Operation: 144 nm (266 km)

Theater area vehicles provide support for theater level commanders. Total weights for these vehicles range from 2000 to 35000 pounds (907 to 15,900 kg) (fighter aircraft size). Support includes tactical and strategic reconnaissance, and recently, strike capability. These vehicles operate from an airport or carrier. Some vehicles in the class are flown remotely piloted, and some with a high level of autonomy. One distinguishing feature of the current inventory within this class of vehicle is endurances beyond 24 hours. Payloads include EO/IR cameras, synthetic aperture radar (SAR), and in the case of the Predator and Predator B aircraft, Hellfire air to ground missiles. Besides the two Predator aircraft, another example of an aircraft in this class is the Global Hawk. Although still in a relatively early stage of development, Joint Unmanned Combat Air System (J-UCAS) is a vehicle in this class which will provide an air defense suppression capability.

Vehicle: Predator B
Manufacturer: General Atomics
Weight: 10,000 lbs (4536 kg)
Internal payload weight: 750 lbs (340 kg)
External payload weight: 3000 lbs (1360 kg)
Endurance: 30+ hr

Radius of Operation: 2500 nm (4625 km)

2.3.2 UAV Technology Development Programs

DARPA and all branches of the military are currently engaged in several technology development programs to enhance the capability of UAVs as a warfighting machine. A brief summary of a few of these programs provides a taste of how UAVs are intended to be used in the future and the types of technologies required to fulfill their roles.

2.3.2.1 J-UCAS

The initial operational role of the J-UCAS program is to develop an air defense suppression system which integrates seamlessly with a 'first day of the war' strike package. Key technical challenges include interoperability with other manned and unmanned assets, highly adaptive autonomous operations, coordinated multi-vehicle flight and robust prognostics and health management systems. Affordability and reduced costs are an important consideration. As a result the system is to be designed with a significant reduction in the manpower required to operate and maintain vehicles.

The concept calls for the J-UCAS system to be a 'system of systems'. Therefore the J-UCAS system is not one vehicle, but a team of vehicles coordinating and working together to perform the mission, managed by one operator. The J-UCAS concept will advance UAV technology considerably. The UAVs that are members of the J-UCAS system require a higher level of autonomy than previously flown. Potentially, nominal human involvement is to occur for approval of the J-UCAS system to launch missiles only. Therefore, mission planning must occur at a high level of autonomy. Dynamic mission re-planning, including contingency management, must be capable 'on the fly' within each UAV in the system, as well as within the J-UCAS system as a whole. Each UAV member within the system must be able to communicate with other members for the purpose of identifying targets, verifying targets, planning an attack, executing the attack, and performing battle damage assessment. The J-UCAS system must also be capable of determining when to return to base, and then integrating with other manned and unmanned assets for terminal area operations such as approach and landing.

The high level of integration and collaboration with elements internal and external to the J-UCAS system drive the need for a common operating system. The common operating system enables the required integration and interoperability in a network centric approach. As such each element in the system is a node, which can both communicate to and from any other node. Examples of nodes are the flight management system, weapons, and sensors of each UAV member within the J-UCAS system. An example of a node external to system is the ground operator. The common operating system provides the interfaces between these nodes and the means to manage the nodes. The common operating system also provides and manages the communication links between members within the J-UCAS system. A standard architecture for plugging into the common operating system increases the platforms availability for missions and reduces operating costs.

Operational assessment of the J-UCAS system is scheduled for 2010. The results for these assessments will then be directed into capabilities and requirements for follow on systems.

2.3.2.2 Unmanned Combat Armed Rotorcraft (UCAR)

The UCAR program is to demonstrate the technical feasibility, military utility, and operational value of UAV rotorcraft affordably performing armed reconnaissance and strike missions. Key technologies are autonomous and collaborative operations, autonomous low altitude flight, affordability and survivability, and target recognition and strike. Similar to J-UCAS in many respects, the UCAR concept employs high levels of autonomy and a ‘system of systems’ approach. As such it must integrate seamlessly with manned assets. One element of UCAR, not part of J-UCAS, is the ability to operate at low altitudes. Therefore, an important component of the UCAR program is the development of an obstacle avoidance sensor. The sensor must identify ground terrain and man-made obstacles, such as buildings or power lines, since the UCAR concept does not restrict operations in urban areas. Target recognition of enemy ground assets, not only hardware but personnel, is another key challenge in the UCAR program. Plans call for UCAR to be at a technology readiness level (TRL) of 7 by 2009.

2.4 UAV Proliferation

Although UAVs represent a relatively small segment of the aerospace market (about $1.25B in research and production funding in 2003), they constitute the dynamic portion of the industry. What attracts so much attention to them is the potential for a major expansion and new roles in both the defense and civil applications (articulated elsewhere in this document). Since the development is in the early stages, there are many uses that are being proposed for them.

However, several pre-conditions must be satisfied to render the UAV a viable, cost effective and regulated alternative to existing resources. Major civil and commercial market barriers include:-

- Lack of airspace regulation that covers all types of UAV systems (encompassing ‘sense and avoid’, airspace integration and airworthiness issues)
- Affordability - price and customization issues (e.g. commercial off-the-shelf, open modular architecture)
- Efforts to establish joint customer requirements (although this is gradually changing)
- Liability for civil operation

- Capacity for payload flexibility
- Lack of secure non-military frequency for civil operation
- Perceived reliability (e.g. vehicle attrition rate vs. manned aircraft)
- Operator training issues
- Recognition/customer perception
- Technology developments for multi-mission capability

2.4.1 Market Forecast

UAV suitability for use in “dull, dirty and dangerous” missions, their increasing success in service and demonstration, increases in payload capability, the war on terrorism (with its homeland security implications) and the need for multi-mission capabilities have unlocked new markets beyond current military/paramilitary requirements. These include diverse civil and commercial applications for a wide range of international public service agencies.

Market forecasts for the UAV industry are tempered by the fact that they do not include the projections for payload costs or operational costs. The lack of inclusion of these cost elements makes it difficult to develop a very accurate forecast of the market. Table I lists various forecasts based on the number of units of demand (basic systems) rather than total market including operations and sensor suites. Of interest to this effort is the fact that all indicate a high rate of growth in the number of units over the next ten years. By extension, the growth in the support market could be considered as explosive as well. As indicated in the previous section, price structure will play a major influence in the civil sector growth rate.

Source	Date	Forecast	Uses	Comments
Department of Defense	FY 2001 budget	Strike force to be 1/3 UAVs by 2010	Military	Airframe and avionics
Teal Group	Dec 2002	Market to double by 2014	Military, science, homeland security	Airframe and avionics
Frost and Sullivan	Oct 2003	5.5B EUR by 2012	Military, science, homeland security	Airframe and avionics
Forecast Int’l	Oct 2003	\$10.6B by 2013 Massive growth 2010	Military, science, homeland security	Airframe and avionics
Teal Group	Aug 2004	\$4.5B/yr by 2014	Military, science, homeland security	Airframe and avionics

Table I. UAV Market Forecasts

2.4.2 UAV Development in the U.S.

A recent study (Forecast International) of the worldwide UAV market concluded that U.S. spending on UAVs amounted to about 73% of worldwide research and production spending in 2003. The U.S. has dominated this market in recent years due, in part, to the depth of research and wide range of production programs. UAV development has been spotty, with clear leadership in endurance UAVs but laggard performance in fielding tactical UAVs, especially compared with Europe. The RQ-4A Global Hawk reached the serial production stage in 2003. Despite the “newness” of the system, it has become synonymous with high-endurance UAVs. A single Global Hawk was employed in Operation Iraqi Freedom, but was credited with providing intelligence that led to destruction of 13 air defense missile batteries, 50 surface-to-air missile launchers and 300 tanks. Because of its reliability, Global Hawk was the first UAV to be granted an overarching Certificate of Authorization by the FAA to fly in U.S. air space. This allows Global Hawk to significantly reduce the time notification to the FAA when a flight is required. This is a critical hurdle, not only for Global Hawk but for UAVs in general, particularly if they are to break into the civilian market.

The dominant U.S. manufacturers include:

- Lockheed Martin
- Aurora Flight Sciences
- General Atomics
- Northrop Grumman
- AeroVironment

2.4.3 European and Worldwide UAVs

Europe currently represents the second-largest UAV market. While quite a bit of research has been funded in Europe over the past decade, procurement has been modest and mostly confined to small numbers of tactical UAV systems. For example, France acquired less than two dozen Crecerelle UAVs and Britain's Phoenix tactical UAV program involved only about 100 air vehicles. More ambitious programs are underway, with most of the major armed forces acquiring more modern tactical UAV systems and beginning to acquire endurance systems comparable to the U.S. Air Force Predator. A recent study concluded that Europe will nearly double its share of the world UAV market in 10 years, to about 19% from about 11% of the market due to these many new programs. Britain has a comprehensive program under its Watchkeeper program, with two teams now competing for an eventual procurement phase. France is planning to acquire an upgraded version of the Crecerelle/Sperwer for its tactical UAV requirement, and is also acquiring a version of the Israeli Heron as part of its Eagle endurance UAV program. France is also sponsoring a broad range of other UAV systems from micro- and mini-UAVs through to other novel applications such as naval UAVs. Germany is finally acquiring the Tucan tactical UAV, a derivative of the long-delayed, multinational Brevel program in which France was once a partner. The German army has been a particularly active supporter of mini-UAVs, with the Luna already in service, and several other programs underway. In the endurance field, Germany is also studying the Global Hawk for maritime surveillance under its Eurohawk program. Italy has significantly expanded its UAV efforts, prompted in no small measure by turmoil in the neighboring Balkans in the 1990s. Having already procured Predators for the endurance role, it is finally funding a long-delayed tactical UAV system for the army and beginning to examine other requirements. Sweden has a broad research effort on UAVs, though so far Swedish procurement has been fairly limited. Many of the smaller European armed forces have already fielded a new-generation tactical UAV system, though often in small numbers. The most popular system has proven to be the Sagem Sperwer.

Non-European countries also have a significant UAV role. Israel, which was the pioneer for many of the current tactical UAV efforts, has continued to be a major player in UAV sales to smaller armed forces around the globe. Israel continues to innovate in the UAV field. One of its more intriguing programs is an effort to contract out UAV services. Aeronautics Unmanned Systems has been employing its Aerostar tactical UAV to conduct surveillance missions for the Israeli Defense Forces under a government contract rather than directly selling the systems. One of Israel's most important UAV sales in recent years was to India, as part of a broader effort to involve the latter in joint military technology ties. India is interested in a robust reconnaissance capability in the difficult terrain of Kashmir, and decided to buy some off-the-shelf Israeli UAVs rather than wait for its indigenous programs to mature. Pakistan is employing indigenous UAVs as well as imported Chinese UAVs along the troubled frontier with India. In the Pacific, Japan has an active UAV program, but long-term goals remain sketchy. Japan is planning to develop an analog to Global Hawk, Australia has shown special interest in endurance UAVs due to the sheer scale of its zone of strategic interest. With conditions in Indonesia remaining so unsettled, Australia is considering the Global Hawk as a means to monitor trouble spots along its northern maritime frontier. Australia has already deployed small numbers of UAVs for surveillance and patrol on several of its peace-keeping missions in the southwestern Pacific. China has displayed a variety of UAVs at international trade shows; though there is little evidence to what extent such systems have been deployed in its army.

Non-U.S. UAV manufacturers include:

- Elbit
- Israeli Aircraft Industries, Inc.
- Sagem SA
- European Aeronautic Defense and Space Company
- Dassault Aviation

2.4.4 Role of US export controls

A potentially significant negative influence on the proliferation of UAV's in the market place is export control. For the international market, UAVs are controlled for export from the United States (US) under the International Traffic in Arms Regulations (ITAR) issued by the State Department. Contained within these regulations is the munitions list which defines those items considered by State to require approval and license to export because of the potential for military use. There are several sections of the current ITAR under which UAVs are controlled for export: Section 121.2 and 121.3 because of the command and control electronics as well as any imaging sensor suite as payload. Also prohibited is the export of navigation systems that contain spread spectrum technology or systems that allow navigation above 60,000 feet.

If a US company wants to export UAVs without navigation or sensors, ITAR may prevent export of these as well. UAVs, including drones and reconnaissance drones, with 500kg payload capability and a range of 300 km are covered within the statute.

It appears that under current ITAR definitions, the international market for US UAV manufacturers may be somewhat constrained. Since the European and Asian manufacturers are not covered by ITAR, it may pose an obstacle for foreign sales by US-based companies. Partnering with a foreign manufacturer may not work since the basic technologies to the items covered by ITAR are subject to the law, as well.

3 UAV Mission Requirements

3.1 Mission Summaries

The following sections provide a brief description of the potential missions documented by the authors to date. A complete description of each mission along with platform and communication requirements may be found in Appendix D. Missions have been divided into the categories defined by Figure 1, i.e. Commercial, Earth Science, Homeland Security, and Land Management.

3.1.1 Commercial

No commercial missions have been documented to date although preliminary discussions indicate that a significant number of these exist including precision agriculture. Commercial missions will be included in the next version of this document.

3.1.2 Earth Science

The following missions have been documented primarily through the Suborbital Science Missions of the Future Workshop and personal interviews. Missions involve both *in situ* and remote sensing applications. The unanimous consensus among scientists however, was that UAV missions would augment rather than replace satellite observations. Inclusion in this report does not imply that these missions have been funded or otherwise validated by any government agency.

Repeat Pass Interferometry for Surface Deformation
This mission would allow measurement of the geophysical processes associated with natural hazards such as earthquakes, landslide, and volcanoes as they are manifested by deformations in the Earth's crust. Measurements of the crustal deformation would be made by an interferometric synthetic aperture radar (SAR) carried by the UAV platform.

Cloud and Aerosol Measurements
This suborbital mission would study transformations of aerosols and gases in cloud systems in the following domains:

- Convective systems: to include areas of Costa Rica, Southern Florida, and Central United States
- Sea breeze cloud formation – wide areas of coastal U.S.
- Marine stratiform – primarily the California coastal areas
- Contrails in the Central U.S. in air traffic regions and ship tracks in oceans
- Synoptic scale systems & Fronts – in the Central U.S. region
- Cirrus outflow – large areas of the tropics, Southern Florida, and Central U.S.

Stratospheric Ozone Chemistry

The purpose of this mission is to observe changes in the stratospheric ozone chemistry by the profiling of source gases, water, aerosols, and temperatures in the mid-latitudes and Polar Regions in the upper troposphere/lower stratosphere. In addition to source gases, tracers as well as reservoir species and radicals are to be measured. The mission will make simultaneous measurements of water vapor, total water temperature, pressure, winds, ozone, aerosols, and polar stratospheric clouds (PSC).

Tropospheric Pollution and Air Quality

The objective of this suborbital mission is to study the sources, evolution, and distribution of tropospheric pollutants. The pollutants and particles and their source emissions would be profiled on regional to hemispheric scales from near the surface to the tropopause region. This profiling would cause determination of where plumes of pollution are transported and how they evolve.

Water Vapor and Total Water Measurements

The objective of this mission is to study water vapor and total water in the tropical tropopause layer. The focus will be to profile water from the mid-troposphere to the lower stratosphere and from the tropics into the mid-latitudes. This study will try to determine what controls upper troposphere/lower stratosphere water and how it impacts climate change feedbacks.

Coastal Ocean Observations

This suborbital mission would help scientists understand further coastal bloom compositions and the changes over time and space. In addition, the science data will help scientists quantify the submerged aquatic vegetation and coral reefs, measure an estuarine condition, and evaluate how nutrients are consumed and released into the coastal zone and the impact on the carbon cycle. The science data gathered would reduce the uncertainties in the fluxes and coastal sea dynamics by resolving horizontal and vertical resolution (improved spatial and temporal resolution) and multiple sensor integration.

Active Fire, Emissions, and Plume Assessment

This suborbital mission would help Earth Science scientists further understand the influence of disturbance on carbon cycle dynamics by observing and measuring: the atmospheric chemistry; the thermal intensity time-series; the plume composition, including the volume, albedo, particle size distribution; and, the fuel type and quality. The measurements would also provide the atmospheric composition focus area a better understanding of fire plume chemical constituents resulting from different fuels under different intensities of fire.

O2 and CO2 Flux Measurements

This suborbital mission would help scientists further understand the flux of O_2 and CO_2 and other trace gases between the surface (land and sea) and atmosphere and how it changes with space and time. Diurnal time series measurements of surface to atmosphere gas flux are critical. Specifically the mission must provide science data that contains CO_2 and O_2 measurements, separating out land from ocean fluxes, to less than 0.1 parts per million.

Vegetation Structure, Composition, and Canopy Chemistry
This suborbital mission would help scientists improve the characterization of terrestrial biomass, leaf level chemistry and canopy water content. The science data will provide vegetation 3-dimensional structure and information on composition and chemistry. In addition, the observations will elucidate functional groups and physiological impacts on the carbon cycle.

Aerosol, Cloud, and Precipitation Distribution
This mission is designed to measure the distribution in space and time of aerosols in regions polluted by industrialized areas. The data collected during this mission will improve the evaluation of climate sensitivity to the forcing of aerosols by:

- Quantifying how urban aerosol sources contribute to global aerosol budgets and loading
- Detecting the indirect effect of anthropogenic aerosol on cloud formation and radiative forcing
- Detecting multi-year to decadal trends in direct and indirect aerosol forcing.
- Developing a statistical data base of pollution impacts downstream of pollution sources

Glacier and Ice Sheet Dynamics
This mission supports measurements of the dynamics of the breakup of polar glacier and polar ice sheets. The measurements enable direct observation of the evolution in time of ice and land topography, iceberg volume, glacier profiles, and glacier channel profiles and provide data for validating simulations of these dynamics and their interaction with the ocean environment.

Radiation - Vertical Profiles of Shortwave Atmospheric Heating Rates
This mission will collect data on the vertical profile of shortwave atmospheric heating rates in polluted and unpolluted clear and cloudy skies. Measurements will take place in mega-cities and industrialized regions in different climatological regimes. The data collected will improve the evaluation of climate sensitivity to the forcing of aerosols by:

- Quantifying how urban aerosol sources contribute to global aerosol forcing
- Detecting the indirect effect of anthropogenic aerosol on cloud radiative forcing

Ice Sheet Thickness and Surface Deformation
The purpose of this mission is the accurate measurement of ice sheet thickness and crustal deformation of underlying surfaces due to ice sheet loading and earth internal activities such as earthquakes. These measurements are important for

the study of glaciers and global warming.

Imaging Spectroscopy
The intent of this mission is to collect spectra as images to determine surface composition, change, water vapor and sulfur dioxide in space and time. Specifically, this mission would measure:

- the composition and change at the surface-atmosphere interface
- accurate and precise 3-dimensional water vapor for GPS based derivations
- 3-dimensional SO_2 and other phenomena associated with active volcanology
- earthquake fault optical spectroscopy properties before and after

Topographic Mapping and Topographic Change with LIDAR
The purpose of this mission would be to generate high-resolution topographic mapping and topographic change-detection of targeted ground areas (including those covered by vegetation) using LIDAR measurements. All-terrain topographic change detection by repeat mapping compliments interferometric SAR measurements of sub-centimeter to decimeter surface levels (e.g., observe decimeter to tens of meter near-field surface deformation in the vicinity of ruptured faults and inflating volcanoes to understand earthquake and magmatic processes; observe decimeter to hundreds of meters topographic change associated with landslides, volcanic eruptions and flows, coastal and fluvial erosion and sediment redistribution). Targets of highest priority are narrow, long, quasi-linear features (e.g. fault zones, coastal zones) amenable to targeted mapping or point features (e.g. volcanoes) amenable to station-keeping monitoring.

Gravitational Acceleration Measurements
This mission would accurately measure gravitational acceleration that varies spatially and temporally near Earth, as a consequence of the inhomogeneity and the dynamics of Earth's mass density structure. This spatial variation occurs at all scales, from thousands of kilometers, due to core/mantle boundary anomalies, to sub-kilometer and smaller, due to local topographic (or bathymetric) masses. Earth's gravitational field defines satellite orbits, affects inertial navigation, reflects oil and mineral deposits, and characterizes crustal geologic structure. The equipotential surface, known as the geoid, defines a reference for sea surface topography (leading to oceanographic current determination through satellite ocean altimetry), and it defines the conventional reference of heights for national vertical geodetic control.

