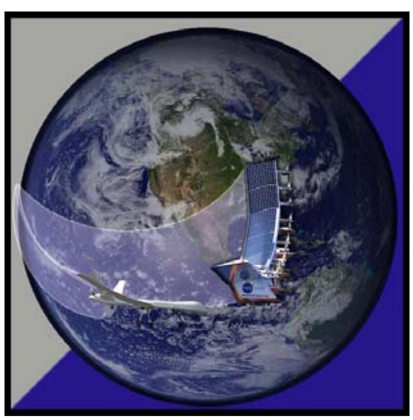
Earth Observations and the Role of UAVs:

A Capabilities Assessment

Version 1.1

Prepared For: Cheryl Yuhas
Suborbital Science Program Manager
NASA Science Mission Directorate

Prepared By: Civil UAV Assessment Team
http://www.nasa.gov/centers/dryden/research/civuav/index.html



August 2006

Table of Contents

List of Appendices

List of Figures

List of Tables

Civil UAV Assessment Team Authors

Principal Authors:
Timothy H. Cox – NASA DFRC
Ivan Somers, PhD – Bandwidth Solutions, Inc.
David J. Fratello – Zel Technologies LLC

Contributing Authors:
Christopher J. Nagy – NASA DFRC
Susan Schoenung, PhD – Longitude 122 West, Inc.
Robert J. Shaw, PhD – NASA Glenn
Mark Skoog – NASA DFRC
Ryan Warner – NASA DFRC

Acknowledgements

The authors are grateful for and would like to acknowledge the efforts of the following personnel who contributed to this document with editing support or workshop support.

Matt Fladeland – NASA ARC
Randy Albertson – NASA DFRC
Jay Levine – Analytical Sciences & Materials, Inc.
California State University at Monterey Bay
University Space Research Association
University of Akron
Virginia's Center for Innovative Technology

Executive Summary

This three-volume document, based on the draft document located on the website given on page 6, presents the findings of a NASA-led capabilities assessment of Uninhabited Aerial Vehicles (UAVs) for civil (defined as non-DoD) use in Earth observations. Volume 1 is the report that presents the overall assessment and summarizes the data. The second volume contains the appendices and references to address the technologies and capabilities required for viable UAV missions. The third volume is the "living" portion of this effort and contains the outputs from each of the Technology Working Groups (TWGs) along with the reviews conducted by the Universities Space Research Association (USRA).

The focus of this report, intended to complement the Office of the Secretary of Defense UAV Roadmap, is four-fold:

- To determine and document desired future Earth observation missions for all UAVs based on user-defined needs
- To determine and document the technologies necessary to support those missions
- To discuss the present state of the art platform capabilities and required technologies, including 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 be updated periodically and used to assess the feasibility of future missions. In addition, this report will provide the foundation to help influence funding decisions to develop those technologies that are considered enabling or necessary but are not contained within approved funding plans. This document is written such that each section will be supported by an Appendix that will give the reader a more detailed discussion of that section's topical materials.

Discussed within Section 2 of the report is an overview of current UAV platforms, in both the civil and military arena. The more detailed discussion is contained in Appendix B. The reader should note that some of the projects discussed have been completed and are no longer operational. However, the contributions made by these projects to the capabilities of UAVs have been substantial. The role of UAVs in enhancing war-fighting capability has long been recognized by the Department of Defense (DoD), and current plans emphasize significant capability growth for UAVs for that purpose within the next ten 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. Table 2.1 in Section 2 reflects several market studies and forecasts for UAV growth. Although a tremendous potential for market growth exists, some limiting factors may prevent this growth and create a degree of uncertainty in these forecasts. Both policy and technology issues are seen as limiting the potential for market growth.

Section 3 of the report summarizes the documentation of the potential civil missions used in the analysis. The Assessment Team addressed a total of 53 missions that were documented and analyzed. These missions came from various government and private sector organizations for both science and public benefit (see Figure 1.1) under the broad categories of:

- Earth Science
- Land Management
- Homeland Security

From these 53 missions, the majority of which fall under the Earth science category, 28 capabilities and technologies are identified as required to support the missions. *Note that for purposes of this document, the Team describes a technology as a capability enabler and a capability as a mission enabler.* Specific capabilities include such items as access to the National Airspace System, long range and endurance, high altitude, terrain avoidance and formation flight. Specific technologies include collision avoidance, Over-the-Horizon communication and Autonomous Mission Management. A complete list of capabilities necessary for the various missions is shown in Figure 4.2. Detailed descriptions of the missions are contained in Appendix C. Appendix D contains the descriptions of the UAV Capabilities. Likewise, a list of technologies related to the missions is shown in Appendix E.