Antarctic Exploration Surveyor
This mission would provide coordinated magnetometer, gravity, and LIDAR measurements from a small, easily deployed autonomous low-cost aircraft platform. These measurements would allow basic mapping to determine ice

sheet bed characteristics and ice sheet elevation. This data would allow scientists to examine the geologic controls on ice sheet dynamics.

Magnetic Fields Measurements
The purpose of this mission would be to measure vector and tensor magnetic fields to support comprehensive magnetic field source models and isolate time-varying crustal field components. The magnetic field spectrum is under-sampled in the spatial wavelengths intermediate between the near-surface (up to 1.1 nm (2 km)) and satellite altitude (190 nm to 380 nm) (350 to 700 km). These measurements are critical to producing models that account for all sources of magnetic fields from crust to core.

Cloud Properties
This mission is designed to collect *in situ* data on cloud microphysics. The data will allow better understanding of cloud dynamics and lead to improved weather and climate models. Weather, climate, and atmospheric composition focus areas will also benefit from the data collected in this mission.

River Discharge
This mission will collect data on the volume of water flowing in a river at multiple points. The data is critical for global and regional water balance studies. Other beneficiaries of this data include USGS, EPA, coastal zone studies, and floodplain mapping efforts.

Snow – Liquid Water Equivalents
This mission was conceived to measure the amount of water stored in the snowpack at very high spatial resolution (≈ 165 ft (50m)). Also, snowpack characteristics such as depth, density, wetness, age, emissivity, albedo, etc will be measured. Measuring the snow characteristics has significant application for decision makers and is important for water budget. It would allow for improvements in snow prediction as well as understanding the climate data record.

Soil Moisture and Freeze/Thaw States
This mission was envisioned for measuring surface soil moisture, deep soil moisture, and the freeze or thaw state of surface soil in the presence of vegetation. Benefits include improved water budgets and better modeling of the carbon cycle.

Cloud Microphysics/Properties
The purpose of this mission is to observe the microphysics and properties of clouds. Specifically this entails measurements of:

- Turbulence, vertical velocity
- Particle size distributions, habit, phases
- Liquid/ice contents
- Highly-accurate thermodynamic information

- Electrical and radiation characteristics

These data would provide better understanding of tropical rainfall and energy release, rain particle growth, and stratospheric water exchange enabling the improvement of satellite algorithms.

Focused Observations – Extreme Weather
The purpose of this mission would be to accomplish process studies involving severe and hazardous weather events to improve the physics in mesoscale models (parameterizations). This approach would use high altitude remote sensing to gather data on precipitation, clouds, electrical phenomenon, and microphysics. These data would improve models used to predict winter storm hazards and provide accurate regional forecasting of rain and snow for economic decisions.

Forecast Initialization
The intent of this mission is to gather data that will improve weather forecasting and augment data available from satellites. This includes both a research element such as determining data sensitive regions (e.g. THORPEX, atmospheric rivers) and an operational element (e.g. NOAA/NCEP winter storms program). Missions would include observations would be made for short term (24 hour) initialization where observable events were already formed, and longer term (3 to 7 days). Additional benefits would include satellite validation (e.g. GPM and GIFTS) and the improved use of satellites for forecasting. Missions would be event oriented with the Eastern Pacific, Northern Atlantic, and Arctic/Antarctic as probable target areas.

Hurricane Genesis, Evolution, and Landfall
The purpose of this mission would be to accomplish observations of hurricanes to improve predictions of hurricane paths and landfall. This approach would use high altitude remote sensing to gather data on precipitation, clouds, electrical phenomenon, microphysics, and dust. Daughter ships or drop-sondes would gather data (four-dimensional cubes of thermodynamic variables and winds) at lower altitudes. Additional data would be gathered in the boundary layer (sea surface temperature and surface winds, surface imaging, turbulent fluxes, water surface state). Measurements of this type would improve hurricane modeling capability to increase human safety.

Physical Oceanography, Meteorology, and Atmospheric Chemistry
During seasonal storms in the North Pacific, North Atlantic, and the Southern Ocean small scale but relatively intense exchanges of mass and energy occur between the ocean surface and the lower atmosphere. This mission would allow scientists to study these exchanges in turbulent, high energy density environments in or near storm systems and will help them understand their broader implications for larger scale phenomena such as:

- Understanding break-up or development of the thermocline and surface mixed layer during high winds

- Understanding transition between disorganized and coherent wave patterns that transit whole ocean basins
- Understanding vertical transport of oceanic aerosols to the marine boundary layer inversion where they participate in the Earth's radiation balance by acting as cloud condensation nuclei
- Understanding the transport of oceanic gases to the free troposphere and stratosphere where they are photo-oxidized and participate in gas-particle conversion and atmospheric processes involving heterogeneous chemistry

3.1.3 Homeland Security

The following mission has been documented from a personal interview. Inclusion in this report does not imply that this mission has been funded or otherwise validated by any government agency.

Coastal Patrol
This is a U.S. Coast Guard mission. It is a surveillance mission of maritime traffic off the shores of the USA (east & west coast, Alaska & Hawaii). Flights would launch and recover from one to three locations within 100 miles (213 km) of the coast for each of the four regions listed above. Missions would traverse our coastal waters 50 to 500 miles (106.5 to 1065 km) off shore.

3.1.4 Land Management

The following missions have been documented from personal interviews. Inclusion in this report does not imply that these missions have been funded or otherwise validated by any government agency.

Forest Fire Damage Assessment
This mission determines the level of damage to an area following a fire. Areas of flight would be in remote areas and occasionally near and slightly into urban/moderately populated areas.

Forest Fire Mapping
This mission determines the location of active fires in support of fire fighting agencies. These fires may include the major fire front as well as hotspots behind the fire front with flames as small as 6 inches (15 cm) high.

Forest Fire Communications
This mission provides a communications relay between the field command center and personnel in the field fighting the fire. Fire fighting typically takes place in rugged terrain, which at times renders standard line-of-sight communication inoperative.

Forest Fire Retardant Application

In recent years the US has seen the advent of Mega-Fires. The appearance of these Mega-Fires has been driven by gradual increases in consumable fuels and the continued encroachment of civilization on our wilderness areas. These Mega-Fires overwhelm our current fire fighting abilities. If loss of life and property is to be prevented in the case of these Mega-Fires, there exists the need to dramatically increase our capacity to apply firefighting resources. Helicopters and large fixed wing vehicles currently conduct the airborne portion of this mission. The mission requirement is to increase the rate of retardant application on a given fire.

Wild Life Census
The mission is to conduct aerial surveys of wildlife species of interest to estimate population size, composition, distribution, and status. In Idaho, logistical constraints such as a limited number of helicopters and biologists, and funding result in a 3-year survey rotation (an area of interest is surveyed once every 3 years). The western states rely on helicopters (and to a lesser extent, fixed-wing aircraft) to conduct such surveys.

Animal Tracking
Many thousands of animals are monitored through radio transmitters. They are monitored periodically (e.g. weekly) throughout the year – often from a fixed-wing aircraft. Collection of data includes such things as the location of the animal, topography and vegetation at the location.

Invasive Plant Assessment
This mission supports the forestry department's assessment of non-indigenous plant species invasion into wilderness areas.

3.2 Existing Mission Capabilities

A comprehensive analysis of existing mission capabilities will be provided in the next update.

3.3 Requisite Capabilities and Technologies

Table II shows which capabilities and technologies are required for each of the missions identified in Section 3.1. The left side of the table lists the missions defined in Section 3.1. The capabilities and technologies (further defined in Section 4.2 are shown along the top of the table. Use of a technology by a given mission is shown by an "X". Technologies and capabilities which are related to DOD development efforts will be designated in the next version.

		Capabilities															Technologies					
		1 Access to the airspace	2 Command/control from outside entity	3 Long Range/Endurance	4 Formation flight	5 Monitor/control multi-ship operation	6 High Altitude	7 Increased Platform Availability	8 Terrain Avoidance	9 Vertical Profiling	10 Deploy / potentially retrieve	11 Quick deployment	12 Precision aircraft state data	13 Precision trajectories	14 All Weather	15 Base of operations in remote area	1 Autonomous mission management	2 Sophisticated contingency management	3 Collision Avoidance	4 Intelligent system health monitoring	5 Reliable flight systems	6 Over-the-Horizon Communication
1	Repeat Pass Interferometry for Surface Deformation	X					X	X				X		X			X	X	X	X	X	X
2	Cloud and Aerosol Measurements	X	X	X	X	X			X	X					X		X	X	X	X	X	X
3	Stratospheric Ozone Chemistry	X	X	X	X		X	X									X	X	X	X	X	X
4	Tropospheric Pollution and Air Quality	X	X	X	X	X	X	X		X		X					X	X	X	X	X	X
5	Water Vapor and Total Water Measurements	X	X	X		X	X	X		X			X				X	X	X	X	X	X
6	Coastal Ocean Observations	X	X	X	X												X	X	X	X	X	X
7	Active Fire, Emissions, and Plume Assessment	X	X	X	X	X					X				X		X	X	X	X	X	X
8	O2 and CO2 Flux Measurements	X	X	X		X			X	X							X	X	X	X	X	X
9	Vegetation Structure, Composition, and Canopy Chemistry	X		X	X	X							X				X	X	X	X	X	X
10	Aerosol, Cloud, and Precipitation Distribution	X	X	X		X	X	X		X			X				X	X	X	X	X	X
11	Glacier and Ice Sheet Dynamics	X	X	X				X			X	X					X	X	X	X	X	X
12	Radiation - Vertical Profiles of Shortwave Atmospheric Heating Rates	X	X		X	X	X	X	X	X	X						X	X	X	X	X	X
13	Ice Sheet Thickness and Surface Deformation	X	X		X	X			X								X	X	X	X	X	X
14	Imaging Spectroscopy	X		X			X					X					X	X	X	X	X	X

Table II. Mission-Technology Allocation

		Capabilities															Technologies					
		1 Access to the airspace	2 Command/control from outside entity	3 Long Range/Endurance	4 Formation flight	5 Monitor/control multi-ship operation	6 High Altitude	7 Increased Platform Availability	8 Terrain Avoidance	9 Vertical Profiling	10 Deploy / potentially retrieve	11 Quick deployment	12 Precision aircraft state data	13 Precision trajectories	14 All Weather	15 Base of operations in remote area	1 Autonomous mission management	2 Sophisticated contingency management	3 Collision Avoidance	4 Intelligent system health monitoring	5 Reliable flight systems	6 Over-the-Horizon Communication
15	Topographic Mapping and Topographic Change with LIDAR	X	X				X						X	X			X	X	X	X	X	X
16	Gravitational Acceleration Measurements												X	X								
17	Antarctic Exploration Surveyor			X				X	X							X						X
18	Magnetic Fields Measurements		X		X	X	X						X									X
19	Cloud Properties	X	X	X	X	X	X			X	X	X	X				X	X	X	X	X	X
20	River Discharge	X	X		X								X	X			X	X	X	X	X	X
21	Snow – Liquid Water Equivalents	X	X	X				X	X		X			X			X	X	X	X	X	X
22	Soil Moisture and Freeze/Thaw States	X	X	X				X		X			X	X			X	X	X	X	X	X
23	Cloud Microphysics/Properties	X	X		X		X	X		X	X	X			X		X	X	X	X	X	
24	Focused Observations – Extreme Weather	X	X	X			X				X						X	X	X	X	X	X
25	Forecast Initialization	X	X	X	X	X	X		X		X	X			X		X	X	X	X	X	X
26	Hurricane Genesis, Evolution, and Landfall	X	X	X	X	X	X		X		X	X			X		X	X	X	X	X	X
27	Coastal Patrol	X	X	X	X	X	X			X	X				X		X	X	X	X	X	X
28	Forest Fire Damage Assessment	X	X	X	X	X	X										X	X	X	X	X	X

Table II (cont.). Mission-Technology Allocation

		Capabilities															Technologies					
		Access to the airspace	Command/control from outside entity	Long Range/Endurance	Formation flight	Monitor/control multi-ship operation	High Altitude	Increased Platform Availability	Terrain Avoidance	Vertical Profiling	Deploy / potentially retrieve	Quick deployment	Precision aircraft state data	Precision trajectories	All Weather	Base of operations in remote area	Autonomous mission management	Sophisticated contingency management	Collision Avoidance	Intelligent system health monitoring	Reliable flight systems	Over-the-Horizon Communication
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6
29	Forest Fire Mapping	X	X	X			X	X				X					X	X	X	X	X	X
30	Physical Oceanography, Meteorology, and Atmospheric Chemistry	X	X	X		X		X	X	X	X				X	X	X	X	X	X	X	
31	Forest Fire Communications	X	X		X	X		X	X			X				X	X	X	X	X	X	
32	Forest Fire Retardant Application	X	X		X	X		X	X	X		X		X			X	X	X	X	X	X
33	Wild Life Census		X	X					X													X
34	Animal Tracking			X																		X
35	Invasive Plant Assessment		X	X					X													X

Table II (cont.). Mission-Technology Allocation

4 UAV Status Assessment

A review of the missions listed in Section 3.1 (and described in detail in Appendix D) suggests a number of technologies and capabilities required for the accomplishment of those missions. Section 4.1 discusses top-level considerations for the success of UAV applications. These tend to have wide applicability to all UAVs. Specific technologies required for missions are described in Section 4.2. Technologies are listed in the order of use by the most missions, i.e. technologies required most frequently are listed first. Section 3.3 provides an allocation of technologies and capabilities to the various missions. The next edition of this report will improve the assessment of technology status and highlight technology gaps and the missions that are impacted.

Many of the general and specific capabilities have been captured in NASA's UAV Sector "GOTChA" chart. Developed by the UAV Sector of NASA's Aeronautics Research Directorate, the GOTChA chart is a hierarchical breakdown of Goals, Objectives, Technical Challenges, and Approaches desirable for improving the state-of-the-art for UAVs. In many of the following sections, a reference is made to the GOTChA chart where warranted. The UAV Sector GOTChA chart is shown in Appendix E.

4.1 UAV Economics

One of the common desires from potential UAV users is the desire to reduce costs for UAV use. One user commented that if the flight cost were to reduce to $400 per hour that Agency would be ready to drop its piloted flight operations and change to UAVs. It is noteworthy that this desire lines up precisely with Goal 6 of the GOTChA chart. However, cost-per-hour quotes for UAV use are often misleading in that they address only the recurring costs of actually flying the vehicle. Non-recurring costs must also be considered. For a recent mission conducted from NASA Dryden Flight Research Center, the total mission cost per flight hour was computed to be on the order of $12,500. The following sections will discuss some of the non-recurring and recurring costs associated with UAV flights and some steps that could be taken to reduce them. These discussions do not include the price of additional technology that might need to be developed to accomplish the mission. A more complete discussion of costs can be found in "Cost and Business Model Analysis for Civilian UAV Missions – Final Report", Basil Papadales, June 8 2004.

4.1.1 Non-Recurring Costs

Payload Integration – The largest non-recurring cost is often the cost of integrating the payload onto the aircraft. Depending on the payload involved, this may require aircraft modifications which can be quite expensive. One of the ways to decrease these costs is to develop, document, and implement payload interface standards to support a “plug and play” concept. NASA’s Earth Science Capability Project has accepted the task to accomplish this. The first set of documented standards is expected to be published around the end of fiscal year 2005.

Vehicle Transport – For many missions, the UAV must be transported from its home base to the area of interest. Depending on the UAV and access to airspace, this may be accomplished by flying the UAV there or by ground shipment. In either case, the cost of transportation must be included in the mission cost.

Support Team Travel – Some UAV missions require a deployment to a specific area of interest. When this occurs, there is a team of support personnel that must accompany the UAV. This usually includes technicians for UAV setup, operation and maintenance, ground operators, payload specialists, and users interested in mission results. The travel costs for these personnel must be included in mission costs. One of the ways to decrease these costs is to make UAVs more operable. Operability refers to the ease with which the UAV can accomplish its mission. One of the large factors in this area is the ability to fly “where you want, when you want”. Access to the NAS on a “file and fly” basis will be a key factor in providing operability. Another factor that determines a UAV’s operability is the ability to quickly deploy and launch. This means that the UAV must be rapidly tailored for a given mission by installing the appropriate payload, transporting the UAV to the test site, and developing the flight plan. Payloads must have the capability to be integrated quickly using standard interfaces and protocols. Finally, the UAV must remain ready during the course of the mission which may include multiple flights over a period of time. This necessitates minimal pre-flight and post-flight procedures and high system reliability. Ground systems to support flight plan development must be intuitive and rely heavily on automation. Large groups of required support personnel are not conducive to operability or affordability. Objective 8 of the GOTChA chart addresses the desired reduction in required human support.

Aircraft Acquisition – For most users it does not make economic sense to acquire an aircraft to accomplish their mission. UAV services would typically be purchased from a UAV operator or owner. The exception to this statement may be an organization that has a constantly recurring mission (e.g. Coast Guard patrol).

4.1.2 Recurring Costs

Recurring costs are those that are proportional to the number of hours the UAV actually flies. Some of these are included in quoted “cost per hour” figures.

Direct Costs – During the actual flight hours of the UAV, some consumables will be expended; these usually include fuel and oil. The cost of routine maintenance is often included in this category since it is often based on a number of operation hours. The cost of ground operators or other support is also part of this category. Increased on-board intelligence such that less ground support is required will help to lower direct costs.

Insurance - Another significant cost in the operation of current UAVs is the cost of insurance. Insurance costs are driven by the amount of risk assumed by the insurer and the number of clients underwriting that risk. Insurance costs will be reduced by increasing the safety and reliability of UAVs (see Section 4.1.3) and increasing the number of UAV operators. As the cost of UAV operations decreases, the number of UAV operators will increase.

Communication Support – The cost of communication must be included for each hour of operation (usually with some margin to account for uncertainty in flight times). The cost will vary greatly with the bandwidth required to support a mission. Communication costs can be reduced substantially by limiting the bandwidth for UAV/Payload to command, control, and health status. In this case, wideband data would need to be stored on-board.

Data Analysis – The cost of data analysis is another cost which is proportional to the number of hours flown.

4.1.3 Reducing Costs

One obstacle that is present in all forecasts is the cost factor (development, acquisition, and operation), especially in the civil market. The general perception of the user community at this time is that UAVs are expensive to use. This perception is especially justified for larger UAVs which are in limited production (which means high cost to procure) and require significant personnel to setup and operate (which means high cost per hour). The mitigation of this obstacle can most easily be accomplished by removing the technical and regulatory barriers to UAV flight. This means that NASA must endeavor to develop technologies from the low technology readiness levels (TRLs, see Appendix F) to ones that can be readily developed in the commercial sense; then cost will become a lesser impact to market development. It also means developing technology and policies that facilitate flight in the National Air Space (NAS). Two technology models that can be used as examples are the commercialization of the Global Positioning System (GPS) and the Earth Observing System (EOS). The GPS industry has grown to the point that receivers and systems have become a part of the infrastructure. Users range from all levels of government to all levels of consumer markets. The EOS segment is not as mature as the GPS industry, but the signs of growth are there including new companies such as Orbimage and Digital Globe, courses in schools teaching remote sensing, clips on news casts taken from remote sensor assets, etc. The civil UAV may foster a similar role in future economic development.

Safety and reliability will also play a major role in reducing the cost of UAV missions. Safety in this context applies to both the safety of the general public and the safety of the platform itself. An onset of UAV mishaps involving the public would result in increased regulation for UAVs and increased costs, locking out some suppliers and users. However, even the loss of UAVs in unpopulated areas can be expensive to the users. In addition to the loss of the vehicle itself, the user would lose the payload/sensor. In some cases, these payloads are one-of-a-kind devices costing millions of dollars, and their loss is difficult to tolerate. One of the topics in early discussions with the Federal Aviation Administration (FAA) was the requirement that the UAV "be just as reliable as a piloted aircraft". This implies both system reliability (minimization of component failures) and onboard intelligence which is capable of making decisions similar to a pilot. Autonomous mission management (Section 4.3.1), sophisticated mission management (Section 4.3.2), collision avoidance (Section 4.3.3), intelligent system health monitoring (Section 4.3.4), and reliable flight systems (Section 4.3.5) will provide major improvements in this area.