The considerations for civil UAV use are 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 UAVs has in cost reduction. Also included are a general description and status for each of the capabilities and technologies identified in Section 3. Over-the-Horizon (OTH) communication and 'file and fly' access to the National Airspace System 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. These sections will give topical discussions with details located in the referenced Appendices.

Section 5 presents the matrix of capabilities vs. proposed missions extracted from the data collected from the series of workshops and interviews with subject matter experts. The matrix lists the weighted values for each of the matrix intersections. The higher the weighted value, the more impact the capability has on a particular mission. The values were determined from the data sets from all of the workshops along with the interviews. The Team-developed weighting definitions are also listed in this section.

As indicated, DoD missions are not considered as part of this report. However, 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.

The goal of fostering the capabilities of UAVs can be accomplished most easily by removing the technical and regulatory barriers to civil UAV flight. This means that NASA should endeavor to develop technologies from the low technology readiness levels (TRLs) to ones that can be readily developed to the operational and commercial stages. In addition, supporting policies must be established and fostered to facilitate UAV flight in the National Airspace System. As a result of these efforts, cost will become a lesser impact to market development. When this occurs, innovation and entrepreneurship will drive down the cost of UAV flights and enhance the safety, reliability, and operability of

UAVs. As the costs go down and access to the airspace becomes routine, the market for UAV will, as expected, expand rapidly based on various market forecasts.

1. Introduction

In 1944, Clarence "Kelly" Johnson (http://www.wvi.com/~sr71webmaster/kelly1.htm) 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]. Throughout this document, the terms UAV, UAS (Unmanned Aircraft Systems) and ROA (Remotely Operated Aircraft) will be considered interchangeable terms.

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 Intelligence, Surveillance and Reconnaissance (ISR), strike and combat support. Recent literature references indicate 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 Administration (NOAA), and Department of Homeland Security (DHS), and others are examples of agencies with UAV interests for non-combat applications. It would be interesting to know whether Johnson predicted any civil role for UAVs.

For the purposes of this Assessment, the term "civil UAV" is defined to indicate that segment of missions flown by organizations other than Department of Defense. It would include such Agencies as NOAA, NASA, DHS and DOE as well as the commercial sector.

1.1 Purpose

This document provides an assessment of the civil 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 Earth observation 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.

[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 that of 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 also rule out unmanned dirigibles or airships. However, for the purposes of this report, these will be 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.

4. Provide the foundations for development of a comprehensive civil UAV roadmap to complement the Department of Defense (DoD) effort (http://www.acq.osd.mil/uas/).

Two aspects of the President's Management Agenda (refer to the document located at: www.whitehouse.gov/omb/budget/fy2002/mgmt.pdf) are supported by this undertaking. First, it is one that will engage multiple Agencies in the effort as 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 addresses the civil UAV market forecast and lists several independent forecasts. One conclusion that can be drawn from these forecasts is that all show a sustained growth for the duration of each long-term forecast.

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 investigation, missions were classified under the categories shown in Figure 1.1:

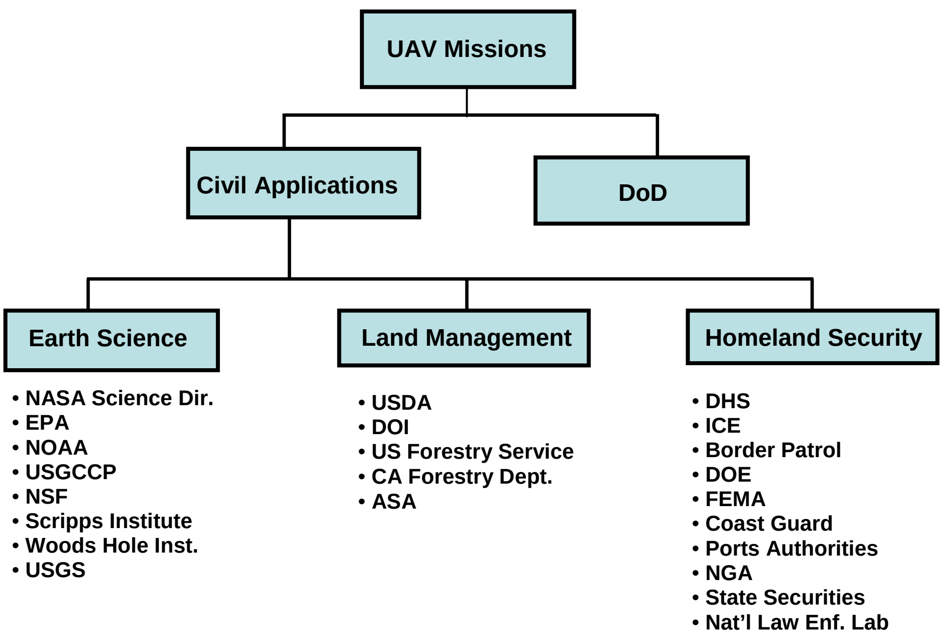


Figure 1.1 - Classification of UAV Users

These categories reflect the current public sector organizations that have shown interest as potential users of UAVs. For this version of the Assessment, the commercial sector will not be addressed. It is expected that this set of users will be a part of a future update.

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 the DoD, Defense Advanced Research Projects Agency (DARPA), and the uniformed services efforts 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 secure communications, sensor suites and munitions). In this role, the completion of the mission without harm to personnel is supra to the economics of the vehicle. As a result of NASA research efforts, continued development of core technologies will help reduce the acquisition and operational flight costs and increase flight safety in order to enhance UAV use in science applications. It is expected that many of the technological advancements and developments made by NASA for its science efforts will be utilized by DoD in its upgrades of UAV fleets.

This report represents the first major update of the Civil UAV Capabilities Assessment which was released in November 2005. The vast majority of the proposed missions included in this update are focused towards the Earth science missions. Additional workshops and interviews with attendees from these earlier workshops constitute the majority of changes to the earlier draft version. Additional minor updates will be made annually with another major update planned for 2009 to this document as shown in Table 1.1.

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

Table 1.1 - Civil UAV Capability Assessment Update Schedule

1.3 Approach

The initial version of the Civil UAV Capabilities Assessment addressed a wide range of user-directed UAV missions and identified the technologies required to accomplish those missions. The document evolved over the past two years. In this version, the scope has expanded from a limited range of missions to a more comprehensive compilation of potential missions. As the assessment matures, 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 continue to be sought from the UAV users regarding the accurate capture of missions and technologies. The current development schedule to date 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 schedule for technology development	Oct 2005 thru Feb 2006
Identify gaps (unsupported technology development)	Feb 2006 thru Apr 2006
Conduct technology gap review	Apr thru Jun 2006
Version 1 Release	September 2006

Table 1.2 - Near-Term Task Schedule

Information for the initial version was gathered primarily from four workshops: the Sub-Orbital Science Mission of the Future workshop held in Arlington, VA in July 2004; the Sensor and Power and Propulsion workshop held in Akron, OH in April 2005, the joint NASA / DHS Workshop held in Herndon, VA in July 2005; and the Land Management and Coastal Zone Dynamics workshop held in Monterey, CA in July 2005. Concurrently, several NASA/NOAA/DOE workshops were held regarding UAVs and many of the information providers attended these as well as the UAV workshops. An additional source of information was personal interviews with subject matter experts (SMEs) who did not attend any of the workshops. Although the attendee list is not exhaustive of the SMEs, it is felt that the information gathered is truly indicative of conventional and unconventional thinking regarding UAVs.

The starting point was to develop a "customer list" – defined as a group of individuals within organizations (see page I.2 of Appendix I) 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 list of organizations is provided in Appendix I. Inclusion in the customer list does not imply support for or concurrence with the findings of this report, but rather, inclusion of input and perspectives in the analysis.

Once the customer list was developed, some participants were interviewed at workshops or individually. A sample interview questionnaire is included in Appendix I. To ensure a mix of different types of applications, missions were classified under the general categories shown previously in Figure 1.1 and potential users were selected from each of the civil categories.

If readers have a desire to be part of this effort, or desire to have missions included, the Assessment Team invites them to contact the authors through the following email address:

uav.cap.access@dfrc.nasa.gov

The project has developed a website for the dissemination of information, reports from previous workshops, announcements of scheduled events and conferences. The URL is:

http://www.nasa.gov/centers/dryden/research/civuav/index.html

1.4 Acronyms and Definitions

Acronyms used in this document are defined on the first use and contained in an Appendix A at the end of this document. Where appropriate, a short description or website has been included in the Appendix to help define the acronym and to direct the reader for additional information.

2. UAV Programs

2.1 Historical Perspective

Since the first automatically controlled flight of an aircraft in 1916, military planners have imagined the value of UAVs 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 United States 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, has intrigued war strategists and planners. 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 era of UAVs 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 to conduct battle-damage assessment for US 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 program in 1969 looked at remotely controlling an aircraft from a ground station, 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; and the Highly Maneuverable Aircraft Technology program.

In the 1990s NASA led a program, with industry partners, to develop technologies to assist a fledgling UAV market. This effort brought the potential of a commercial UAV market into focus. Continuing work developed from this effort seeks resolution of major technological and policy impediments that restrain the development of these aircraft to their full 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 of up to 6 months.