The cost of the military UAV is orders of magnitude greater than the level where civil use would make economic sense. For example, a Predator B, without any payload or sensor suite, costs greater than $5M per copy, not including the support personnel or command and control systems. Without the need for technologies required for military UAVs such as stealth, weaponry, military hardening, etc., the economics of civil use UAVs can be reduced dramatically. As new technologies are developed for the airframe, sensors, propulsion, etc., these price points will be further reduced over time. Innovation, competition, and economies of scale in production will also reduce acquisition costs. For civil use to make a sensible business case, these costs would need to be in the tens of thousands, not millions of dollars. The operating costs along with the acquisition costs will determine the success for civil applications.

4.2 Capabilities

The following sections discuss the specific technologies and capabilities required to accomplish the missions listed in Section 2. For each technology or capability, a description of the technology will be provided followed by a status of that technology. Future editions of this report will provide a better and more current update of these statuses. Within the title of each section, a first-cut estimate of the need of that technology is given. If the technology/capability supported at least half of the missions, it received a "High" rating. If it supported at least 25% of the missions, it earned a "Medium" rating. The remainder (those supporting less than 25%) were rated "Low". Scheduled milestones for various existing UAV projects are shown in Section 4.4.

4.2.1 Access to the National and International Air Space

Need: High

Virtually all of the missions discussed will require access to either the United States national air space and/or foreign air space at some point in the flight pattern. Even missions intended for remote areas require access to get the aircraft to the area. Often, this will require access not only to United States air space, but foreign air space as well. Access to the National Air Space can only be obtained through certification of the aircraft or through a waiver termed a Certificate of Authorization (COA). There currently exists no method to certify a UAV through the FAA. Therefore, all UAV flight within the NAS has been obtained through certificates of authorization thus far. A certificate of authorization takes up to sixty days to obtain and only permits execution of a predefined mission flight path on specific dates at specific times and is typically valid for a very limited time period. Many of the missions require fast access to the air space; it is not sufficient to obtain a certificate of authorization because many of the missions intend to study phenomena which are not predictable sixty days in advance. The goal is to achieve seamless integration into the NAS (the so-called “file-and-fly” status) through certification which means that the flight may begin shortly after the flight plan is filed. This is the same system used for piloted aircraft. An FAA certification process must be established to achieve this. Several attributes of the UAV will likely be required to be granted certification. One of these is a method for the UAV to safely integrate into the air traffic system. This will require the UAV operator to respond in a timely fashion to commands from air traffic control. Typically changes to course, altitude, speed, etc. are required to avoid other air traffic. Another likely system is called contingency management which allows the vehicle to plan for an alternate course of action if something goes wrong requiring it to deviate from its original flight plan. Inherent in contingency management is a vehicle health management system which is capable of detecting anomalous conditions or situations. A third attribute is a collision avoidance system which allows the UAV to detect other aircraft and maneuver around them. In summary, the UAV must achieve the equivalent level of safety as a manned aircraft. A significant effort in systems sophistication, aircraft reliability, and policy/regulation development will be required to accomplish this. The technologies discussed in Sections 4.3.1 through 4.3.5 are large contributors to this effort.

Current UAVs cannot fly in the air space in the manner described here. Developing the ability to provide “file-and-fly” is the goal of NASA’s HALE ROA Access to the NAS project (often called Access 5). This project is to be accomplished in four steps.

1) Develop and recommend policy to the FAA for routine UAV flight above 40000 feet assuming launch and recovery in controlled air space.
2) Develop and recommend policy to the FAA for routine UAV flight above 18000 feet assuming launch and recovery in controlled air space.
3) Develop and recommend policy to the FAA for launch and recovery in designated ROA-capable airfields.
4) Develop the technology (if necessary) for sophisticated contingency management handling.

Steps 3 and 4 are currently unfunded. The Access 5 approach towards achieving these goals is a seamless integration of UAVs into the air space with little to no additional requirements being placed on existing piloted aircraft. Before UAVs have file-and-fly capabilities, two other steps are necessary. Once the policy has been developed and recommended, it will still require FAA implementation. Finally, UAVs will likely need the on-board technology to satisfy the policies adopted by the FAA. The schedule for Access 5 is shown in Section 4.4. Sections 4.3.1 through 4.3.5 discuss supporting technologies required to achieve this capability. The overall intent for routine operations in the NAS is Objective 6 of the GOTChA chart. Much of the technology required to provide this capability is discussed in other sections describing individual technologies, but integrating them into the airframe is not a trivial task. Access 5 only addresses United States air space. Clearance to fly in the air space of other countries is being addressed but is probably a little behind Access 5 pace. Currently, some areas (notably Africa and Australia) are UAV friendly. The ability to fly UAVs in other areas of the world is more limited.

4.2.2 Command and control from an outside entity

Need: High

Typical UAV operations utilize a mission manager programmed during pre-flight to steer the vehicle around a prescribed course and altitude. Some mission managers will allow the operator to define new waypoints in flight. Future mission concepts require an ability for the aircraft's mission manager to be directed during its mission from a number of sources, including a ground-based operator or scientist observer, other aircraft (e.g. formation flying), a payload sensor, or satellites. This ability to re-direct a flight is instrumental for tracking dynamic phenomena such as hurricanes or volcanic plume, for adjusting to unplanned phenomena of interest, and for steering around unplanned obstacles, such as adverse weather, to meet a mission objective. An enabling technology to meet this capability is OTH communication, where a 'sensor web' approach to the mission can easily be achieved. One consideration is that allowing other entities to take control of the vehicle provides a mechanism that hostile entities (e.g. terrorists, hackers) can take advantage of. The system which develops must preclude takeover by any hostile operations.

Currently some limited command and control authority can be exerted from a ground-based operator on some UAVs. However, the technology required for future missions has much broader implications on command and control in terms of the level of autonomy it interfaces with and the infrastructure that is implied. One example is in the scenario where the payload sensor 'drives' the platform. This technology is currently planned under NASA's AuRA project, but it is only in its formulation stage. This capability supports Approach 11 of the GOTChA chart.

4.2.3 Long Range and Endurance

Need: High

Many of the missions conceive of a platform, or series of platforms, which clearly extend range and endurance beyond the capability of existing vehicles. These missions require ranges of 10,000 to 13,000 nautical miles (18500 to 24000 km) and endurances between 24 to 72 hours. A few of the missions indicated that endurances up to two to three weeks would be beneficial, if feasible. In particular the long-endurance requirements of these missions, as conceived, highlight the necessity for a UAV platform.

Some existing production UAVs are capable of endurance in the 24 to 36 hour time frame. A few, notably Northrop-Grumman's Global Hawk, have significant range capability. NASA, in conjunction with several private companies, is working on the technologies to enhance this capability. Under the HALE ROA project, NASA is developing several new aircraft with long endurance (one to two weeks) capability. The largest advances in technologies for these aircraft will come in the propulsion and power generation areas. Improvements in both of these areas are Goals 3 and 4 of the GOTChA chart. Long range also supports Goals 1 and 2.

4.2.4 Formation flight

Need: High

A technology related to precision trajectories is the ability to fly a formation of aircraft maintaining precise distances between them. Formation flight provides the ability to carry a synchronized set of scientific sensors on a team of coordinated vehicles. In a flight formation, one entity would be the "lead"; all other aircraft would fly relative to the lead. The lead could be another UAV, a piloted aircraft, or even a satellite. While it is not expected that an aircraft would keep pace with a satellite, the ability to position the aircraft relative to the satellite is desirable. Formation flight can be thought as two separate capabilities. The first is a series of aircraft which might be hundreds of meters to several miles apart. In this case, precision is desirable, but sensors would need to work over large distances. The second capability is close maneuvering wherein a pair of aircraft would fly relative to each other in close proximity. This capability would be used to accomplish air refueling as well as a small aircraft "docking" to a larger one. Proximity sensors for this requirement would probably be different from large-distance formation navigation and would require accuracies down to the several-centimeter level.

Most UAV operations involve one aircraft on a single mission. Objective 8 from the GOTChA chart calls for a significant reduction of human operators necessary to control a group of UAVs leading to a reduction in cost per flight hour. The closest system to the "distant" formation is DOD's station keeping equipment, but accuracies for this capability are far less than what is desired for precision formation flight. Some components of the close formation technology have been successfully flight tested in NASA's Autonomous Formation Flight program and in the J-UCAS program. These technologies can be leveraged to meet the future science mission capability for formation flight.

4.2.5 Monitor/control of multi-ship operations

Need: High

Many of the future mission concepts require ground (operator) control of multi-ship operation and coordination. A key enabling technology which supports multi-ship missions is the over-the-horizon communication (see Section 4.3.6). Since a key motivation for using UAVs as an earth science platform is reduced cost per flight hour, the ability of one operator to monitor multiple vehicles significantly reduces the support personnel required on-station. Also, some of the missions describe coordination with mini- or micro- air vehicles.

Currently UAV operations involve one aircraft on a single mission. The concept for future missions, where one operator controls a team of coordinated vehicles, is just beginning to be developed with MAVs and J-UCAS. Part of the J-UCAS program is to develop the capability of four or more UAVs to operate as a coordinated team. This effort supports Objective 8 of the GOTChA chart.

4.2.6 High Altitude

Need: High

Many of the missions require a platform, or series of platforms capable of sustained flight at altitudes above 40,000 feet (12 km), with up to 100,000 feet (30 km) being desirable for some missions. A complicating factor in required aircraft design is performance for an aircraft which climbs to an altitude and cruises there versus an aircraft that must traverse wide altitude bands. The latter capability is called vertical profiling and is discussed in Section 4.2.9. An aircraft that will accomplish both high altitude and vertical profiling is decidedly more complex.

Although an important capability, the ER-2 and Global Hawk have routinely flown at most of the altitudes outlined in the future science missions. Therefore, the ability to fly at relatively high altitudes is an existing capability that only needs to be defined as a requirement in the aircraft development. One caveat is that some missions desired flight in the region of 100,000 ft (30 km) altitude. The Helios aircraft has flown in that altitude region, but it is considered to be a prototype and has limited payload capability. The inclusion of the 100,000 ft (30 km) requirement with a significant payload presents an added level of difficulty. High altitude technology supports Goals 1 and 2 of the GOTChA chart.

4.2.7 Increased Platform Availability

Need: Medium

A key development for enabling future missions will be to increase the availability of the science platform for collecting data. In other words, future missions will require that the ratio between the amount of time the platform is either on a mission or ready to start a mission to the total time the platform is on deployment be increased. One key component in increasing availability is the ability to significantly reduce the amount of time to pre-flight and launch a mission. This not only increases the availability of the platform for data collection, but also increases the likelihood of being able turn a mission around to collect data on dynamic events as they are discovered. Electrical and power interfaces will have to be standardized. The ability to integrate varied payloads in a 'plug and play' capability is necessary for quick deployments and for quick a turn-around between missions where a sensor package may change. Intuitive flight planning tools and pre-flight processes and an efficient process for downloading and archiving on-board recorded data will also be key factors in reducing the time on the ground. And platforms must allow maintenance and pre-flight procedures to be performed easily and efficiently. Another key component to increasing availability is increased platform endurance, which allows the capability to extend mission duration. An added benefit to increasing availability is a lower cost per flight hour, as the personnel required to be on station are reduced.

Current technology assessments indicate limitations on availability are based on human endurance, turn–around processes, payload, aircraft and payload maintenance processes, and data downloading and archiving procedures. Taking the on-board pilot 'out-of-the-loop' and smart integration of these processes with intelligent vehicle health management technology, autonomous mission management technology, and the OTH web-based approach to communication will allow much greater aircraft availability. For example the ability of the flight planner to interface with the mission manager at the mission objective level will reduce the level of human involvement in pre-flight processes. Another example is the ability of the platform management system to identify when excess bandwidth exists in the OTH and then to download and archive on-board recorded data during the mission. This will reduce the level of human interaction in performing this function post-flight. NASA's Earth Sciences Capability Demonstration project is working on payload interface standards to facilitate the "plug-and-play" concept for payload integration. Much of this type of interface has not been done before and depends heavily on other technologies such as autonomous mission management. These capabilities support Goal 6 of the GOTChA chart.

4.2.8 Terrain Avoidance

Need: Medium

To increase the spatial resolution for some missions, a requirement is placed on the platform to fly 500 feet (152 m) above ground level or even lower. The missions envision the use of both MAVs and UAVs in this capacity and may include flight in mountainous terrain. As such, complex flight path maneuvering and terrain avoidance is required of the platform's flight management system.

The technology for terrain avoidance and terrain following has existed for several years on military vehicles. Commercial airliners have employed an Enhanced Ground Proximity Warning System for many years. While the technology is available to implement this capability, the integration to the platform requirements still exists. This capability is included in Approach 10 of the GOTChA chart.

4.2.9 Vertical Profiling

Need: Medium

Some of the missions depict the collection of spatial data in the vertical axis above a particular ground station of interest. Although drop-sondes can be used for a limited set of vertical spatial measurements, some of the missions envision the entire platform performing vertical profile maneuvers to collect the data. As such, the platform must deploy to a region of interest and collect data across a vertical profile from its altitude ceiling down to 1000 feet above ground level. This implies that the aircraft has sufficient performance and power to maintain a reasonable climb rate over the majority of its envelope which will impact the trade study for efficient climb versus efficient cruise.

Designing a flight management system to perform vertical profiling requires no new technology. Many current UAVs are capable of vertical profiling. However, the combination of vertical profiling and high altitude, long endurance may tax the aircraft designers.

4.2.10 Deploy / potentially retrieve

Need: Medium

One of the capabilities required for several of the missions is to have a UAV act as a mother ship for the deployment of drop-sondes, buoys, or small UAVs called daughter ships. In the case of the drop-sondes or buoys, the mother ship would release these at designated locations (pre-defined or initiated from the ground). The dispensing of drop-sondes or buoys is relatively simple but suffers from several drawbacks. First, the drop-sondes or buoys are not controllable; they are maneuvered only by the wind and gravity. Second, a long mission may require a large stock of drop-sondes or buoys to adequately cover the area of interest. This may have some significant consequences on mother ship payload weight and volume. Third, there are some environmental concerns about "littering" areas with many drop-sondes or buoys which may not be recoverable. An alternative to this approach is the use of daughter ships which would be launched, fly to an area to collect data, and then would fly back to the mother ship and re-dock. Daughter ship data would be downloaded to the mother ship and the daughter ship would be refueled for later use. This has the advantage that the daughter ships would be re-usable, so the mother ship would not need to carry nearly as many of them. The daughter ships would also be under the control of the mother ship so that precise areas for information gathering could be targeted. Daughter ships would be more complex and, consequently, more expensive, but their ability to be recovered and used again may offset the increased cost of purchase.

Deploying aircraft or drop-sondes from a mother ship has been done previously and does not require new technology developments. However, retrieving a daughter ship does require some technology development, principally in the area of precision state data and formation flying. Also, very little experience has been accumulated with the concept of re-docking. Lockheed-Martin has made some proposals involving launching and re-capture of UAVs. The common feeling is that if the technology exists to autonomously refuel a UAV, that same technology can be used to re-dock it. The concept of re-docking to a high altitude, long endurance aircraft is also without precedent.

4.2.11 Quick deployment times

Need: Medium

Several of the missions envisioned a UAV which could deploy within a few days to an area of interest and launch a mission to collect data on a dynamic phenomenon as it developed. The capability to quickly deploy ties together many of the other capabilities previously defined. Key enabling technologies are access to the NAS, quick and efficient payload integration, an OTH network available when needed, and an intelligent mission management system which reduces pre-flight planning activity.

This capability is strongly linked with platform availability. Currently, quick and easy access to the NAS is not available but is being developed by NASA and the FAA. Payload interface standards have been developed to some degree and will be improved by NASA's Earth Science Capability Demonstration project. OTH capability will also be improved by the same project. The intelligent mission management capability will be developed by NASA's AuRA project. These efforts support Objective 8 of the GOTChA Chart. However, the integration of these technologies into a cohesive system has not begun.

4.2.12 Precision aircraft state data

Need: Medium

Several missions required the ability to measure attitude data to relatively high precision (as high as 0.001 degrees). There is an additional requirement, however, for the aircraft to provide state data to the sensors or experiment packages. The state data might be in the form of aircraft attitudes, position, ground speed, air speed, etc. While it is possible that each individual experiment packages might measure their own data, this approach would be cumbersome, expensive, and inconsistent with the plug-and-play philosophy. Provisions should be made for the UAV to accurately measure its state data and make it available to the experiment package(s).

For the most part, current technology can provide instruments capable of generating state data to the desired level of precision. Therefore, this capability exists but must be specified in the requirements for a given platform, and there will be a cost associated with the requirement.

4.2.13 Precision trajectories

Need: Low

Several missions require the location of the UAV to be controlled very precisely. Flight trajectories within ±5 meters from the prescribed flight path are desirable. This capability requires both the real-time knowledge of where the UAV is and the ability to control or maneuver the UAV to the desired position in the sky. Additionally, some missions have constraints on the dynamics of the flight path so that high-gain system may not be suitable.

The development of a common method of knowing the current location of the aircraft is well within the capability of current technology. NASA's Jet Propulsion Laboratory (JPL) has flight tested a Global Differential Global Positioning System (Global DGPS) which advertises accuracies in the 10 centimeter range over populated land areas and 50 centimeter range over areas like the North and South Poles. The development of UAV control systems to maneuver the aircraft correctly will be largely dependent on the characteristics of the UAV in question. For years autopilots have been designed that follow a given trajectory. The issue is whether a particular UAV system can be adjusted to provide the desired precision. Unfortunately the ability to achieve the desired precision is dependent on the type of aircraft. Aircraft with light wing loadings and low speeds are more susceptible to crosswinds and gusts which may hamper the ability to maintain an accurate position. Regardless of the controllability characteristics of the UAV in question, very little new technology needs to be developed to perform this function. The Danish Center for Remote Sensing has demonstrated flights to approximately five-meter accuracy using a business jet. NASA's Earth Science Capability Demonstration project is pursuing the capability to maintain aircraft position with a 10-meter (or better) tube. However, the integration to UAVs on a wide scale has yet to be demonstrated.

4.2.14 All-Weather

Need: Low

Some of the missions, such as the Hurricane Tracking Mission, indicate that platforms are required to penetrate severe storms and fly in all types of weather, including icing conditions, strong wind shears, lightning, and severe convective environments.

Building a platform rugged enough to withstand flight in severe storms is within current technology. However this requirement places additional burdens on flight controls, and potentially platform performance goals, depending on the design solution of system. For example, it would be difficult to develop a high altitude, long endurance aircraft (which may require a "gossamer" design) which would also survive high winds and turbulence. One design solution for performing these is to launch a series of rugged MAVs into the storm from a mother ship. The mother ship can meet performance requirements without the burden of meeting this requirement. The technology currently exists to build all-weather aircraft, but the requirement must be stated at the time aircraft is developed. It is difficult to "retrofit" all-weather capability to an existing aircraft. All-weather capability will add to the cost of the aircraft design and construction.

4.2.15 Base of operations in remote area

Need: Low

The capability to deploy a small, inexpensive UAV from a remote location near an area of interest was conceived to obtain specific scientific data in remote areas. The requirement for this capability is a UAV platform which requires very little support equipment and minimal personnel for pre-flight, launch, and recovery. With this capability, range and endurance requirements on the UAV platform can be reduced. This concept may also impact the mode of operation for an autonomous ground station which could pave the way for a planetary-exploring UAV.

Certainly MAVs can be launched with minimal support personnel and equipment without any advances in technology; however the concept of a fully automated ground station has not been demonstrated. Using them for the Earth Science application may depend on payload sensor technology advances, since payload weight and volume capability is limited. Also, it is likely that high levels of automated mission management, intelligent flight control, and health monitoring may not be available because of the limited computation resources on a MAV. Therefore payload sensors on a MAV may have to be expendable. The construction of a more sophisticated, even autonomous, base of operations in a remote area (even the Moon or another planet) remains in the conceptual state only.