2.2 Civil and Military UAVs

Civil and military UAVs are in operation today performing certain missions. Appendix B presents a list of civil UAVs chosen primarily for previous roles in science missions. It will serve as a sampling of civil UAV systems and is not intended to be complete and exhaustive. A more complete listing of UAVs may be found in the following reference: *Aviation Week and Space Technology, "2005 Aerospace Source Book". January 17, 2005.*

A brief summary of the various classes of military UAVs in current operation or development, as well as a description of some recent military technology development programs which will provide the capability for operational concepts using UAVs over the next 20 years is contained in Appendix B as well. More specific information on military UAVs can be found in the DoD UAV Roadmap (Unmanned Aircraft Systems Roadmap, Office of the Secretary of Defense, August 2005). A general history of military UAV development and future direction is shown in Figure 2.1.

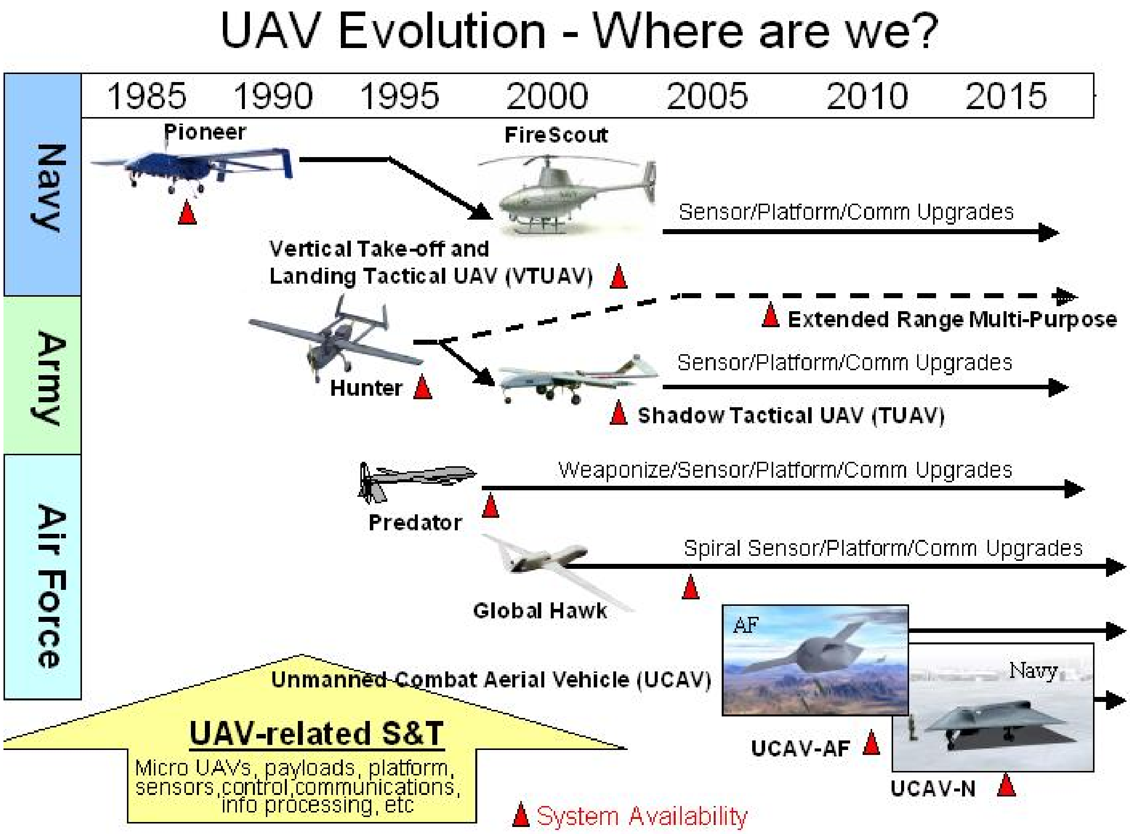


Figure 2.1 - History of Military UAVs (source: http://www.sd-auvsi.org/pdfs/uavdod_103101.pdf)

Table 2.1 lists some of the major science missions utilizing UAVs. This list is not intended to be exhaustive but rather a look at the breadth and content experience of both on-going and completed missions. Further information on a particular mission is found by following the web link provided.