4.3 Technologies

4.3.1 Autonomous mission management

Need: High

A high level of autonomy in the mission management function is required to take advantage of using a UAV platform to support the missions. Less direct human interaction in flying the UAV allows less on-station personnel, less on–station support infrastructure, and one operator to monitor several vehicles at a given time. These goals must be balanced with the requirement for the operator and vehicle to respond to air traffic control in a timely manner. The mission management system should also allow re-direction of the mission (including activating the contingency management system) from the ground. This would especially be useful for moving phenomena which cannot be adequately located prior to mission initiation. It is envisioned that the human interaction with the on-board mission manager system will occur at the mission objectives level. In the ideal scenario, the on-board mission manager, starting with the mission objectives, would be responsible for pre-flight planning, real-time flight path adjustments during the mission, and even real-time mission objective adjustments during the mission based on air traffic control and contingency management. It is also desired for the scientist or possibly the payload sensor to interact with the mission manager, as well as the operator responsible for the mission. Providing these functions will require a shift in the paradigm of how flight management software is currently written. The desired system is an open behavior system. This approach enables much of the capability conceived in the future missions, such as efficient mission re-tasking, increased platform availability, efficient contingency management, and coordinated team formation flying. As such it is highly dependent on the current condition at the time a behavior is executed and is difficult to precisely predict. Increasing the complexity is the fact that any intent to deviate from the original mission plan must be first conveyed to and approved by air traffic control prior to being executed.

The level of autonomy in the future mission management function is significantly more sophisticated then exists with current UAVs. Additionally, verification and validation of these systems will be a challenge. Currently the Joint Unmanned Combat Air System program (J-UCAS) is employing a similar software approach to mission management. NASA, under the AuRA program, is also working on a similar Intelligent Mission Management system. Autonomous mission management supports Approach 9 of the GOTChA chart. The TRL is estimated at 4, since some components of these methods are modeled in the simulation environment.

4.3.2 Sophisticated contingency management

Need: High

UAVs will require some level of contingency management system to all flight in the NAS. The on-board contingency management system should react to unforeseen events and failures according to the something like the following priorities:

1) Minimize expectation of casualty (Ec)
2) Minimize external property damage
3) Maximize the chance of aircraft survival

4) Maximize the chance of payload survival

For the long term, it will be unreasonable to consider many UAVs as expendable. In addition to the cost of UAV, the cost of its sensor suite (which may be one-of-a-kind) must be considered. Loss of the UAV and payload should only be considered when there is a significant risk to the general public or property. One of the primary contingencies to be planned for is the loss of link between the UAV and the operator. In this case, if the vehicle can not continue on its original mission plan the vehicle should have the capability to achieve an approved landing area while considering the priorities above and attempting to re-establish the communications. During these events, the UAV must have alternate means to communicate its intended flight plan. However, other contingencies must also be considered. These might include sensor or payload failures, aircraft failures, and other communication failures. The contingency management system should be able to decide, depending on the nature of the problem (see Section 4.3.2), whether it should attempt landing at the airport it was based out of, or a landing at an alternate airport, or some other impact (ditch) in a remote area. Intelligent contingency management will also reduce the human oversight required for UAV flight and contribute to the goal or reducing mission costs.

Contingency management for UAVs at the level described will require a sophistication that currently doesn't exist. Relatively little development of this capability has occurred to date although several promising concepts have been proposed. Global Hawk and Predator have contingency management systems to some degree, although they lack the sophistication and intelligence that would be desirable for ease of use. NASA, under the HALE ROA in the NAS project, is currently working to define a UAV "code of ethics" and policy regarding contingency management systems. Contingency management supports Objective 7 of the GOTChA chart. An overall TRL of 4 is assigned.

4.3.3 Collision Avoidance

Need: High

To fly with few restrictions in the NAS, UAVs will require some sort of collision avoidance system. The intent is to have an "equivalent level of safety" when compared to piloted aircraft. This system will allow UAVs to "see" or detect other aircraft (piloted or uninhabited) and avoid them. The technology for this system is decomposed into two elements "see" and "avoid". The "see" portion involves the detection of intruding aircraft through some type of sensor. The "avoid" portion involves predicting if the intruding aircraft poses a danger and what course of action should be taken through a software algorithm. For sensors, the priority should be to detect aircraft at sufficient distance so that emergency maneuvering can be avoided. The first step in this development will be to implement a <u>cooperative</u> sensor for collision avoidance. Under the cooperative category, aircraft will have transponders or data links notifying other aircraft of their position. The second and more difficult portion is <u>non-cooperative</u>

detection. In this case, the “other” aircraft does not share its position (as would be the case for many general aviation aircraft) and must be detected with radar or optics. For avoidance, sensor information must be used to predict future positions of host (ownship) and intruder aircraft to determine collision potential. If a collision potential exists, a safe escape trajectory must be derived and automatically executed if the operator has insufficient time to react.

Some significant work has already been done in this area. The NASA ERAST project tested both a cooperative and non-cooperative sensor. Also, the Air Force has completed a project evaluating an avoidance algorithm coupled to an automatic evasion maneuver. Both cooperative and non-cooperative sensors were demonstrated in the Air Force project with promising results. Collision avoidance systems are also being worked under NASA HALE ROA Access to the NAS project, and collision avoidance supports Objective 7 of the GOTChA chart. The overall TRL for this technology is estimated to be at 6. However, no viable non-cooperative sensor or sensor suite has been developed to date placing this component at a TRL of 2.

4.3.4 Intelligent system health monitoring

Need: High

The ability of a UAV system to reliably identify failures and classify them according to their impact on vehicle safety and mission success is a key technology for flying UAVs with an acceptable level of safety. This technology, generic to any UAV application, allows intelligent contingency management based on the failed vehicle state and is a foundation for free access to the air space by UAVs. Additional cost benefits are accrued by using this system to monitor sub-systems for maintenance purposes. Identification of sub-systems as they deteriorate will focus maintenance efforts, decreasing the turn-around times between missions and reducing costs per flight hour.

Health monitoring concepts and limited systems have been around for some time, but comprehensive and generic systems have languished due to lack of funding. Specific systems have been developed and proven, particularly for new fighter aircraft. Additional work is in progress under NASA’s Autonomous Robust Avionics (AuRA) project. Intelligent system health monitoring is covered under Technical Challenge 6 of the GOTChA chart. As overall TRL of 5 is assigned.

4.3.5 Reliable Flight Systems

Need: High

The ability of a UAV flight system to adapt to system or hardware failures is a key technology for flying UAVs with an acceptable level of safety and perhaps the most critical system for the aircraft is the flight control system (FCS). This technology, generic to any UAV application, provides for high reliability and is one of the foundations for unrestricted access to the air space by UAVs. Initial reports from the FAA regarding UAVs indicate they are looking for "reliability comparable to a piloted aircraft". The issue of reliability can be addressed from two viewpoints. The first is basic reliability of the onboard systems. The second is the reliability of an on-board pilot in being able to recognize a failure and adapt to the situation (see Section 4.3.2 on Sophisticated Contingency Management). Both of these viewpoints must be considered in assessing the reliability of UAV flight systems. This technology is especially important for long endurance flights in remote areas, where options for recovery are limited.

One approach to system reliability is simply to increase the redundancy of flight systems. This comes with both an initial cost and an on-going weight penalty. Another approach would add on-board intelligence to recognize and remedy a failure. Simulations of adaptive flight control systems have shown promise for many years, and several methods of adaptive control have found their way to flight test projects. The latest of these is a neural-net based system scheduled to fly on an F-15 aircraft at NASA. It is likely that the final solution will be a compromise or combination of the two approaches. Efforts on reliable flight systems for UAVs are supported by Approach 9 of the GOTChA chart. Based on ongoing intelligent flight control efforts, a TRL of 6 is assigned.

4.3.6 Over-the-Horizon Communication

Need: High

A key technology which supports all of the future missions is the ability to transmit data over the horizon (OTH). The OTH capability is a "web-based", network approach to communication for a given mission. Key elements within the mission are considered as a node. Data then can flow to and from any node to any other node. Examples of nodes are a scientist observer, a UAV operator, the vehicle's platform's mission manager, satellites orbiting overhead, the vehicle's payload, other aircraft, etc. This means that an aircraft flying over the North Pole could be controlled by an operator in California while experiment data was monitored by a scientist in Washington, DC. The OTH network must include the ability to pass high bandwidth data, even in remote areas such as the poles. The network should be available with very little interface required by the mission planning team. Additionally, the network should be configurable based on the data flow requirements for a given mission. In other words the network should be able to provide the level of bandwidth required for a given mission so that missions which don't require high bandwidth communication do not have to pay for the resources necessary to effect it. This technology will reduce the cost per flight hour by creating more efficient data handling and reducing the need for personnel at the base of operations. The communication network might also satisfy the requirement to have a voice link between the FAA controller and UAV operator, although other options are also being considered.

Satellite communication links have been used in flight operations to provide over-the-horizon communication. However, the concept described here significantly expands the concept beyond what has been flown to date. Adjustable bandwidth's and a 'web-based' use as needed approach are concepts which still require significant technology developments. There is strong interest in this concept from both civilian (NASA) and DOD agencies. NASA is pursuing this technology under their Earth Sciences Capability Demonstration project in conjunction with the Integrated Network Enhanced Telemetry (iNet) efforts. For this technology a TRL of 3 is estimated.

4.4 Technology Development Schedule

The information for this section predominantly reflects the effort NASA is associated with at the time of publication. It includes some DOD related work, but is not intended to be comprehensive of DOD UAV related efforts. The information was obtained from NASA Vehicle System Program and sub-project plans and interviews with project people. It does not reflect at this time UAV development work being accomplished in other government agencies (except as noted in sections 4.2 and 4.3), the private sector, or academia. The triangles on the chart indicate a project completion milestone. The word boxes in the chart are milestone labels and do not indicate schedule activity.

		FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14
Access to the air space	4.2.1			Access to FL400^		Access to FL180	Class A,B,C air space	File & Fly >FL180^			
Autonomous mission management	4.3.1	Mission-level decision aid			Demo IMM for payload directed LE						
Sophisticated contingency management	4.3.2			FL400 CM^		FL180 CM^	Class A,B,C airspace CM^	Mature CM^			
Collision avoidance	4.3.3			GCAS – ACAS Development Evaluation							
Intelligent system health monitoring	4.3.4			OPFMS flight demo		OPFMS auto reconfigure flight					
Reliable flight system	4.3.5			Initial UAV Adaptive Optimal Demo			UAV Adaptive Optimal				
Over-the-Horizon Communication	4.3.6					OTH & Networks Req't					
Command/control from outside entity	4.2.2						JUCAS Capability Development				
Long Range/Endurance	4.2.3							SOLEO#	Global Observer#		
High Altitude	4.2.6										
Formation flight	4.2.4	PRGNC for Formation				PAGNC & PRGNC Mixed Fleet					
Monitor/control multi-ship operation	4.2.5						JUCAS Capability Development Program				
Efficient turn-around/Availability	4.2.7	*									

		FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14
Precision aircraft state data	4.2.12	*									
Deploy / potentially retrieve	4.2.10										
Quick deployment	4.2.11	*									
Vertical Profiling	4.2.9	*									
Terrain Avoidance	4.2.8			GCAS – ACAS Development Evaluation							
Precision trajectories	4.2.13			10m Flight Demo							
All Weather	4.2.14	*									
Base of operations in remote area	4.2.15	*									

* = Technology is available to enable these capabilities. These capabilities are viewed as procurement issues in nature.
^ = Denotes deliverable to FAA are policy guidelines and capability/technology demonstrations.
# = Proof of concept vehicles.

Table III: Technology Development Schedule

The information for this section predominantly reflects the effort NASA is associated with at the time of publication. It includes some DOD related work, but is not intended to be comprehensive of DOD UAV related efforts. The information was obtained from NASA Vehicle System Program and sub-project plans and interviews with project people. It does not reflect at this time UAV development work being accomplished in other government agencies (except as noted in sections 4.2 and 4.3), the private sector, or academia. The triangles on the chart indicate a project completion milestone. The word boxes in the chart are milestone labels and do not indicate schedule activity.

4.5 Payload sensor development: autonomy and miniaturization

Although not considered directly under the version of the document, the conceived missions require payload sensor development in parallel with the UAV technology development. Autonomous operation of some payloads will be required, and for other payloads the ability of the scientist to remotely control its configuration will be required. The ability of a payload to either autonomously calibrate itself or to be calibrated more efficiently than current technology allows will enhance the utility of the UAV science platform and reduce mission costs. For some missions small daughter vehicles carry a subset of payload sensors for specific data collection tasks. Therefore some payloads may require miniaturization to support those missions. For now, this technology is not included in the Technology/Mission Allocation table (see Section 3.3).

Payloads for the UAVs will vary with the intended mission. Some missions will require a suite of sensors along with communications systems while others will utilize a single sensor. Many of the missions will require that two types of measurements be made: *in situ* data collection and remotely-sensed data. Some of the missions will require that orbiting platforms (space-based) provide additional data. It is expected that the capabilities (ranges and resolutions) and size (physical and weight) will change over the years prior to the initial proof-of-concept test flights. The status and TRLs of payload sensor development will not be included in this version of the assessment document, but an evaluation will be made in the final version.

One approach suggested to forecast these technology changes is to establish a group of subject matter experts with theoretical design focus on the various types of sensors. Included in the sensor technologies would be: lidar, radar, infrared, magnetometers, visual and spectroscopy devices. The group would be asked to develop time lines for which various performance characteristics of the sensors would be available including size and weight reductions and levels of increased performances. The results would then be used to forecast as a function of time the volumes, power requirements, etc. for a particular mission or set of missions. This forecast could then be used to establish the timing of the program plans for the test schedules. The information could also be used to support R&D in those technology areas that appear weakest but necessary for mission success.

Appendix A

Customer List

The Civil UAV Assessment Team maintains a contact listing of all those that have attended the workshops, have espressed interest in UAV missions or have been interviewed by the Team.

Appendix B

Interview Questionnaire

Civil UAV Capability Assessment – Customer Interview Form

Rev. Date: 1-Jul-04

Customer ________________________ Phone ________________________

Agency or Company _______________ Division ______________________

Date of Interview __________________ Interviewer ____________________

(What is your current "State of the Art"?)

What is your current mission requirement?

- Payload
  - Image based Surveillance
  - Environmental Sampling
  - Payload Delivery
  - Communications
  - Serviceability
  - Other ____________________________
- Flight Environment
  - Proximity to Population
  - Altitude
  - Range
  - Endurance
  - Climate
- Monitoring Requirements
  - Real-Time or Post Flight
  - Bandwidth for Real-Time
  - Volume (for On-Board Storage)
- Reliability
  - Mission Success
  - Vehicle Loss Rate

What is your current knowledge of UAV capabilities?

- Current Missions

- Platforms

- Availability

- Air space Restrictions

- Reliability

- C3 Options

Customer ______________________________

(What is your vision of the future?)
What is your opinion about the use of UAVs to accomplish your mission?

What missions do you foresee for UAVs over the next ten years (2004-2014)? Include dates if available

Over the following fifteen years (2014 – 2029)? Include dates if available

What phenomena will you want to measure?

(What are your specific requirements?)
What kinds of technologies will be required to support these missions?

How will you want to measure it?

What type of scientific instrumentation will you need to make those measurements?

Over what time period and scale will you want for your measurements?

What flight conditions will you want to make measurements at? (speed, altitude, endurance)

What will be the weight, volume, and power requirements of the scientific instrumentation?

Are there special environmental requirements you will need for the instrumentation (vibration, temperature, pressurization, stability, etc.)?

What data will the scientific instrumentation require from the platform?

What type of maneuvering will you want from the platform in order to collect your measurements? (loiter, vertical profiling, etc.)

What will be the requirement for accessing the environment to be measured? Will you need viewing or sampling ports for the scientific instrumentation?

What will be the communication requirements for the instrumentation? Will real-time data monitoring be necessary? What about on-board data storage? Will uplinked control of the instrumentation be desired, and if so what type of functions will be performed?

Customer ______________________________

What support equipment will be necessary for pre-flight instrumentation checkout?

Is there anything else we should know about?

Is there anyone else you think we should talk to regarding this subject?

- What other elements (horizontal or vertical) of your organization may benefit from the use of UAVs?

- Should anyone in your chain of authority be made aware of this effort?

Appendix C

Acronyms, Abbreviations and Definitions

ASC/RA	Aeronautical Systems Center / Reconnaissance Aircraft
AFRL	Air Force Research Laboratory
AuRA	Autonomous Robust Avionics – A NASA project intended to enable aircraft to fly with reduced or no human intervention, to optimize flight over multiple regimes, and to provide maintenance on demand towards the goal of a feeling, seeing, sensing, sentient air vehicle. <http://avst.larc.nasa.gov/projects_aura.html>
cm	centimeter
C	a frequency sub-band
CA	California
Cnty.	County
CIRPAS	Center for Inter-Disciplinary Remotely Piloted Aircraft Studies (see Section 2.1)
CO_2	Carbon dioxide
COA	Certificate of Authorization
Dept.	Department
DHS	Department of Homeland Security
Dir.	Directorate
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
Ec	Expectation of Casualty
Emer.	Emergency
EO	Electro-Optical
EOS	Earth Observing System – EOS is composed of a series of satellites, a science component, and a data system supporting a coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. <http://eospso.gsfc.nasa.gov/>
EPA	Environmental Protection Agency
ESCD	Earth Sciences Capability Demonstration
FAA	Federal Aviation Administration
FCS	Flight control system
FedEx	Federal Express
FEMA	Federal Emergency Management Agency
ft	feet
FTIR	Fourier Transform Infrared – An analytical technique used to identify organic and inorganic materials which measure the absorption of various infrared light wavelengths by the material of interest. These infrared absorption bands identify specific molecular components and structures. <http://www.mee-inc.com/ftir.html>
FY	Fiscal Year
GHz	Giga-Hertz
GIFTS	Geostationary Imaging Fourier Transform Spectrometer – This

	satellite uses an Imaging Fourier Transform Spectrometer to observe atmospheric temperature, water vapor content and distribution, and the concentration of certain other atmospheric gases present at a given altitude over time < http://oea.larc.nasa.gov/PAIS/GIFTS.html>
GPM	Global Precipitation Measurement – This science mission has the goals of improving the accuracy of climate predictions, providing more frequent and complete sampling of the Earth's precipitation, and increase the accuracy of weather and precipitation forecasts < http://gpm.gsfc.nasa.gov/index.html>
GPS	Global Positioning System
Grp.	Group
HALE	High Altitude Long Endurance
hr	hour
Hz	Hertz
ICE	Immigration and Customs Enforcement
IMU	Inertial Measurement Unit
iNet	Integrated Network Enhanced Telemetry
INST	Institute
IR	InfraRed
ISR	Intelligence, Surveillance, and Reconnaissance
ITAS	Integrated Tailored Aero Structures
J-UCAS	Joint Unmanned Combat Air System
K	a frequency sub-band
Ka	a frequency sub-band
Ku	a frequency sub-band
kg	kilograms
km	kilometer
kW	kilowatt
L	a frequency sub-band
lbs	pounds
LEAP	Low Emission Alternative Propulsion
LIDAR	LIght Detection And Ranging – This instrument transmits light which interacts with and is changed by a target. Some of this light is reflected / scattered back to the instrument where it is analyzed. It can be used to measure distance, speed, rotation, or chemical composition and concentration. <http://wwwghcc.msfc.nasa.gov/sparcle/sparcle_tutorial.html>
m	meter
M	Million
MAV	Mini Aerial Vehicle
Mbps	Mega-bits per second
MODIS	Moderate Resolution Imaging Spectroradiometer - This instrument aboard the Terra and Aqua satellites is used for acquiring data about the global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere.