Project	Sponsor	Dates	Aircraft	Mission Description
Environmental Research and Sensor Technology (ERAST) [1]	NASA	1995 - 2003	Raptor Perseus Pathfinder Helios Altus Altair	Technology Demonstrations
Atmospheric Radiation Monitoring (ARM) [2]	DOE / NASA	1994 - present	Gnat, Altus	Clear air radiation measurements and profiles
UAV Science Demonstration Projects [3]	NASA	2001 - 2003	Altus	Cumulus Electrification measurements
UAV Science Demonstration Projects [3]	NASA	2001 - 2003	Pathfinder Plus	Coffee field ripeness / harvest optimization
CAMEX 4 [4]	NASA	2002	Aerosonde	Meteorology

FiRE [5]	NASA	2001	Altus	Wildfire imaging demonstration
Channel Islands [6]	NOAA / NASA	2005	Altair	Coastal mapping, ocean color, atmospheric chemistry
Ophelia [7]	NOAA / NASA	2005	Aerosonde	Hurricane operational intensity forecast
WRAP Small UAV demo [8]	NASA/USFS/ USDA	2005	MLB Bat, APV-3, RMAX	Tactical fire imaging demonstration
TCSP, Costa Rica [9]	NASA	2005	Aerosonde	Cloud science, hurricane genesis
MAC, Maldives [10]	NSF/NOAA/NASA	2006	ACR Manta	Cloud physics
FiRE	NASA/USFS	2006 (ongoing)	Altair	Western States

Table 2.1 - UAV Science Mission Experience

1. ERAST Website: http://t2www.nasa.r3h.net/lb/centers/dryden/history/pastprojects/Erast/erast.html
2. Atmospheric Radiation Monitoring Website: http://www.er.doe.gov/ober/CCRD/uav.html
3. UAVSDP Website: http://geo.arc.nasa.gov/uav-nra/index.html
4. CAMEX 4 Website: http://www.camex.nsstc.nasa.gov/
5. Wegener S., et al, "Demonstrating Acquisition of Real-Time Thermal Date Over Fires Utilizing UAVs," AIAA paper no. 2002-4109, 2002.
6. Fahey, D. et al, "The NOAA Unmanned Aerial System Demonstration Project Using the General Atomics Altair UAS" Proc. of AIAA Infotech@Aerospace Conference, Workshop and Exhibit, Arlington, VA, 26-29 Sept. 2005.
7. See: http://www.noaanews.noaa.gov/stories2005/s2508.htm
8. Wildfire Research and Applications Partnership: http://geo.arc.nasa.gov/sge/WRAP/
9. "Mission Summary Report: TCSP05 Aerosonde Campaign" FR# 5U015, NASA/GSFC/WFF, August 2005.
10. "Project Atmospheric Brown Clouds," http://www-c4.ucsd.edu/ProjectABC/

2.3 UAV Proliferation

Although UAVs currently represent a relatively small segment of the aerospace market (about $1.25B in research and production funding in 2003), they constitute one of the more dynamic areas 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-requisites 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)

- Lack of efforts to establish joint customer requirements (although this is gradually changing)
- Liability for civil operation
- Capacity for payload flexibility
- Lack of sufficient secure non-military frequencies for civil operation
- Perceived reliability (e.g. vehicle attrition rate vs. manned aircraft)
- Operator training issues
- Recognition/customer perception of the UAV market
- Technology developments for multi-mission capability

2.4 Market Forecast

The suitability of UAVs in “dull, dirty and dangerous” missions (these missions may be the long, boring and repetitive ones or ones required to operate in dirty areas such as volcanic plumes or missions that put the pilot in harm’s way), the increasing success of UAVs in military service and demonstration, the increases in payload capability of more recent UAVs, the war on terrorism (with its homeland security implications of long endurance surveillance), and the need for multi-mission capabilities are several factors which have opened new markets for UAVs 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 2.2 lists various forecasts based on the number of units of demand for basic systems; these forecasts do not reflect the total market including operations and sensor suites.

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
Frost and Sullivan	Oct 2005	\$1.45B /year by 2015	Civil and commercial	Airframe and avionics
Frost and Sullivan	Mar 2006	\$17B by 2011	Military, civil and commercial	Airframes and avionics

Table 2.2 - UAV Market Forecasts

Of interest to this effort is the fact that all indicate a high rate of growth in the number of units demanded over the next ten years. By extension, the growth in the support market could be considered explosive as well. UAV price structure will be the major influence in the civil sector growth rate. Unless the missions can be flown for less cost by a UAV, then piloted vehicles will continue to be utilized.

2.5 Role of U.S. export controls

A potentially significant negative influence on the proliferation of UAVs in the market place is export control. For the international market, UAVs are controlled for export from the 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. (See: http://fas.org/spp/starwars/offdocs/itar) 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 (C^2) 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-like regulations, it may pose an obstacle for foreign sales by US-based companies. This obstacle would impact negatively the competitive position of the US in the world market. Partnering with a foreign manufacturer may not be an option since the basic technologies to many of the items covered by ITAR are subject to the law as well.

3.0 UAV Mission Summaries

The goals of the Workshops and interviews with subject matter experts (as mentioned previously in Section 1.3) included the collection of potential Earth observation missions that could be accomplished or enhanced with UAVs. The described missions have been divided into the categories defined by Figure 1.1, i.e.; Earth Science, Land Management and Homeland Security. Table 3.1 lists all of the potential missions segregated into the three categories.