	<http://modis.gsfc.nasa.gov/about/index.html>
NAS	National Air Space
NASA	National Aeronautics and Space Administration
Natl	National
NCEP	National Centers for Environmental Prediction – This organization delivers national and global weather, water, climate and space weather guidance, forecasts, warnings and analyses to its partners and external user communities. <http://wwwt.ncep.noaa.gov/mission/>
NGA	National Geospatial-Intelligence Agency – This organization provides geospatial intelligence, which includes but is not limited to imagery, maps, charts, and environmental data, in support of national security. <http://www.nga.mil>
nm	nautical miles
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NFS	National Forest Service
NSF	National Science Foundation
O_2	Oxygen
OTH	Over-The-Horizon
P	a frequency sub-band
PAGNC	Precision Absolute Guidance, Navigation, and Control
PRGNC	Precision Relative Guidance, Navigation, and Control
PSC	Polar Stratospheric Clouds
ROA	Remotely Operated Aircraft
SAR	Synthetic Aperture Radar
sec	Second
Serv.	Services
SO_2	Sulfur dioxide
TBD	To Be Determined
Tech	Technology
THORPEX	THe Observing-system Research and Predictability Experiment – THORPEX is an international research and development program to accelerate improvements in the accuracy high impact weather forecasts. <http://www.wmo.int/thorpex/mission.html>
TRL	Technology Readiness Level
UAV	Uninhabited Aerial Vehicle
UPS	United Parcel Service
US	United States
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VHF	Very High Frequency
VIIRS	Visible Infrared Imager Radiometer Suite – The group of instruments collects visible/infrared imagery and radiometric data, which includes atmospheric, clouds, earth radiation budget, clear-air land/water surfaces, sea surface temperature, ocean color, and

	low light visible imagery. http://www.ipo.noaa.gov/Technology/viirs_summary.html>
W	Watts

Appendix D

UAV Mission Descriptions

A list of representative missions has been compiled and is described in the following sections. It is recognized that this list is not complete; additional efforts will be completed after the initial version of this report. Missions are not listed in any particular order. Within each mission section, the paragraphs will address:

1) The mission description, benefits and justification
2) The platform operational requirements
3) The payload attributes and requirements
4) The communication requirements

D.1 Commercial Missions

D.2 Earth Science UAV Missions

Mission: Repeat Pass Interferometry for Surface Deformation
Source: NASA Science Mission Directorate / Earth Surface and Interior Structure Focus

This mission would allow measurement of the geophysical processes associated with natural hazards such as earthquakes, landslide, and volcanoes as they are manifested by deformations in the Earth's crust. Measurements of the crustal deformation would be made by an interferometric synthetic aperture radar (SAR) carried by the UAV platform. The benefits of these measurements include:

- Driven by slow plate motions, rapid injection of magma into the plumbing system of a volcano can lead to explosive eruptions over hours to days. Measurements from this system will lead to better models of the internal plumbing and magma flow within a volcano.
- Steady slip along a fault in the crust can lead to sudden, major earthquakes and days of continuing slip. Using measurements from this system a better understanding and assessment of the rate of slip and rebound surrounding a seismic event can be obtained.
- Gradual movement of hillsides as a result of heavy rainfalls may eventually lead to catastrophic landslides. Accurate measurements of surface deformation over areas prone to landslide will assist in assessment of the process.

Interferometric measurements would be made by flying a single aircraft along a precisely defined trajectory or by a pair of aircraft flying in a precision formation. Passes would be made days or weeks apart to monitor the change in topography.

The aircraft platform should be able to fly a defined trajectory within approximately ±16 feet (±5 meters) accuracy. The platform must be able to fly above normal air traffic, approximately 45,000 feet (14 kilometers) is desired. The platform should be capable of flying in a variety of weather conditions and operate from conventional airports. The aircraft should have a minimum range of 2000 nautical miles (3700 km). The aircraft must also provide the ability to mount an external, side-looking, active array antenna (1.6 ft by 6.5 ft (0.5 m by 2.0 m)) without obstruction.

Payload weight and volume are estimated to be 660 pounds (300 kilograms) and 35 cubic ft respectively (one cubic meter). Two thousand watts of direct current power are estimated to operate the radar.

The aircraft will require a low-bandwidth, over-the-horizon communication link to support radar operation and health/status monitoring (a high-bandwidth capability would be an asset).

Mission: Cloud and Aerosol Measurements
Source: NASA Science Mission Directorate / Atmospheric Composition Focus
This suborbital mission would study transformations of aerosols and gases in cloud systems in the following domains:

- Convective systems: to include areas of Costa Rica, Southern Florida, and Central United States
- Sea breeze cloud formation – wide areas of coastal U.S.
- Marine stratiform – primarily the California coastal areas
- Contrails in the Central U.S. in air traffic regions and ship tracks in oceans
- Synoptic scale systems & Fronts – in the Central U.S. region
- Cirrus outflow – large areas of the tropics, Southern Florida, and Central U.S.

To accomplish this mission, formation flying of four vehicles would be required – three for *in situ* sampling of the in-flow region, out-flow region, and convective core, and one for high altitude remote sensing aircraft (near tropopause). This formation would allow profiling of cloud and clear sky environments (optical, composition, and microphysical parameters) to examine variability of aerosols and direct and indirect chemical and radiative effects of clouds and aerosols.

In addition, investigations of the fundamental microphysics of cloud drop formation and evolution could be accomplished by looking at inflow and outflow through these systems to see the transformations. For example, the sensors would determine differences in the inflow into cumulus convection in the boundary layer and lower troposphere and the outflow in the mid-to-upper troposphere. Aerosols and pollutants are modified by these convective systems as they are lofted into upper troposphere/lower stratosphere. It is expected that these flights may occur in severe convective environments (i.e., strong vertical wind shear, severe lightning). Observations of these aerosol & cloud events could be made synergistically with inputs from satellite platforms.

In the performance of this mission the *in situ*, in-flow measurement platform is required to fly between the surface and 20,000 feet (6 km). As such its vehicle management system should employ terrain avoidance. The other *in situ* platforms are required to fly between 20,000 and 60,000 feet (6 km and 18 km). And the remote platform must fly between 40,000 to 60,000 feet (12 km to 18 km). All platforms are required to have a range of 6000 nm (11100 km) and an endurance of 24 hr. Although the vehicles would operate with pre-programmed profiles, their vehicle management systems must support re-tasking during the mission. The *in situ* vehicle management system must be able to receive re-tasking commands from the remote platform. The *in situ*, convective platform must be sustainable in severe turbulence (165 ft/sec, 50 m/sec downdraft), lightning strikes, and large hail. The platforms must be available for a 4 week campaign where 3 flights per week are flown.

All instrument payloads for these missions would have dedicated computation and data storage. Aircraft data inputs such as altitude, attitude, latitude, longitude, speed and time are required for data analyses. The typical sensor suite for the remote sensing vehicle would be nine instruments with a total weight of 2000 lbs (900 kg). The necessary volume for the suite would be around 150 ft^3 (4.25 m^3). Some of the sensors will require unrestricted ports for accuracy. The *in situ* measurements platforms would have between 14 and 24 instruments (depending on focus with a weight range between 1600 lbs and 2800 lbs (725 and 1275 kg). The volume for the instruments would be less than 180 ft^3 (5 m^3). The operating environmental conditions require free stream sampling, no pressurization, some air flow scoops and venting. Instrument cooling may be a major issue for tropospheric sampling and active temperature control may be necessary.

Since optimal mission achievement requires in-flight re-tasking in near-real time, over the horizon (OTH) communications capabilities is essential. This re-tasking of the vehicle would occur in mid-flight as meteorological, cloud, and near real time radar imagery evolves. It is estimated that a minimum data rate of 9600 baud for the instruments would be needed.

Mission: Stratospheric Ozone Chemistry
Source: NASA Science Mission Directorate / Atmospheric Composition Focus
The purpose of this mission is to observe changes in the stratospheric ozone chemistry by the profiling of source gases, water, aerosols, and temperatures in the mid-latitudes and Polar Regions in the upper troposphere/lower stratosphere. In addition to source gases, tracers as well as reservoir species and radicals are to be measured. The mission will make simultaneous measurements of water vapor, total water temperature, pressure, winds, ozone, aerosols, and polar stratospheric clouds (PSC). Part of this study will be to determine whether the stratospheric ozone layer (i.e., Antarctic ozone hole, Arctic ozone levels, mid-latitude) will recover to pre-1980 levels and how climate change will interact with the expected decrease of ozone-depleting substances. An alternative scenario for this mission might be to split the payload into *in situ* and remote sensing instruments and to fly these payloads in formation on separate aircraft. In this mode, the *in situ* vehicle's measurements would be taken simultaneously with those in the remote sensing platform and correlated with each other.

The platforms must provide a long range (>13000 nm, 24000 km), long duration (2 – 5 days), high altitude (70,000 ft, 21 km), and heavy lift capability. Cruise speed must be between Mach .4 to .7. In addition the platforms must be highly reliable, 1000 flight hours over a 4 month period, and they must conduct missions at a frequency of 1 per week during a 1 month campaign.

These measurements will be accomplished by both *in situ* and remote sensing suites of instruments. The 21 *in situ* instruments will have a total weight of 2500 lbs. (1125 kg) and a volume of 150 ft^3 (4.25 m^3). The 6 remote sensing instruments will have a total weight of 1000 lbs (450 kg) and a volume of 75 ft^3 (2.1 m^3). Additional support of the mission includes:

- All instruments with dedicated computers and data storage.
- Aircraft performance data (altitude, latitude, longitude, time, attitude) required by the instruments.

- Experimenters will need easy access to instruments, and instruments with capability to be off-loaded from aircraft after each flight.
- All instruments weight, volume, and power estimates are based upon current capabilities.
- Environmental conditions – free stream sampling, no pressurization, some air flow scoops and venting.

Real time communication for re-tasking aircraft in mid-air during the mission as meteorological, PSC, and chemical forecasts evolve as well as OTH communications capability are essential. The OTH network requires a minimum baud rate of 9600.

Mission: Tropospheric Pollution and Air Quality
Source: NASA Science Mission Directorate / Atmospheric Composition Focus
The objective of this suborbital mission is to study the sources, evolution, and distribution of tropospheric pollutants. The pollutants and particles and their source emissions would be profiled on regional to hemispheric scales from near the surface to the tropopause region. This profiling would cause determination of where plumes of pollution are transported and how they evolve.

The mission would involve formation flying of four aircraft platforms for *in situ* measurements in the boundary layer, mid-tropospheric and upper tropospheric regions and a high altitude remote sensing platform (near tropopause). This type of formation would begin with a pre-programmed scenario with the capability of re-tasking during the mission. The aircraft formation would follow plume events over several days and over several thousand km. The observation data of these plume events would be combined with data from geostationary platforms.

The platforms required to do this mission should have a range of 8100 nm (15,000 km) and an endurance of 2 to 4 days. Remote sensing vehicles should operate 40,000 to 60,000 feet (12 km to 18 km). The *in situ* vehicles operate from near the surface to 60,000 ft (18 km). The *in situ* vehicle management system should be able to receive re-tasking commands from the remote platform. In addition the platforms should be highly reliable, 1000 flight hours over a 4 month period, and they should conduct missions at a frequency of 1 per week during a 1 month campaign. Turn-around time between missions should be less than 48 hours.

The sensor suite will consist of seven instruments for the remote sensing vehicle with an expected weight of 1600 lbs (725 kg) and a volume of 100 ft^3 (2.8 m^3). The instruments required for the *in situ* measurements have an expected weight of 2500 lbs (1130 kg) and a volume of 150 ft^3 (4.25 m^3). All instruments weight and volume estimates are based upon current capabilities. Additional mission support factors are:

- All instruments with dedicated computers and data storage.
- Aircraft performance data (altitude, latitude, longitude, time, attitude) required by the instruments.
- Experimenters will need easy access to instruments, and instruments with capability to be off-loaded from aircraft after each flight.

- Environmental conditions – free stream sampling, no pressurization, some air flow scoops and venting.

Over the horizon communication and control of the aircraft by ground base is required. Also necessary is the capability for near real-time re-tasking based upon observations from the remote sensing platform. The minimum acceptable baud rate is 9600.

Mission: Water Vapor and Total Water Measurements
Source: NASA Science Mission Directorate / Atmospheric Composition Focus
The objective of this mission is to study water vapor and total water in the tropical tropopause layer. The focus will be to profile water from the mid-troposphere to the lower stratosphere and from the tropics into the mid-latitudes. This study will try to determine what controls upper troposphere/lower stratosphere water and how it impacts climate change feedbacks. The study will utilize two platforms for the measurements: one for the *in situ* platform instruments in the upper troposphere/lower stratosphere; and one for the remote sensing platform instruments that will be in the stratosphere.

The platforms to perform this mission require 22,000 nm (40,000 km) range capability and 3 to 5 days endurance capability. Both aircraft platforms will operate between 30,000 and 70,000 feet (9 and 21 km). The platform must have high reliability, that is, the aircraft must be able to conduct 2 to 3 flights over a one month campaign. The vehicle management systems of both platforms must work together as a coordinated team, and must accept real-time re-tasking in mid-air as meteorological, cloud, and chemical forecasts evolve.

The instruments on both platforms will measure simultaneously water vapor, total water, water isotopes, temperature, pressure, winds, ozone and other gases and particles. The *in situ* platform will have available 17 instruments with a total weight of 1800 lbs (820 kg) requiring a total volume of 120 ft^3 (3.4 m^3). The five remote sensing instruments, consisting of 2 Light Detection and Ranging (LIDAR) units, 1 Fourier Transform InfraRed (FTIR), 1 microwave, and 1 drop-sonde[2] are expected to have a total weight of 1200 lbs (550 kg) using a total volume of 80 ft^3 (2.3 m^3). All instruments will have dedicated computers and data storage. Vehicle performance data (altitude, latitude, longitude, time, and attitude) will be required by the instruments. Experimenters will need easy access to instruments, and instruments will probably be off-loaded from aircraft after each flight. All instruments weight and volume estimates are based upon current capabilities. Additionally, the operating environment will require free stream sampling, no pressurization, air flow scoops and venting. Some ports and side window for LIDAR, microwave and FTIR will be needed.

Real-time re-tasking of the aircraft requires an over the horizon network capability with a minimum of 9600 baud rate.

Mission: Coastal Ocean Observations

[2] Several of the missions originally referred to the drop-sonde concept in a variety of terms such as sonde or smart-sonde. To keep consistent terminology the term ‘drop-sonde’ will be used throughout this report.

Source: NASA Science Mission Directorate / Carbon Cycle, Ecosystems, and Biogeochemistry Focus

This suborbital mission would help scientists understand further coastal bloom compositions and the changes over time and space. In addition, the science data will help scientists quantify the submerged aquatic vegetation and coral reefs, measure an estuarine condition, and evaluate how nutrients are consumed and released into the coastal zone and the impact on the carbon cycle. The science data gathered would reduce the uncertainties in the fluxes and coastal sea dynamics by resolving horizontal and vertical resolution (improved spatial and temporal resolution) and multiple sensor integration. This approach leverages the suborbital platform inherent advantages of high frequency and high resolution measurements that can be used to resolve temporal variation in space time and spectra.

The mission calls for the aircraft platform to loiter over a particular region of interest, such as a bay, or perform transects of larger coastal regions. The science data from the suborbital platform will be integrated with a deployable underwater vehicle(s), which provides measurements such as salinity, temperature, and chemical and optical properties. The underwater vehicles will be deployed from air or land. Measurements will yield, at a minimum, a profile and quantification of the biomass, and the sea surface roughness and salinity. Primary areas of interest are the continental shelves off North America and in the tropics. Data will be gathered from the coast from to 25 to 110 nm (50 to 200 km), depending on the depth of the shelf. The missions will be cued from Moderate Resolution Imaging Spectroradiometer (MODIS) / Visible Infrared Imager Radiometer Suite (VIIRS) ocean color measurements or *in situ* buoys, or following cyclone/hurricane events. Aircraft will be deployed before the bloom to observe and measure the development and waning. This mission may be flown in tandem with the CO_2 flux mission.

Aircraft platform requirements include one 24 hr mission per season, with measurements every 65 ft (20 meters). The platform should fly above 40,000 feet (12 km) to avoid commercial traffic. The vehicle management system should allow integration of payload measurements with underwater vehicles and buoys for the purposes of re-tasking.

The suborbital payload will consist of five instruments: hypersprectral sensor (350 nm to 1000 nm, 650 km to 1850 km); tunable laser diode; Terminal Imaging Radar sensor (8-12micron); a scatterometer (Ku band) for roughness; and, a microwave for salinity. The two sensors and laser diode combine for 165 lbs (75 kg) weight and 300 W required power. The microwave will be similar to that used for Aquarius satellite.

The command and control and data telemetry will be at 20 Mbps. Over-the-horizon network capability is required with near real-time communication with underwater vehicles and buoys to support flexibility in tasking.

Mission: Active Fire, Emissions, and Plume Assessment

Source: NASA Science Mission Directorate / Carbon Cycle, Ecosystems, and Biogeochemistry Focus

This suborbital mission would help Earth Science scientists further understand the influence of disturbance on carbon cycle dynamics by observing and measuring: the atmospheric chemistry; the thermal intensity time-series; the plume composition, including the volume, albedo, particle size distribution; and, the fuel type and quality. The measurements would also provide the atmospheric composition focus area a better understanding of fire plume chemical constituents resulting from different fuels under different intensities of fire. The suborbital platform is ideally suited for these measurements because of its loitering capabilities and the fact that the plume measurements are dangerous and dirty.

The mission will be based on the fire season, which in North America is from May through September. The mission requires a flying formation of at least two platforms – one (disposable) for *in situ* plume measurements and the other, at a higher altitude, for fire dynamics. An alternative to the configuration is to drop the instruments into the plume. The mission will follow the plume and will range from the source of the plume to deposition. Deployment will be contingent upon human or satellite detection. Specifically, the deployment may be cued from:

- MODIS/VIIRS active fire detection or human detection; specific flight preparations would be determined by fire season and fire risk assessment. In addition, flights would follow dry lightning storms to search for new fires.
- A high-altitude, long duration aircraft could loiter over an area for week to months, wait for fire and task lower altitude assets.
- A prescribed burn that would allow for more thorough assessment of pre and post fire carbon mass balance.

The platforms must have an endurance capability of 24 to 72 hours, the typical duration of a fire. Range must be up to 5500 nm (10000 km). The *in situ* platform may also have several unique issues:

- plume sampling would require the ability of the platform to withstand extreme vertical velocities coming off the fire
- an electric propulsion system would prevent issues associated with engine air intake and fuel flammability
- airframe and sensor materials would need to be fire proof.

The suborbital payload for this mission will consist of three groups of instrumentation: a) isotope ratio mass spectrometers, gas chromatographer, non-dispersive infrared (IR) analyzer; b) imaging spectroscopy and c) a LIDAR. The spectrometers, chromatographer and IR analyzer will weigh between 110 and 220 lbs (50 and 100kg), and will require an accurate IMU and a 3-dimensional wind field at 10 Hz or better. The imaging spectroscopy will be less than 110 lbs (50kg), 18 ft^3 (0.5 m^3) and require 200 W. The LIDAR will be a waveform and will be able to resolve particles ranging from less than 0.05micron – 20 microns. It will weigh approximately 66 lbs (30kg) and require 600 W. Both the imaging spectroscopy and the LIDAR require downward looking ports. The imaging spectroscopy will have a 16 to 66 ft (5 to 20 m) horizontal and a 2.7 to 27 nm (5 to 50 km) swath; the LIDAR will cover a 3.25 ft (1 m) horizontal, 0.5 ft (15 cm) vertical and less than 1.6 nm (3 km) swath.

The command and control and data telemetry will require over-the-horizon capability. In addition, real-time data would be telemetered to the field.

Mission: O2 and CO2 Flux Measurements
Source: NASA Science Mission Directorate / Carbon Cycle, Ecosystems, and Biogeochemistry Focus
This suborbital mission would help scientists further understand the flux of O_2 and CO_2 and other trace gases between the surface (land and sea) and atmosphere and how it changes with space and time. Diurnal time series measurements of surface to atmosphere gas flux are critical. Specifically the mission must provide science data that contains CO_2 and O_2 measurements, separating out land from ocean fluxes, to less than 0.1 parts per million. The data must have a vertical resolution of column CO_2 that is expressed as a function of atmospheric pressure gradients, with resolved differences as low as 10 millibar and a horizontal resolution of 328 ft (100 m) for interferometer and 33 ft (10 m) for flux measurements.

These observations and measurements will support the carbon cycle science focus area roadmap. They will provide higher resolution data on sources and sinks of atmospheric CO_2 on land and in the ocean and information to scale up flux measurements from tower networks.

Flight characteristics will include multiple platforms, depending on the complexity of the mission, that resolve horizontal distribution and errors introduced by advection. Scientific measurements will be global (land and sea) and seasonal. The mission flight path will vary according to changes in weather, input from *in situ* sensors, and other UAVs in swarm, etc. Flight profiles and maneuvers in time, space and geographic coordinates include:

- multiple altitudes, either by ascending spiral or stacked array
- flying as low as possible, appropriate to regime being measured by the interferometer
- determining the speed as a function of the integration time of instruments
- determining airspeed as a function of the speed of the air mass being measured
- establishing a racetrack pattern to follow the air mass.

One unique mission issue is the fact that the land fluxes are 10 to 50 times greater than the ocean fluxes.