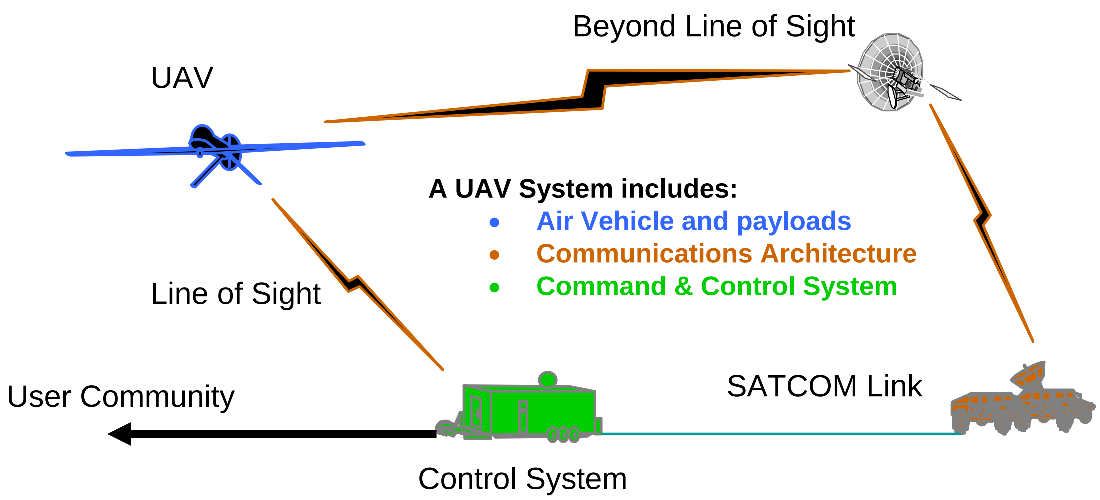
Earth Science Missions	
Repeat Pass Interferometry for Surface …	Magnetic Fields Measurements
Cloud and Aerosol Measurements	Cloud Properties
Stratospheric Ozone Chemistry	River Discharge
Tropospheric Pollution and Air Quality	Snow – Liquid Water Equivalents
Water Vapor and Total Water Meas.	Soil Moisture and Freeze/Thaw States
Coastal Ocean Observations	Cloud Microphysics/Properties
Active Fire, Emissions, and Plume Assess.	Focused Observations – Extreme Weather
O2 and CO2 Flux Measurements	Forecast Initialization
Vegetation Structure, Composition, …	Hurricane Genesis, Evolution, and Landfall
Aerosol, Cloud, and Precipitation Dist.	Physical Oceanography
Glacier and Ice Sheet Dynamics	Tracking Transport and Evolution of Poll.
Radiation - Vertical Profiles of Shortwave...	Clouds/ Aerosol/ Gas/ Radiation Inter.
Ice Sheet Thickness and Surface Def.	Long Time Scale Vertical Profiling of Atmos.
Imaging Spectroscopy	Global 3D Continuous Measurement
Topographic Mapping and Topographic…	Transport and Chemical Evolution in the...
Gravitational Acceleration Measurements	
Antarctic Exploration Surveyor	
Land Management and Coastal Region Missions	
Wildlife Management Population Count	Identification and Tracking of Maritime…
Wildlife Management Telemetry Mission	Shallow Water Benthic Ecosystem
Wildlife Habitat Change Mission	Carbon Dioxide Flux
Precision Agriculture	Wildfire / Disaster: Real-time Comm.
Water Reservoir Management	Wildfire/Disaster: Predict, Measure …
Range Management	Wildfire: Fire Retardant Application
Urban Management	Wildfire/Disaster: Reducing Risk to Responder
Coastal Water Quality	Wildfire/Disaster: Pre- and Post-Event…
Homeland Security Missions	
Marine Interdiction, Monitoring, Detection	BORTAC Situational Awareness
Tunnel Detection and Monitoring	Coastal Patrol
Broad Area Surveillance	

Table 3.1 - Mission List

A complete description of each potential mission listed in Table 3.1 along with platform and communication requirements may be found in Appendix C.

4.0 UAV Status Assessment

Figure 4.1 provides a graphic representation of the components for a typical UAV System, depicting some of the capabilities needed and the enabling technologies required for performing a given mission. As can be seen in the diagram, there are many capabilities and technologies required to support a mission. As a result of this system complexity, DoD and other agencies have started to use the term Uninhabited or Unmanned Aerial System (UAS) in place of UAV.