This mission places the following requirements on the platforms. The platforms must have a 24-hour endurance capability to obtain data for diurnal patterns. The platforms will have a pressurized, temperature controlled hard-drive for on-board data storage. The vehicle management system must provide for coordinating multiple platforms and inputs from several sources. The system must also provide for low altitude flight down to 328 ft (100 m), thereby requiring terrain avoidance algorithms.

The suborbital payload will consist of two groups of instrumentation: isotope ratio mass spectrometers, gas chromatographer, non-dispersive IR analyzer; and an upward-looking Michelson interferometer in the 4 micron band. The spectrometers, chromatographer and IR analyzer will weigh between 110 and 220 lbs (50 and 100 kg), and will require an accurate IMU and a 3-dimensional wind field at 10 Hz or better. The upward looking Michelson interferometer will weigh approximately 110 lbs (50kg), have an upward viewing port and fly in an attitude as low as possible.

The command and control and data telemetry will require over the horizon capability for control and data relay. The data rate is expected to be greater than 1 Mbps.

Mission: Vegetation Structure, Composition, and Canopy Chemistry
Source: NASA Science Mission Directorate / Carbon Cycle, Ecosystems, and Biogeochemistry Focus
This suborbital mission would help scientists improve the characterization of terrestrial biomass, leaf level chemistry and canopy water content. The science data will provide vegetation 3-dimensional structure and information on composition and chemistry. In addition, the observations will elucidate functional groups and physiological impacts on the carbon cycle.

The missions will include observations at flux tower locations and long term ecological experiments and ecological transects along ecological gradients. Collection opportunities will be optimized using meteorological data. To accomplish the mission, the formation will require 3 to 7 platforms each carrying P/L band radars and a subset carrying hyperspectral and LIDAR instruments. Weekly, during all seasons, the missions will cover major ecological biomes distributed worldwide.

To perform this mission the platforms will be required to cruise at approximately 40,000 ft (12 km) with an endurance of between 12 and 24 hours. The platforms will be in straight and level flight with sufficient geolocation and attitude through GPS or metrology.

The payload will consist of four instruments: a) Radar: interferometric, weighing less than 660 lbs (300 kg), less than 35 ft^3 (1 m^3), 2 to 3 kW, 16 to 32 ft (5 to 10 m) horizontal, 3.3 ft (1 m) vertical and 2.7 to 11 nm (5 to 20 km) swath; b) Imaging spectroscopy, a hyperspectral sensor (350 nm to 2500 nm, 650 km to 4600 km), weighing less than 110 lbs (50 kg), 16 ft^3 (0.5 m^3), 200 W with a downward-looking port, 16 to 66 ft (5 to 20 m) horizontal and 2.7 to 27 nm (5 to 50 km) swath; c) LIDAR: two frequency (1700 ft (525 m), 1050 nm (1950 km)) digitized waveform, weighing less than 66 lbs (30 kg), approximately 600 W or power, downward-looking port, 3.2 ft (1 m) horizontal and 0.5 ft (15 cm) vertical with less than 1.6 nm (3 km) swath; and d) Very High Frequency (VHF) antenna, details to be defined.

Mission achievement requires over the horizon communications capabilities; with telemetry and command and control rates at 1 Mbps. In addition, precise position and attitude information to the level of sub-meter positioning for GPS (1 ft, 30cm); 5-10 arc sec attitude knowledge and active metrology for radar implementation will be needed.

Mission: Aerosol, Cloud, and Precipitation Distribution
Source: NASA Science Mission Directorate / Climate Variability and Change Focus

This mission is designed to measure the distribution in space and time of aerosols in regions polluted by industrialized areas. The data collected during this mission will improve the evaluation of climate sensitivity to the forcing of aerosols by:

- Quantifying how urban aerosol sources contribute to global aerosol budgets and loading
- Detecting the indirect effect of anthropogenic aerosol on cloud formation and radiative forcing
- Detecting multi-year to decadal trends in direct and indirect aerosol forcing.
- Developing a statistical data base of pollution impacts downstream of pollution sources

Other areas impacted by these observations include water cycle variability, regional weather, cloud and precipitation, and the carbon cycle through absorbing aerosols.

This mission requires the UAV platform to follow a pollution stream and collect spatially varying data on the chemical evolution and aerosol formation in the air. The UAV mission will range from 110 nm (200 km) upstream from a pollution source to 1100 nm (2000 km) downstream of that source. At various points downstream (5.5, 27, 135, and 675 nm) (10, 50, 250, and 1250 km) the aircraft will perform vertical and cross-track profile measurements. Flights will take place mainly in urban centers around the globe, but may also include flights into remote tropical and temperate latitudes. In some locations a sampling of the cloud systems may be desirable. To reconstruct the evolution of polluted air for a variety of meteorological conditions this mission should be repeated daily at a given source for a minimum of three weeks. To detect trends in the multi-year time scale this set of missions should be completed once a year. A large number of flights (about 10000 flight hours) over several years are required to collect the desired data, therefore it is critical to keep the cost per flight hour low (< 1000 $/hr). In general, the statistical nature of climate studies requires low flight hour costs.

Other variations of the mission are also postulated. Simultaneously collecting data along the direction of the pollution transport would be ideal. This would require multiple aircraft (possibly a piloted and unpiloted mixture) deployed from different locations working in close coordination. Another variation of the mission is to measure temporal effects by collecting data over a diurnal cycle at each measurement location.

The mission requires the vehicle’s flight management system to allow a ground commanded re-direction of the flight path during the flight. Also, since data collection occurs near urban pollution sources, air space access for UAVs and cooperation with air traffic control is necessary. The platform’s range must be a minimum of 1100 nm

(2000 km). The platform must be capable of maneuvering between 2,000 and 60,000 feet (0.61 and 18 km) to sample cloud systems. Endurance requirements, based on the diurnal cycle mission variations, are 20 to 30 hours. In addition mission variations require the vehicle management system to allow multiple platform coordination.

To perform the mission the platform must carry a large variety of payload sensors as listed: scanning polarimeter, atmospheric gas and particle samplers (e.g. mass spectrometer), broadband and spectral flux radiometers with precise attitude measurements (< 0.1 degree from horizontal), interferometer for measuring water vapor, LIDAR, cloud radar, and simple imagers. Payload weight is anticipated to be 1100 lbs (500 kg) and power requirements are 5 to 10 kW. Some external sampling probes and up and down looking ports must be provided.

Since data monitoring requirements are primarily for the purpose of quality assurance, the aircraft must only support low communication bandwidths. However, an OTH communication network may be required, which supports operations in remote locations.

Mission: Glacier and Ice Sheet Dynamics
Source: NASA Science Mission Directorate / Climate Variability and Change Focus
This mission supports measurements of the dynamics of the breakup of polar glacier and polar ice sheets. The measurements enable direct observation of the evolution in time of ice and land topography, iceberg volume, glacier profiles, and glacier channel profiles and provide data for validating simulations of these dynamics and their interaction with the ocean environment. Other benefits include measures of the impacts on ocean currents, regional weather and climate, water cycle variability, and clouds and precipitation.

To understand the impact of ice sheet dynamics on various systems the initial states of those systems must be measured. Thus, this mission requires two phases. The first phase involves initial mapping and documenting of the polar regions, particularly those where breakups are anticipated (e.g. Larsen C in Antarctica). This phase, in particular, involves a relatively large number of flight hours. As such low costs per flight hour (<1000 $/hr) and quick turn-around times between flights (or multiple platforms) are critical. The second phase occurs when the beginning of a breakup is detected. At that point a quick deployment of the platform and its support equipment to the nearest serviceable airport is necessary. Unique characteristics of this mission will include dropping buoys for ocean measurements, and dropping radio frequency transponders on large icebergs that break off the ice sheet for tracking purposes. After collecting data during the break-up a final mapping and documenting of the polar region occurs.

For both phases of the mission the platform must have the range to reach any part of either polar region from a base of operations, with an endurance of up to 24 hours. High altitude flight is not required, but variations in altitude from 12,000 feet (3.6 km) to 20,000 feet (6.1 km) are. Turn-around times between flights should allow the platform to be available for a mission at least 50% of its deployment time. During the ice breakup, the platform should be able to perform 1 mission every 3 days over the course of a 2 month campaign. During the second phase, the ability to upload a new flight profile to the vehicle's flight management system to re-task the platform while in flight is critical for catching interesting dynamic events as they develop. The platform must provide for deployment of drop buoys as well.

Because of the large variety of measurements required, e.g. ocean salinity, temperature, and current flow both at the surface and at iceberg depths; a host of sensor payloads are carried by the platform. These are listed as follows: radar depth sounder, scanning LIDAR, drop buoys, drop-sondes, microwave sounder, radio frequency transponders for tracking icebergs, magnetometer, atmospheric gas and particle samplers, and simple imagers. Anticipated payload weight is 1000 lbs (454 kg) and power requirements are 10 kW.

An over-the-horizon network to support data quality assurance is required, but data bandwidth can be low.

Mission: Radiation - Vertical Profiles of Shortwave Atmospheric Heating Rates
Source: NASA Science Mission Directorate / Climate Variability and Change Focus
This mission will collect data on the vertical profile of shortwave atmospheric heating rates in polluted and unpolluted clear and cloudy skies. Measurements will take place in mega-cities and industrialized regions in different climatological regimes. The data collected will improve the evaluation of climate sensitivity to the forcing of aerosols by:

- Quantifying how urban aerosol sources contribute to global aerosol forcing
- Detecting the indirect effect of anthropogenic aerosol on cloud radiative forcing

The data also impacts weather forecasting, the role of heating rates in cloud and precipitation processes, carbon cycles through absorbing aerosols, and the capability for detecting bio-aerosol sources and dispersion.

The mission concept calls for a major platform to make cloud and aerosol state parameter measurements and up to ten Mini-Aerial Vehicles (MAVs) platforms to make radiative flux measurements. A geographic point of interest within a region is selected and the major platform is launched and flown to that point. At that time either the MAVs are launched from the major platform, or the MAVs are launched separately and rendezvous with major platform. In either case each of the smaller UAVs are assigned to hover or circle at a given altitude to form a column around the point of interest. The major platform then flies in upward and downward spirals around the column. After data is collected the mission is repeated at another point of interest within a 54 nm by 54 nm (100 km by 100 km) region of interest. Collection of 50 sets of data within a region is desired. To get the effects due to varying weather conditions the mission is repeated on a near daily basis. Many flight hours are required to perform this mission in order to obtain statistically meaningful data across a variety of aerosol types and meteorological conditions. A low cost per flight hour is essential (<1000 $/hr).

The platforms in support of this mission must be capable of flying between the surface and 60,000 feet (18.3 km). The MAVs must be able to hover over a geographic location within a 328 feet (100 meter) radius at a given altitude. On-station endurance for both platforms is 6 hours for one set of data, centered on solar noon. Vehicle management system for the major platform must allow re-tasking, while the vehicle management system on both types of platforms must allow for coordinated flying. The system must support flying within the air space and, since the major platform in particular will fly near the surface, the system should employ terrain avoidance algorithms.

Payload for the major platform consists of broadband and spectral flux radiometers with upward and downward looking ports, drop-sondes or balloon sondes for temperature and water profiles, atmospheric gas and particle samplers, LIDAR and cloud radar, and sky imagers. Payload weight is anticipated to be 660 lbs (300 kg) and total power required to be 3 to 5 kW.

Payload for the MAV platforms include broadband and spectral flux radiometers with upward and downward looking ports, temperature monitoring, a simple imager, and a transmitter to transmit data to the major platform. Payload weight is anticipated to be 22 to 44 lbs (10 to 20 kg). The total power is estimated to be 10W with a total payload volume of 7 cubic inches (100 cubic cm).

Some unique communication requirements exist for this mission. The location and altitude targets for the MAVs are uploaded from the ground to the major platform during the mission. These targets can be adjusted as the mission progresses. The major platform then communicates to each of the MAVs their assigned altitude. The data from the MAVs consists of status and information required to perform the mission as well as the payload sensor data, which is recorded on-board the major platform or down-linked for recording on a ground computer.

Mission: Ice Sheet Thickness and Surface Deformation
Source: NASA Science Mission Directorate / Earth Surface and Interior Structure Focus

The purpose of this mission is the accurate measurement of ice sheet thickness and crustal deformation of underlying surfaces due to ice sheet loading and earth internal activities such as earthquakes. These measurements are important for the study of glaciers and global warming.

The approach would be to use many (> 50) MAV platforms, each carrying a synchronized VHF or Ultra High Frequency transmitter/receiver module, in formation flight. This would require relative positioning of the platforms with respect to a coordinate system to within a fraction of a wavelength. These would operate at about 500 feet (152 m) to achieve high resolution and for signal/noise considerations. The MAVs would fly parallel straight lines to get a raster image of 5.4 nm by 1 nm (10 km by

2 km).

Since flight at low altitude is required, the vehicle management system should employ a terrain avoidance algorithm. The system must also allow multi-ship coordination amongst vehicles in formation flight. The platform range requirement is estimated to be 100 nm (185 km).

Payload requirements for weight and volume would be about 7 lbs (3.2 kg) and 70 cubic inches (1000 cubic cm). The MAV platform would need to supply about ten watts of power to the payload.

It would also need a relatively high data rate communication link to a satellite, base station, or mother ship for data collection, command, and control.

Mission: Imaging Spectroscopy
Source: NASA Science Mission Directorate / Earth Surface and Interior Structure Focus

The intent of this mission is to collect spectra as images to determine surface composition, change, water vapor and sulfur dioxide in space and time. Specifically, this mission would measure:

- the composition and change at the surface-atmosphere interface
- accurate and precise 3-dimensional water vapor for GPS based derivations
- 3-dimensional SO_2 and other phenomena associated with active volcanology
- earthquake fault optical spectroscopy properties before and after

Baseline data would be collected and updated periodically. Phenomena (volcanic eruption, earthquake, flood, etc) data could also be measured as desirable.

The UAV platform would fly at approximately 45000 feet (13.7 km) altitude and would need an endurance of 12-24 hours. Rapid response would be necessary to support phenomena measurements. Mission support anywhere in the world should be possible.

The payload for this mission would weigh about 110 lbs (50 kg) and would require the volume of about 17.6 ft^3 (0.5 m^3). About 200W of power would be required. A down-looking port is also necessary.

Real-time communication for quick-look data is required.

Mission: Topographic Mapping and Topographic Change with LIDAR
Source: NASA Science Mission Directorate / Earth Surface and Interior Structure Focus

The purpose of this mission would be to generate high-resolution topographic mapping and topographic change-detection of targeted ground areas (including those covered by vegetation) using LIDAR measurements. All-terrain topographic change detection by repeat mapping compliments interferometric SAR measurements of sub-centimeter to decimeter surface levels (e.g., observe decimeter to tens of meter near-field surface deformation in the vicinity of ruptured faults and inflating volcanoes to understand earthquake and magmatic processes; observe decimeter to hundreds of meters topographic change associated with landslides, volcanic eruptions and flows, coastal and fluvial erosion and sediment redistribution). Targets of highest priority are narrow, long, quasi-linear features (e.g. fault zones, coastal zones) amenable to targeted mapping or point features (e.g. volcanoes) amenable to station-keeping monitoring. The mission requires data to be collected over a series of offset, parallel, overlapping flight tracks to build up a corridor of data covering the region of interest.

To collect the desired data the platform should operate at a constant altitude of 65000 feet (19.8 km) with a ground speed of about 200 knots (100 m/sec). Target positioning (achieved by combination of platform navigation and sensor steering to compensate for platform roll) should provide a ground track with cross-track accuracy of 490 ft (150 m). Precision knowledge of the flight path (2 inches) (5 cm) and sensor attitude (5 arc sec) is required for post-mission processing of the data. Platform range should be on the order of 2000 nm (3700 km). The platform should be capable of autonomous operation with human intervention and should provide on-board intelligence with operational limits for instrument health and safety as is done for orbital instruments. The platform's vehicle management system must be able to optimize flight path based on weather and cloud cover information to acquire data in clearest areas.

The primary payload is a geodetic imaging LIDAR (i.e., scanning laser altimeter) capable of 1.5 million range observations per second (1.6 nm (3 km) swath width, 5 returns per 3.28 ft (1 m) pixel, & 200 knots (100 m/sec) ground speed). Based on expected advances in instrument technology, the expected weight, volume and power requirements are 65 pounds (30 kg), 2.5 cubic feet (64000 cm^3), and 200 watts respectively.

Low-rate, over-the-horizon communication is required for performance assessment and command/control. A high-bandwidth (megabits/second) data downlink is also required for time intervals on the order of a day. Full-rate data should be stored on board for retrieval at the end of a flight. A sensor web implementation is needed to autonomously provide weather and cloud cover information to the platform.

Mission: Gravitational Acceleration Measurements
Source: NASA Science Mission Directorate / Earth Surface and Interior Structure Focus

This mission would accurately measure gravitational acceleration that varies spatially and temporally near Earth, as a consequence of the inhomogeneity and the dynamics of Earth's mass density structure. This spatial variation occurs at all scales, from thousands of kilometers, due to core/mantle boundary anomalies, to sub-kilometer and smaller, due to local topographic (or bathymetric) masses. Earth's gravitational field defines satellite orbits, affects inertial navigation, reflects oil and mineral deposits, and characterizes crustal geologic structure. The equipotential surface, known as the geoid, defines a reference for sea surface topography (leading to oceanographic current determination through satellite ocean altimetry), and it defines the conventional reference of heights for national vertical geodetic control.

The UAV platform would fly a grid pattern at 15,000 to 30,000 feet (4.5 to 9 km) altitude utilizing long (~60 nautical miles (111 km)) straight tracks. The accuracy requirements for trajectories are on the order of 100 feet (30.5 m). Time synchronization with GPS time is critical, and geospatial registration is required to an accuracy of 10 feet (3.1 m).

Simple gravimetry systems weigh about 20 pounds (9.1 kg), require about 0.4 cubic feet of volume (.01 m^3), and consume about 20 W of power; higher accuracy units require more of each capability, and specialized, high-cost measurement units are also available.

Real-time data transmission to a base station is not required, since post-mission processing of data is the common application, but on-board data recording is necessary.

Mission: Antarctic Exploration Surveyor
Source: NASA Science Mission Directorate / Earth Surface and Interior Structure Focus
This mission would provide coordinated magnetometer, gravity, and LIDAR measurements from a small, easily deployed autonomous low-cost aircraft platform. These measurements would allow basic mapping to determine ice sheet bed characteristics and ice sheet elevation. This data would allow scientists to examine the geologic controls on ice sheet dynamics.

To perform this mission flights would be conducted from the coast into the interior at a low altitude, thereby setting the range requirement for the platform. One concept would be to deploy from an ice breaker, which would allow a lower range (~500 nautical miles (925 km)) to be used.

The UAV platform payload would include a lightweight compact vector or scalar magnetometer, a strap-down gravity measurement system, and a small LIDAR system.

A low-data-rate telemetry system would be required for communication purposes.

Mission: Magnetic Fields Measurements
Source: NASA Science Mission Directorate / Earth Surface and Interior Structure Focus
The purpose of this mission would be to measure vector and tensor magnetic fields to support comprehensive magnetic field source models and isolate time-varying crustal field components. The magnetic field spectrum is under-sampled in the spatial wavelengths intermediate between the near-surface (up to 1.1 nm (2 km)) and satellite altitude (190 nm to 380 nm) (350 to 700 km). These measurements are critical to producing models that account for all sources of magnetic fields from crust to core.

Flight scenarios could range from a calibrated vector magnetometer on a single UAV platform, to simultaneous measurements from coordinated platforms over a wide area (thus eliminating noise from external time-varying fields), to magnetic tensor measurements using four MAVs flying in formation. Measurements would be obtained either in a grid pattern or long prescribed flight lines.

The platform is required to collect data flying a pre-designated flight plan at altitudes ranging from 3000 feet (1 km) to 100,000 feet (30.5 km). The platform should be capable of night flying, because of a preference for the quiet external field environment. Additionally, the platform would need to magnetically quiet.

The magnetometer weight is less than 5 pounds (2.3 kg) and would require approximately 60 cubic inches of volume (983 cm^3). Instrument attitude would need to be known within a few arc-sec of accuracy. Data would be sampled in the 1 to 20 samples per second range.

The data volume is relatively low and could be stored onboard, although some low bandwidth communication for command and monitoring would be desirable.

Mission: Cloud Properties
Source: NASA Science Mission Directorate / Water and Energy Cycles Focus
This mission is designed to collect *in situ* data on cloud microphysics. The data will allow better understanding of cloud dynamics and lead to improved weather and climate models. Weather, climate, and atmospheric composition focus areas will also benefit from the data collected in this mission.

The concept for this mission requires at least two, perhaps three, types of platforms. An imager platform hovers or circles a region of interest looking for critical environmental characteristics. It activates and then directs a second type of platform to perform spiral descents and ascents through clouds for *in situ* measurements. The capability to fly multiple *in situ* platforms (even if weighing < 4.4 lbs (2kg)) at once would increase the science return. *In situ* platforms could be tailored for specific measurements and tasked based on previous platform data. One option may be to include a third type of platform that stores and launches multiple *in situ* MAV platforms. It is desired to collect data anywhere in the globe, excluding polar regions. When a region of interest develops, the entire system has to be able to be shipped to base of operations, integrated, and launched within 1 to 3 days.

The imager platform requires an ability to station keep anywhere from a low altitude of 3000 feet (1 km) to a high altitude, perhaps 82,000 ft (25 km). To obtain temporal variations the imager must have at least 24 – 48 hours of endurance. Ideally one-week endurance would provide greater return on the science. A transport range for the imager platform of 5400 nm (10,000 km) before station keeping is desirable. Storage platform requirements are the same as the imager platform. The *in situ* platform requires altitude capability from 82,000 ft (25 km) to the surface. Range and endurance can be less (perhaps on the order of 5.4 nm (10 km) range) than the imager since *in situ* platforms can be launched in succession. But the total *in situ* platform system should provide data collecting capability that is equal to the imager endurance. The *in situ* platform may require a smart system that can direct its instrumentation based on imager commands or its own sensor data. A unique requirement for the *in situ* platform is that it should not influence (via chemical or heat exhaust) its own cloud measurements as it flies through the clouds. All aircraft involved require positional accuracy to 33 ft (10m) with an attitude accuracy of 0.1 degree for the imager.

Instrumentation for the Imager platform includes a passive microwave imager with minimally a 19 to183 GHz range, but ideally a 10 to 600 GHz range, a dual-pole multiple frequency microwave radar, a LIDAR, and smart drop-sondes. *In situ* type instrumentation is required for the *In situ* platform such as cloud particle imagers.

Communication links between the imager and the *in situ* platform should be available. The *in situ* platform should send measurement data back to the imager platform data recording. Using the OTH network, it is desired to send data to a ground station for data recording and data review. Given a storage platform, additional communication between it and the imager platform would be required.

Mission: River Discharge
Source: NASA Science Mission Directorate / Water and Energy Cycles Focus
This mission will collect data on the volume of water flowing in a river at multiple points. The data is critical for global and regional water balance studies. Other beneficiaries of this data include USGS, EPA, coastal zone studies, and floodplain mapping efforts.

To support the objective of this mission river geometry measurements and river height measurements are required. Two platforms will be utilized to collect these measurements. One platform equipped with a LIDAR, will be used to measure river geometry. The other platform, equipped with a SAR, will be used to measure river height. Three scenarios are presented to envision how this system might be used. In the first scenario the LIDAR platform is sent to fly the length of a river channel of interest. River geometry and path measurements from the LIDAR are fed back into the platform guidance routine, allowing the LIDAR to fly the platform along the river channel. After completing the flight, the data from the LIDAR platform is extracted and transferred into the radar platform vehicle management system. This platform then flies over the river in regions of interest to measure river height. The second scenario is a variation of the first one. In this scenario the radar platform flies in formation at some distance behind the LIDAR platform. In this case the geometry data from the LIDAR platform is required by the radar platform for guidance purposes. In the third scenario heavy upstream rains have occurred for a previously LIDAR mapped river. The radar platform is then deployed by itself to measure the river height dynamics. Flights during the low flow season, late summer or early fall, are best for collecting the geometry data. River heights should be measured at least once per year, especially during high flow periods. River geometry data should be collected a few times for each river, but river height data should be collected on demand, perhaps weekly.

For all scenarios the LIDAR platform must be able to fly below the clouds. The radar platform must collect data at a high enough altitude, 16,500 to 33,000 ft (5 to 10 km), for robust measurements. Accurate position knowledge is required for both vehicles. Endurance for the vehicles is established by how long it takes to fly a given river channel, and given the desired level of resolution, how long it takes to fly it's primary, secondary channels, etc.

Payload sensors required for these missions include a scanning LIDAR for the LIDAR platform and a dual-frequency radar on the Radar platform. LIDAR constraints in weight, volume, and power are 55 lbs (25 kg), 7 ft^3 (0.2 m^3), and 500W respectively. The dual frequency radar constraints for weight and power are 440 lbs (200 kg) (depending on antennae size) and 1 – 5 kW. Also, a C-band along-track radar interferometer on both platforms would allow additional calibration and cross-platform comparison.

Real-time ground station communication requirements for this mission can be of the quality assurance nature, hence low bandwidth. In the case of the second scenario real-time trajectory information from the LIDAR platform must be transmitted to the radar platform.

Mission: Snow – Liquid Water Equivalents
Source: NASA Science Mission Directorate / Water and Energy Cycles Focus
This mission was conceived to measure the amount of water stored in the snowpack at very high spatial resolution (≈ 165 ft (50m)). Also, snowpack characteristics such as depth, density, wetness, age, emissivity, albedo, etc will be measured. Measuring the snow characteristics has significant application for decision makers and is important for water budget. It would allow for improvements in snow prediction as well as understanding the climate data record.

The mission can be motivated by either a seasonal event, such as a large snowfall in a particular region, or a season long monitoring of selected snow covered regions all over the globe. The platform is programmed with a flight profile based on the location of the desired region of observation. Maneuvers and flight profiles will change based on the location, but flights in mountainous terrain are required. Collecting data at low above ground level altitudes and at specific points of interest are desired. Also, at points of interest the ability to drop a drop-sonde with *in situ* measurement capability would be of interest. Limited flight path re-direction from a ground control station is required. After the mission is completed the data, recorded on-board the platform, is downloaded and the airplane turned-around for another flight within 1 hour. The platform must be available for flight primarily in the spring, but also in the winter and fall.

Specific mission requirements include the ability of the platform to fly 330 ft (100m) above ground level, within a few meters precision, in mountainous terrain, while providing a relatively stable platform (3 degrees pitch, 5 degrees roll, and 3 degrees yaw) for payload sensors. As such the vehicle management system will have complex flight path maneuvering and terrain avoidance requirements. And the management system must allow re-direction from a ground station during the flight. The platform must fly a desired track within < 33 ft (10m). And since seasonal monitoring is a key concept for this mission, a 70 – 80% duty cycle over a 6-month season is required to get sufficient coverage. Desired endurance is 24 hours, but can be relaxed for complex terrain missions. The ability to launch multiple platforms is a desired feature that would enable greater spatial coverage.

Payload instrumentation required for this mission includes a dual-frequency SAR (C and Ku band), a dual frequency radiometer (K and Ka band), a camera, and a thermal camera. Total weight is about 660 lbs (300 kg), and total power required about 1 kW. Drop-sonde *in situ* sensors would have to be developed.

A relatively low bandwidth data communication link is required for real-time quality assurance data monitoring and limited platform re-tasking during the flight.

Mission: Soil Moisture and Freeze/Thaw States
Source: NASA Science Mission Directorate / Water and Energy Cycles Focus
This mission was envisioned for measuring surface soil moisture, deep soil moisture, and the freeze or thaw state of surface soil in the presence of vegetation. Benefits include improved water budgets and better modeling of the carbon cycle.

The mission is simply to fly the platform aircraft from the base of operations to a specified point of interest. The aircraft circles this location or flies repeated passes over this location for the purposes of collecting data. Variations in altitude between circles or passes may be required. As the mission progresses a team on the ground reviews the data and, if desired, re-directs the flight path or alters sensor specifications via an uplink capability from a ground station. After the mission, sensor data recorded on-board is downloaded quickly and the platform prepared for the next flight. An alternative to downloading on-board data after the mission is to develop the capability to download the data periodically during the mission. Geographic regions of interest include all land areas not covered by snow or ice.

To support this mission, the platform will typically fly between 3300 and 33,000 ft (1 and 10 km) in altitude, depending on the observation scale desired. A 70-80% duty cycle is required to support the mission, but for missions in remote areas the platform should have an endurance of 24 hours over the point of interest, and be capable of flying 2 to 3 times a week, as required. Ground track precision should be < 33 ft (10m) and a pointing accuracy of <0.1 degree is necessary for payload sensors. The platform systems should support high-speed download of the data, which is desirable for quick turn-around of the platform for the subsequent flight.

Payload instrumentation includes active and passive microwave with L band for measuring surface soil moisture and P bands and potentially longer wavelengths for deep soil moisture. Multi-polarization and conical scanning is desired. Total weight is less than 440 lbs (200 kg). Volume is dictated by antennae size, typically 10.8 to 53.8 ft^2 (1 to 5 m^2). The power required, depending on the instruments, range from 1 to 5 kW.

A low bandwidth uplink command is necessary with higher bandwidth downlinks available for real-time decision making.

Mission: Cloud Microphysics/Properties
Source: NASA Science Mission Directorate / Weather Focus
The purpose of this mission is to observe the microphysics and properties of clouds. Specifically this entails measurements of:

- Turbulence, vertical velocity
- Particle size distributions, habit, phases
- Liquid/ice contents
- Highly-accurate thermodynamic information
- Electrical and radiation characteristics

These data would provide better understanding of tropical rainfall and energy release, rain particle growth, and stratospheric water exchange enabling the improvement of satellite algorithms.

Cloud-penetrating UAV or MAV platforms might be launched from a mother ship or might take-off from the ground and fly into a cloud in formation. The platforms would be capable of different flight profiles, but would be under the supervision of a mother ship, other lead aircraft, or a ground-based control station. They would require a controlled descent and safe recovery at locations of opportunity, including automated landing site selection. These aircraft should be able to launch and fly on very short notice (2 to 3 hours).

The platforms would be hardened to severe environments (e.g. electrical, icing, turbulence). Ideally, they would fly at a slow airspeed (~100 knots (50 m/sec)), but should retain some maneuverability against headwinds. The altitude range for these UAVs would be from ground level to 100,000 feet (30.5 km). They would need a range of in excess of 500 nautical miles (925 km) and an endurance of about five hours.

They would carry particle size probes, a laser hygrometer, radiation pyrometers, electric field sensors/probes, and microwave sensors (optional).

The UAVs would require aircraft-to-aircraft or aircraft-to-ground high bandwidth/line-of-sight communications. On-board partial processing of measurements may also be required.

Mission: Focused Observations – Extreme Weather
Source: NASA Science Mission Directorate / Weather Focus
The purpose of this mission would be to accomplish process studies involving severe and hazardous weather events to improve the physics in mesoscale models (parameterizations). This approach would use high altitude remote sensing to gather data on precipitation, clouds, electrical phenomenon, and microphysics. These data would improve models used to predict winter storm hazards and provide accurate regional forecasting of rain and snow for economic decisions.

The UAV platform for this mission would fly at altitudes of 50,000 (15.2 km) to 65,000 feet (19.8 km) and would have a range of approximately 1000 nautical miles (1850 km) with an endurance of 1 to 2 days for continuous coverage of the storm event. The platform would be autonomously guided by satellite and ground-based measurement systems using targeted and adaptive operation with possible real-time human intervention.

Sensors would include remote sensing of temperature and water vapor, a radar and radiometer for clouds and precipitation, sensors for electrical activity and lightning, and drop-sondes when possible. It is expected that these sensors would weigh approximately 1000 pounds (455 kg) and would require 1 to 2 kilowatts of power. Appropriate viewing ports would be necessary. A pod may be necessary to carry the drop-sondes.

Communication rates on the order of 300 kilobits/second are required to telemeter data in real-time. On-board processing of the merged sensor data may also be required. Real-time control of the instruments (at a low bandwidth) will also be needed.

Mission: Forecast Initialization
Source: NASA Science Mission Directorate / Weather Focus
The intent of this mission is to gather data that will improve weather forecasting and augment data available from satellites. This includes both a research element such as determining data sensitive regions (e.g. THORPEX, atmospheric rivers) and an operational element (e.g. NOAA/NCEP winter storms program). Missions would include observations would be made for short term (24 hour) initialization where observable events were already formed, and longer term (3 to 7 days). Additional benefits would include satellite validation (e.g. GPM and GIFTS) and the improved use of satellites for forecasting. The use of UAVs provides an opportunity for measurements from vertical profiling that are not available from satellites. Missions would be event oriented with the Eastern Pacific, Northern Atlantic, and Arctic/Antarctic as probable target areas.

Several types of platforms would be used for this mission. A mother ship would fly at high altitudes (~50, 000 feet (15.2 km)), with an endurance ranging from twelve hours to several days. Platform range would need to be better than 1000 nautical miles (1850 km). At least two tropospheric and five boundary layer aircraft would be required for supplemental measurements. The tropospheric aircraft would need to fly in the 20000 to 40000 feet (6.1 to 12.2 km) range; the boundary layer aircraft would fly between 500 feet (.15 km) and 20000 feet (6.1 km). Daughter ships would need to be rugged with all-weather performance during lightning, icing, graupel, turbulence. The daughter ships would need to be autonomously controlled in formation flight by a lead entity: a satellite, the mother ship or a ground control station but would allow for human intervention. The daughter ships could be expendable, but would preferably be redockable to the mother ship so that they could be reused. An alternative to daughter ships would be drop-sondes.

Sensors for the high-altitude aircraft would include *in situ* meteorological measurements, remote sensing of temperature and water vapor, a radar and radiometer for clouds and precipitation, sensors for electrical activity and lightning, sensors for surface wave spectra (GPS reflectance, LIDAR), and instruments for visible imaging for eye wall (Rossby waves). Appropriate viewing ports would be necessary. A pod may be necessary to carry the drop-sondes. The total payload weight would be on the order of 1000 lbs (455 kg). Sensors for the tropospheric aircraft would be similar to instrumentation found on drop-sondes. Boundary layer aircraft would carry an infrared pyrometer, an instrument to measure *in situ* winds (new instrument development), an instrument for surface imaging (visible), a sensor to measure turbulent fluxes (new instrument development), and other instruments commonly found on a meteorological drop-sonde.

Communication rates on the order of 300 kilobits/second are required to telemeter data in real-time. A wide-band, line-of-sight data link will be necessary to coordinate data. On-board processing of the merged sensor data may also be required. Real-time data assimilation into forecast models would be the goal. Real-time control of the instruments (at a low bandwidth) will be needed.

Mission: Hurricane Genesis, Evolution, and Landfall
Source: NASA Science Mission Directorate / Weather Focus
The purpose of this mission would be to accomplish observations of hurricanes to improve predictions of hurricane paths and landfall. This approach would use high altitude remote sensing to gather data on precipitation, clouds, electrical phenomenon, microphysics, and dust. Daughter ships or drop-sondes would gather data (four-dimensional cubes of thermodynamic variables and winds) at lower altitudes. Additional data would be gathered in the boundary layer (sea surface temperature and surface winds, surface imaging, turbulent fluxes, water surface state). Measurements of this type would improve hurricane modeling capability to increase human safety.

Several types of UAV platforms would be used for this mission. A mother ship would fly at high altitudes (~65,000 (19.8 km)) above the storm. Mission durations would be on the order of two to three weeks, but could be accomplished with multiple platforms with less endurance capability. Aircraft range would need to be better than 1000 nautical miles (1850 km). At least two tropospheric and five boundary layer aircraft would be required for supplemental measurements. The tropospheric aircraft would need to fly in the 20,000-40,000 feet (6.1 to 12.2 km) range; the boundary layer aircraft would fly between 500 feet (.15 km) and 20,000 feet (6.1 km). Daughter ships would need to be rugged with all-weather performance during lightning, icing, graupel, turbulence. The daughter ships would need to be autonomously controlled in formation flight by a lead entity, a satellite, the mother ship or a ground control station but would allow for human intervention. The daughter ships could be expendable, but would preferably be redockable to the mother ship so that they could be reused. An alternative to daughter ships would be drop-sondes, although many would have to be carried by the mother ship to provide measurements for two weeks.

Sensors for the high-altitude aircraft would include *in situ* meteorological measurements, remote sensing of temperature and water vapor, a radar and radiometer for clouds and precipitation, sensors for electrical activity and lightning, sensors for surface wave spectra (GPS reflectance, LIDAR), and instruments for visible imaging for eye wall (Rossby waves). Appropriate viewing ports would be necessary. A pod may be necessary to carry the drop-sondes. Sensors for the tropospheric aircraft would be similar to instrumentation found on drop-sondes. The boundary layer aircraft would carry an infrared pyrometer, an instrument to measure *in situ* winds (new instrument development), an instrument for surface imaging (visible), a sensor to measure turbulent fluxes (new instrument development), and other instruments commonly found on a meteorological drop-sonde.

Communication rates on the order of 300 kilobits/second are required to telemeter data in real-time. A wide-band, line-of-sight data link will be necessary to coordinate data. On-board processing of the merged sensor data may also be required. Real-time control of the instruments (at a low bandwidth) will be needed.

Mission: Physical Oceanography, Meteorology, and Atmospheric Chemistry
Source: University of Hawaii / Department of Oceanography
During seasonal storms in the North Pacific, North Atlantic, and the Southern Ocean small scale but relatively intense exchanges of mass and energy occur between the ocean surface and the lower atmosphere. This mission would allow scientists to study these exchanges in turbulent, high energy density environments in or near storm systems and will help them understand their broader implications for larger scale phenomena such as:

- Understanding break-up or development of the thermocline and surface mixed layer during high winds.
- Understanding transition between disorganized and coherent wave patterns that transit whole ocean basins
- Understanding vertical transport of oceanic aerosols to the marine boundary layer inversion where they participate in the Earth’s radiation balance by acting as cloud condensation nuclei.
- Understanding the transport of oceanic gases to the free troposphere and stratosphere where they are photo-oxidized and participate in gas-particle conversion and atmospheric processes involving heterogeneous chemistry.

The mission would require one or possibly two UAV platforms. The concept calls for a low-altitude UAV to be designed to operate from an oceanic research vessel. During the appropriate season the ship would be stationed near a cyclogenesis region. When periodic lows developed and passed near the ship, this UAV platform could deployed into the cyclogenesis region with high waves and turbulence. Since cloud cover may preclude the platform from using satellite data to autonomously track the storm system, it may be desirable to have a second UAV platform at a higher altitude to perform this function. This data could be downlinked to the control station on the ship to allow an operator on the ground to re-direct the low-altitude platform’s flight path. At various points in the mission it would be desirable for the low-altitude platform to deploy drop-sondes or buoys to track ocean surface features. Another feature of the mission would require the low-altitude platform to fly along- and across wind patterns for collecting thermodynamic, gas, and aerosol data. After the mission the low-altitude platform would be recovered by the ship.

To perform this mission the low-altitude UAV platform requires an endurance of 6 to 24 hours. Altitude range does not have to be great, but should cover 10 ft (3 meters) from the surface up to 19,700 ft (6000 meters). As such the vehicle management system should include terrain avoidance and should be able to operate in seas with 33 ft (10m) face-height swells. The management system should also allow flight path re-direction from the ground station. Despite the maneuvering required and the turbulence, it is desired to keep the platform at a relatively stable attitude. The platform must be rugged, capable of operating in Beaufort scale 6+ winds/sea state. An additional feature is that the platform should be waterproof, corrosion resistant, and able to withstand the likely event it crashes into the ocean. In this event a transponder and a neutrally buoyant recovery system would aid in the recovery of the vehicle. The platform should fly 3 days continuously with re-fueling, or fly 2 to 3 times per week.

The payload is divided into three classes of measurements: meteorology/thermodynamic, trace gases, and aerosols/droplets. The total estimated weight is 2200 to 8800 lbs (1000 to 4000 kg), and the estimated volume is 35.3 to 141 ft^3 (1 to 4 m^3). The payload requires rear-facing trace gas sampling ports, self-aspirating aerosol sampling ports designed to reduce droplet shatter, and forward and nadir viewing imaging equipment that is self-cleaning in the presence of sea spray.

Fast, reliable communication links that allow real-time monitoring of the platform and data recording on the ground station is essential. Also, some uplink control of the low-altitude payload instrumentation is necessary.