Enabled by: Autonomous Mission Management, Reliable Flight Systems, Navigation Accurate Systems, Terrain Avoidance, Power and Propulsion

Figure 4.1 - Unmanned Aerial Vehicle System

The mission descriptions listed in Appendix C suggest that a large number of capabilities and technologies will be required for the accomplishment of those missions. In this portion of the document, Section 4.1 looks at the top-level economic considerations for the success of UAV applications. These tend to have wide applicability to all UAVs. The next edition of this report will improve the assessment of technology status and highlight technology gaps and the missions that are impacted.

Sections 4.2 and 4.3 address the capabilities and technologies that affect the economic issues related to UAVs. Appendices D and E, respectively, detail the capabilities and technologies required for the mission set. Specific capabilities required for missions are listed in the order of use by the largest number of missions, i.e. capabilities required most frequently are listed first.

Mission readiness is summarized in Section 4.4 by showing the forecasted technology maturity that supports the capabilities required by the missions. This section is particularly useful for getting a "first order" understanding of the technology gaps in UAV system development. Section 4.5 identifies the relevant policies affecting UAV development, and break-through technologies that are high risk, in the sense of reaching a useable level of maturity, but would have a resounding, revolutionary impact.

Many of the general and specific capabilities have been captured in NASA's UAV Sector "GOTChA" chart. The GOTChA used in this assessment is for illustrative purposes. It was developed by the UAV Sector of NASA's Aeronautics Research Mission Directorate. Because of organizational restructuring at NASA Headquarters, this organization does not exist. However, for purposes of defining a potential program, this example provides a wealth of information. The GOTChA chart is a management tool that breaks down the Goals, Objectives, Technical Challenges, and Approaches of a project – in this example, improving the state-of-the-art for UAV missions to perform Earth science observations. 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 F in this volume.

4.1 UAV Economics

The total costs for UAV operations do not make economic sense currently for many of the missions described in this document. Other than the "dull, dirty and dangerous missions", only for those missions where human life is put in harm's way can the use of UAVs be justified over a human-piloted flight. Thus a major reduction in operating cost is necessary if this class of vehicles is to become a significant part of the air space. One potential user commented at a workshop that if the flight costs were to reduce to $400 per hour that his 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 shown in Appendix F.

Whenever a new technology or concept, such as civil applications of UAVs, is developed the initial costs are usually beyond the reach of most potential users. In many cases, adoption of the technology by the government helps to mitigate the development costs and reduces the procurement costs. For example, when Henry Ford introduced the automobile in the early 1900s, very few sales were made because of costs and low rate of production. When the War Department (now known as DoD) purchased 2,000 for use as trucks and personnel transportation, economies of scale allowed the manufacturing costs per unit to drop and the selling price was reduced accordingly. Another example of acquisition being impacted by government policy is the Boeing 707 commercial airliner and the military procurement of the KC-135. Without the KC-135, jet fleets would have taken longer to penetrate the commercial market for widespread use.

Metrics such as cost-per-hour for UAV use are often misleading in that they address only a portion of the total cost, i.e., recurring costs of actually flying the vehicle. Non-recurring costs must also be identified and included in the cost summary. The following sections will discuss some of the non-recurring and recurring cost categories 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

Non-recurring costs are those expenditures that occur once and are not directly proportional to the number of hours the aircraft actually flies. Typically, these costs include engineering, fabrication, test and integration, etc. Additionally, the following are considered 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.

- 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. Large groups of required support personnel are not conducive to operability or affordability.

- 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 and Border Patrol), which would need to include aircraft acquisition costs in the mission cost.

4.1.2 Recurring Costs

Recurring costs are those that are directly proportional to the number of hours the UAV actually flies. Typically, these costs 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 or cycles. The cost of ground operators or other support is also part of this category.

- 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.

- 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.

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

4.1.3 Cost Drivers and Potential for Reductions

One obstacle that is noted in all forecasts is the total 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 too expensive to use for most missions. 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 operating cost per hour). The mitigation of this cost obstacle can most easily be accomplished by modifying certain regulatory barriers to UAV flight imposed by the FAA and continued development of UAV-relevant technologies. Implied in this action is that NASA and the Federal Government must endeavor to develop UAV-enabling technologies from the low technology readiness levels (TRLs, see Appendix G) to ones that can be readily developed in the commercial sense; then cost will become a lesser impact to market development since a major portion of the developmental costs are expended. It also implies developing technologies and policies that facilitate flight in and out of the National Airspace System (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 newscasts taken from remote sensor assets, etc. The civil UAV may foster a similar development in the future economic development of this sector of the aerospace industry.