D.3 Homeland Security Missions

Mission: Coastal Patrol
Source: US Coast Guard
This is a U.S. Coast Guard mission. It is a surveillance mission of maritime traffic off the shores of the USA (east & west coast, Alaska & Hawaii). Flights would launch and recover from one to three locations within 100 miles (213 km) of the coast for each of the four regions listed above. Missions would traverse our coastal waters 50 to 500 miles (106.5 to 1065 km) off shore.

Aircraft will be flown primarily at an altitude between 20,000 (6.1 km) and 50,000 feet (15.2 km) ; however, occasional descents to 2,000 feet (.61 km) will occur with potential multiple unplanned climbs and descents during any given mission. The aircraft would fly from one sea region to the next and loiter in each region for a period of time. The UAV would provide surveillance support to the cutter Commander responsible for that region during that loiter-period. As such, partial or full command and control may be passed to an operator onboard that cutter. This is a year-round mission precipitating the need for an anti-icing capability. Platform range will be a minimum of TBD nm. The vehicle management system should allow for direct control or flight path re-direction from a ground station. An additional variation of this mission may include the carriage and deployment of a mini-UAV (MAV) that would be used in closer proximity to suspicious vessels. The MAV would be released at altitudes 20,000 feet (6.1 km) and above and fly to altitudes as low as 100 feet (30 m). The MAV would maneuver as directed to within 300 feet (91 m) in real-time in and around the vessel under suspicion. The MAV would either terminate its mission into the ocean or be recovered on shore.

Payloads will consist of various EO and IR sensors up to TBD pounds and TBD cubic feet. Sensing requirements include the ability to read vessel name, detect ship personnel activity, determine dumping activities and detect driftnets deployed in the water.

Sensor data from the UAV and MAV must be available real-time. OTH network communications for command and control of the UAV are required. Command and control of the MAV could be routed through the mother ship.

D.4 Land Management Missions

Mission: Forest Fire Damage Assessment
Source: US Forest Service
This mission determines the level of damage to an area following a fire. Areas of flight would be in remote areas and occasionally near and slightly into urban/moderately populated areas.

This mission could be conducted at high altitude (20,000 (6.1 km) to 60,000 feet (18.3 km)) with high fidelity sensors or low altitude using low fidelity EO and IR sensors. The high altitude approach to this mission would parallel other High Altitude, Long Endurance (HALE) missions. The low altitude approach would require multiple MAVs collaborating on areas of overflight. Collaboration may be directed from a single point ground control element or directly between the UAVs.

The low-altitude payloads would be in the one or two pound (.5 or 1 kg) category, thus enabling the use of smaller and more economical MAVs. Additional payload required with weight and volume requirements are TBD.

Communication requirements are TBD, but some level of real-time availability is anticipated.

Mission: Forest Fire Mapping
Source: US Forest Service

This mission determines the location of active fires in support of fire fighting agencies. These fires may include the major fire front as well as hotspots behind the fire front with flames as small as 6 inches (15 cm) high.

Launch and recovery would occur at either field locations or dedicated fire fighting airfield locations. Flights emanating and terminating at field locations would require aircraft with high crosswind and gust limits. Payloads would provide multi-spectral imagery in real-time that must be geo-referenced and available at field locations within TBD minutes of real-time. This geo-referenced data could be fed into fire prediction models on the ground to better understand the hazards to personnel and better direct resources. This is a seasonal mission. Fire season starts in late spring in the south east of the US and ends in November in the west. The Alaska fire season lasts from late May to early September. It may be more cost effective for aircraft supporting fire fighting to be able to adapt to another mission in the winter time to allow cost sharing.

The platform required for this mission may need to have range capabilities of 2,000 nm (3700 km) and transit from one fire location to the next around the country. Air space requirements extend from 10,000 to 60,000 feet (3.1 to 18.3 km) in and around the fire area (this area is typically a special use area during a fire), as such, transit to and from the fire area would occur from altitudes of 20,000 feet (6.2 km) up to 60,000 feet (18.3 km).

Payload requirements are TBD.

Communication requirements are TBD.

Mission: Forest Fire Communications
Source: US Forest Service
This mission provides a communications relay between the field command center and personnel in the field fighting the fire. Fire fighting typically takes place in rugged terrain, which at times renders standard line-of-sight communication inoperative.

The mission requires a UAV to loiter over the fire fighting personnel and maintain line-of-sight between them and the field command center. One larger UAV could be used at medium to high altitude (possibly the same vehicle used for mapping in 3.29) or multiple MAVs could be used at lower altitudes. Platforms in the low to medium altitude range require either awareness of plume location to avoid engine out or propulsion with the ability to operate in dense smoke for extended periods. This is a seasonal mission. Fire season starts in late spring in the south east of the US and ends in November in the west. The Alaska fire season lasts from late May to early September. It may be more cost effective for vehicles supporting fire fighting to be able to adapt to another mission in the winter time to allow cost sharing.

Payload requirements are TBD.

Communication requirements are TBD.

Mission: Forest Fire Retardant Application
Source: US Forest Service
In recent years the US has seen the advent of Mega-Fires. The appearance of these Mega-Fires has been driven by gradual increases in consumable fuels and the continued encroachment of civilization on our wilderness areas. These Mega-Fires overwhelm our current fire fighting abilities. If loss of life and property is to be prevented in the case of these Mega-Fires, there exists the need to dramatically increase our capacity to apply firefighting resources. Helicopters and large fixed wing vehicles currently conduct the airborne portion of this mission. The mission requirement is to increase the rate of retardant application on a given fire.

Mission: Wild Life Census
Source: Idaho Department of Fish and Game
The mission is to conduct aerial surveys of wildlife species of interest to estimate population size, composition, distribution, and status. In Idaho, logistical constraints such as a limited number of helicopters and biologists, and funding result in a 3-year survey rotation (an area of interest is surveyed once every 3 years). The western states rely on helicopters (and to a lesser extent, fixed-wing aircraft) to conduct such surveys.

The UAV mission concept calls for streaming IR video and a real-time camera controlled by a ground operator. Real-time camera control functions would include zoom and pan functions and include a fixed geo-referencing capability, slaving the EO camera to the IR line-of-sight. The vehicle would need to operate at low altitudes in and around terrain. Air space could be restricted to overflight of sparsely populated areas. The viability of this mission would be constrained by the cost of operations. As an example, the current elk survey mission for Idaho covers 70,000 square miles (317,600 km^2) at the cost of $1.8M over a 3-year period. The current deer survey mission for Idaho covers 42,000 square miles (190,500 km^2) at the cost of $1.8M over a 3-year period. UAV endurance could be traded off for multiple cheaper vehicles covering the same area in a less amount of time. The platform for this mission must operate in and around terrain, thereby imposing a terrain avoidance algorithm in the vehicle management system. Additional platform requirements are TBD, including range and endurance. Similar missions exist in most of the other states as well as Canada, Africa, Central America, etc.

Payload consists of low resolution infrared video camera and high resolution still imagery.

Communication requirements consist of IR video downlinks and a real-time camera control by a ground operator.

Mission: Animal Tracking
Source: Idaho Department of Fish and Game

Many thousands of animals are monitored through radio transmitters. They are monitored periodically (e.g. weekly) throughout the year – often from a fixed-wing aircraft. Collection of data includes such things as the location of the animal, topography and vegetation at the location.

The platform for this mission would fly at a reasonably low altitude looking for signal from animals with transmitters. A grid pattern would be used to traverse large areas.

Sensor equipment would include receivers to identify animals to be tracked.

Communications requirements for this mission are minimal.

Mission: Invasive Plant Assessment
Source: Idaho Department of Fish and Game
This mission is the forestry department’s assessment of non-indigenous plant species invasion into wilderness areas.

The UAV mission concept calls for streaming IR video and a real-time camera controlled by a ground operator. Real-time camera control functions would include zoom and pan functions and include a fixed geo-referencing capability, slaving the EO camera to the IR line-of-sight. The vehicle would need to operate at low altitudes in and around terrain. Air space could be restricted to overflight of sparsely populated areas. The viability of this mission would be constrained by the cost of operations. The platform for this mission must operate in and around terrain, thereby imposing a terrain avoidance algorithm in the vehicle management system. Additional platform requirements are TBD, including range and endurance.

Payload consists of low resolution infrared video camera and high resolution still imagery.

Communication requirements consist of IR video downlinks and a real-time camera control by a ground operator.

To accomplish this mission, the combined methods of day and night operations, real-time directed precision drops based off of mapping information (3.29 above) and rapid re-supply will be used. Night operations will be enabled by terrain awareness through digital terrain data which will enable automatic terrain following and terrain collision avoidance. Precision application will be accomplished through automated deliveries driven by desired pattern shape and density of retardant, terrain awareness through digital terrain systems, and plume avoidance, all directed in near real-time from field command locations based on available fire mapping data. Multiple aircraft might be used to blanket a large area with retardant. Rapid re-supply may be accomplished via preloaded containers swapped out at the local airfield or an airborne re-supply ship.

The platform requires a vehicle management system that will allow flight path re-direction from an operator located at a ground station. It must also incorporate terrain following or avoidance algorithms. Consistent with air space requirements, the platform must fly from the surface to 20,000 feet (6.1 km) within the special use air space of the fire, transit between the fire area and remote airfield at altitudes ranging from 5,000 to 20,000 feet (1.5 to 6.1 km), and deployment from NFS airfields to remote airfields at 20,000 feet (6.1 km) and greater. More specific platform requirements are TBD. This is a seasonal mission. Fire season starts in late spring in the south east of the US and ends in November in the west. The Alaska fire season lasts from late May to early September. It may be more cost effective for vehicles supporting fire fighting to be able to adapt to another mission in the winter time to allow cost sharing.

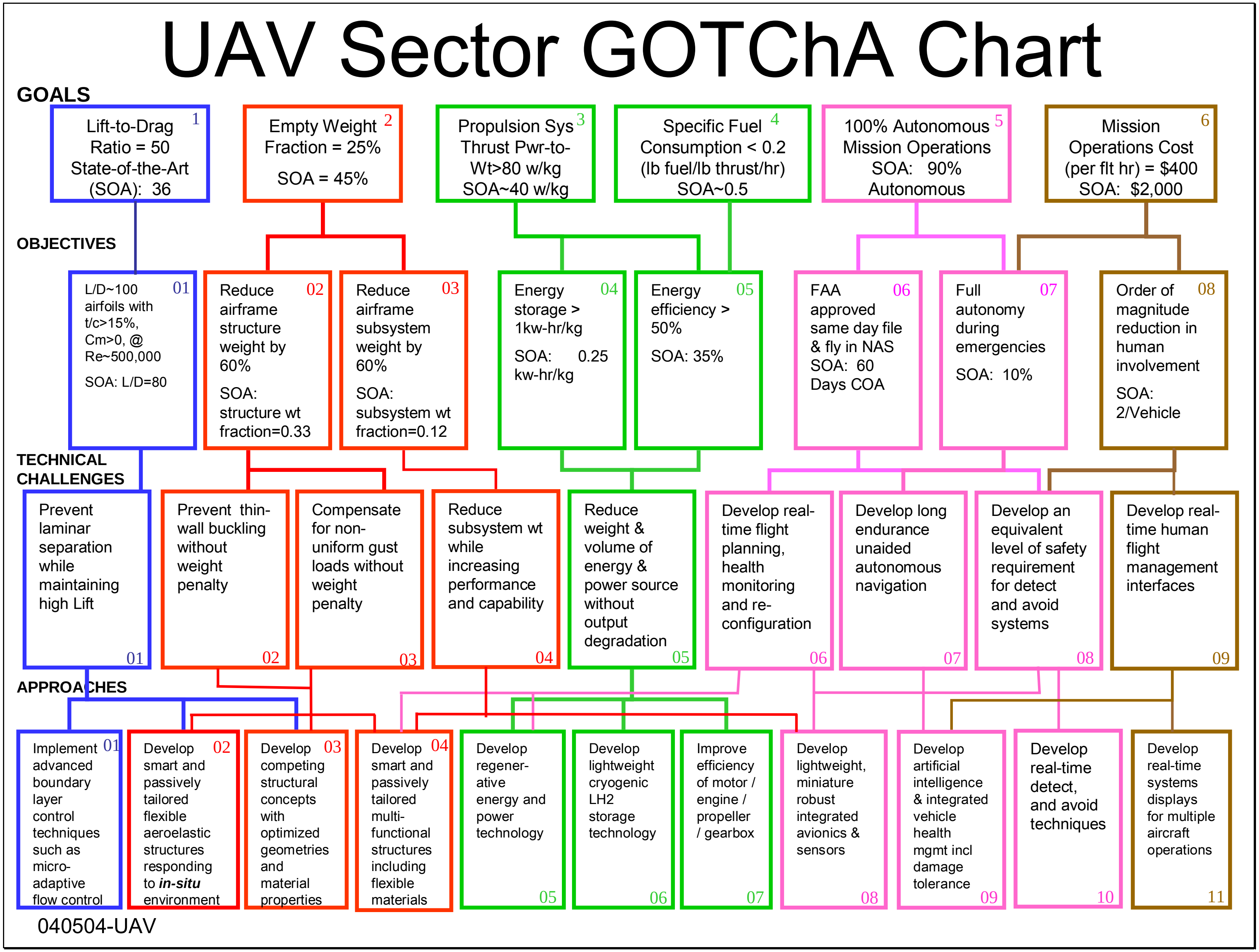
Payload requirements are TBD.

Near real-time communication is required for ground based command and control.

Appendix E

NASA Aeronautics Research Mission Directorate

UAV Sector GOTChA Chart


UAV Sector GOTChA Chart
GOALS
Lift-to-Drag Ratio = 50 State-of-the-Art (SOA): 36 1
Empty Weight Fraction = 25% SOA = 45% 2
Propulsion Sys Thrust Pwr-to-Wt>80 w/kg SOA~40 w/kg 3
Specific Fuel Consumption < 0.2 (lb fuel/lb thrust/hr) SOA~0.5 4
100% Autonomous Mission Operations SOA: 90% Autonomous 5
Mission Operations Cost (per flt hr) = $400 SOA: $2,000 6
OBJECTIVES
L/D~100 airfoils with t/c>15%, Cm>0, @ Re~500,000 SOA: L/D=80 01
Reduce airframe structure weight by 60% SOA: structure wt fraction=0.33 02
Reduce airframe subsystem weight by 60% SOA: subsystem wt fraction=0.12 03
Energy storage > 1kw-hr/kg SOA: 0.25 kw-hr/kg 04
Energy efficiency > 50% SOA: 35% 05
FAA approved same day file & fly in NAS SOA: 60 Days COA 06
Full autonomy during emergencies SOA: 10% 07
Order of magnitude reduction in human involvement SOA: 2/Vehicle 08
TECHNICAL CHALLENGES
Prevent laminar separation while maintaining high Lift 01
Prevent thin-wall buckling without weight penalty 02
Compensate for non-uniform gust loads without weight penalty 03
Reduce subsystem wt while increasing performance and capability 04
Reduce weight & volume of energy & power source without output degradation 05
Develop real-time flight planning, health monitoring and re-configuration 06
Develop long endurance unaided autonomous navigation 07
Develop an equivalent level of safety requirement for detect and avoid systems 08
Develop real-time human flight management interfaces 09
APPROACHES
Implement advanced boundary layer control techniques such as micro-adaptive flow control 01
Develop smart and passively tailored flexible aeroelastic structures responding to in-situ environment 02
Develop competing structural concepts with optimized geometries and material properties 03
Develop smart and passively tailored multi-functional structures including flexible materials 04
Develop regener-ative energy and power technology 05
Develop lightweight cryogenic LH2 storage technology 06
Improve efficiency of motor / engine / propeller / gearbox 07
Develop lightweight, miniature robust integrated avionics & sensors 08
Develop artificial intelligence & integrated vehicle health mgmt incl damage tolerance 09
Develop real-time detect, and avoid techniques 10
Develop real-time systems displays for multiple aircraft operations 11
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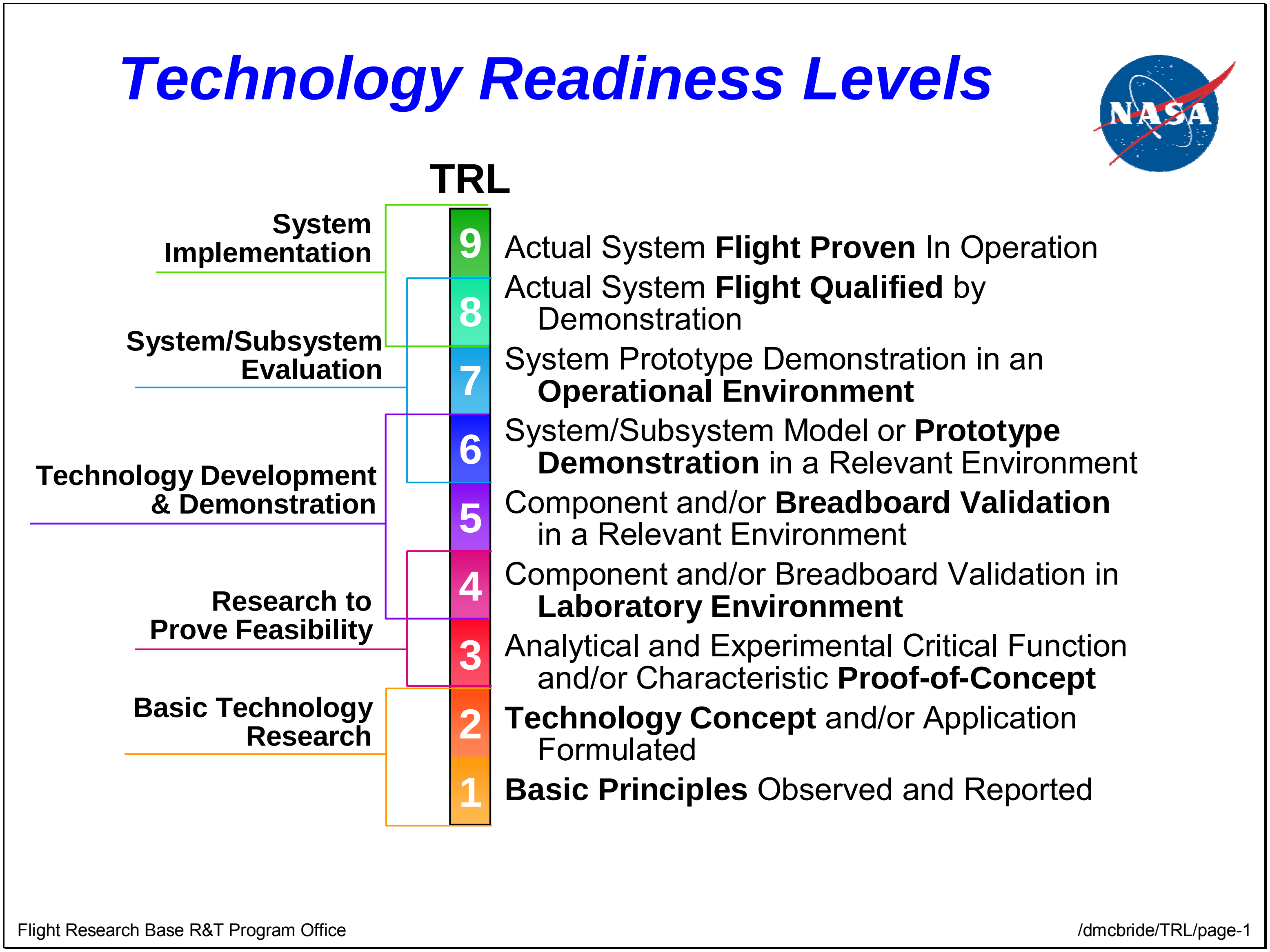
Appendix F

Technology Readiness Levels


Technology Readiness Levels
TRL
System Implementation
System/Subsystem Evaluation
Technology Development & Demonstration
Research to Prove Feasibility
Basic Technology Research
9 Actual System Flight Proven In Operation
8 Actual System Flight Qualified by Demonstration
7 System Prototype Demonstration in an Operational Environment
6 System/Subsystem Model or Prototype Demonstration in a Relevant Environment
5 Component and/or Breadboard Validation in a Relevant Environment
4 Component and/or Breadboard Validation in Laboratory Environment
3 Analytical and Experimental Critical Function and/or Characteristic Proof-of-Concept
2 Technology Concept and/or Application Formulated
1 Basic Principles Observed and Reported
Flight Research Base R&T Program Office
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