The impacts to safety and reliability must be considered as part of the process 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. Any onset of UAV mishaps involving the public could result in increased regulation for UAVs leading to increased operating costs and, perhaps, resulting in the “locking out” of some suppliers and users. The unexpected loss of UAVs in unpopulated mission areas would also not be tolerable from a reliability viewpoint. In addition to the loss of the vehicle itself, the user would lose the payload/sensor and put the mission results in jeopardy. In some cases, these payloads may be one-of-a-kind devices and the loss would affect the collection of data. The FAA has the requirement that the UAV maintain an equivalent level of safety and reliability as a piloted aircraft. (Note: The Radio Technical Commission for Aviation (RTCA) functions as a Federal Advisory Committee. Its recommendations are used by the Federal Aviation Administration (FAA) as the basis for policy, program, and regulatory decisions and by the private sector as the basis for development, investment and other business decisions. RTCA – in conjunction with the FAA established Special Committee 203 to address the minimum acceptable safety performance standards for UAVs in the NAS. This is an ongoing effort with final reports due CY07.) This requirement applies to both system reliability (minimization of component failures) and onboard intelligence which is capable of making decisions similar to a pilot. Autonomous mission management, sophisticated contingency mission management, collision avoidance, intelligent health monitoring system, and reliable flight systems will provide major improvements in this area.

The cost of military UAV operations is much greater than the levels where civil use would make economic sense. For example, a Predator B, without any payload or sensor suite, costs greater than $5M per copy. When adding in the costs of the support personnel, C^3I systems and sensor suites, costs rise dramatically. Without the need for technologies required for military UAVs such as C^3I and weaponry delivery systems, the economics of civil-use UAVs can be reduced substantially. 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 for most missions, these costs would need to be at or below the range of the costs to provide the mission completion utilizing a piloted vehicle. The operating costs and the acquisition costs of UAVs when compared with an alternate method of completing the same mission will determine the level of success for civil applications. This reasoning does not apply to some “dull, dirty and dangerous” missions not accomplished easily with piloted vehicles.

Reducing the costs of UAV missions involves addressing the system cost drivers. These drivers may be economic, technological, political and/or legislative in nature. Several areas that may be opportunistic for lowering costs are discussed in the following paragraphs.

One opportunity to decrease non-recurring costs is to develop, document, and implement payload interface standards to support open architecture technology, or “plug and play”, concept. Doing so would help alleviate costs associated with payload integration. NASA’s Earth Science Capability Demonstration Project has an effort underway to address this. The first set of documented standards is expected to be published around the end of fiscal year 2006.

Another way to decrease non-recurring 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”. Developing technologies to address Access to the NAS on a “file and fly” basis is a key factor in providing increased operability. Another capability that impacts UAV 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 data-collection location, and developing the flight plan. Payloads must have the capability to be integrated quickly using standard interfaces and protocols developed with open architecture technology. Finally, the UAV must remain ready during the course of the mission which may include multiple flights over a period of time. Autonomous mission management technology reduces pre-flight procedure time by relying on ground systems to support intuitive flight plan development with a high level of automation. Intelligent system health monitoring technology can reduce post-flight procedure times, while maintaining a high level of reliability. Objective 8 of the GOTChA chart addresses the desired reduction in required human support.

Additional cost reductions may be available through increased on-board intelligence. This would reduce the number of required ground support personnel and help lower recurring costs. Another recurring cost, insurance cost, will be reduced by increasing the safety and reliability of UAV systems through reliable flight systems, sophisticated contingency management, and intelligent system health monitoring technologies. For the commercial applications, as access to the airspace increases, a larger number of UAV operators will help reduce the insurance costs by spreading the cost associated with risk across a larger number of users and platforms (This assumes that the civil government uses will be insured by the Federal Government).

Communication costs can be reduced substantially by limiting or minimizing the bandwidth needed by the UAV/Payload to command, control, and communicate health status. In this case, wideband data would need to be stored on board the aircraft. Note that this option would work for research missions but not operational missions. Intelligent data handling technology could help reduce bandwidth requirements by processing the data on-board and down-linking only the mission-necessary information. Over-the-horizon (OTH) and network communication technology can be employed, transparent to the user, to adjust the bandwidth requirements to just the level needed based on the mission requirement. This helps reduce unnecessary costs associated with having to buy high bandwidth equipment when it is only required for a fraction of the mission time.

4.2 Capabilities

Appendix D contains a listing of the specific capabilities required to accomplish the proposed missions. For each capability, a description is provided followed by a status of that capability. It is expected that future updates of this report will provide the then-current status of these capabilities. Figure 4.2 shows an overview of the capabilities required. For each capability, a first-cut estimate of the need of that capability is given. If the capability supports at least half of the missions, it received a "High" rating. If it supports at least 25% of the missions, it earned a "Medium" rating. The remainder (those supporting less than 25%) were rated "Low". It should be noted that these ratings do not imply priority.

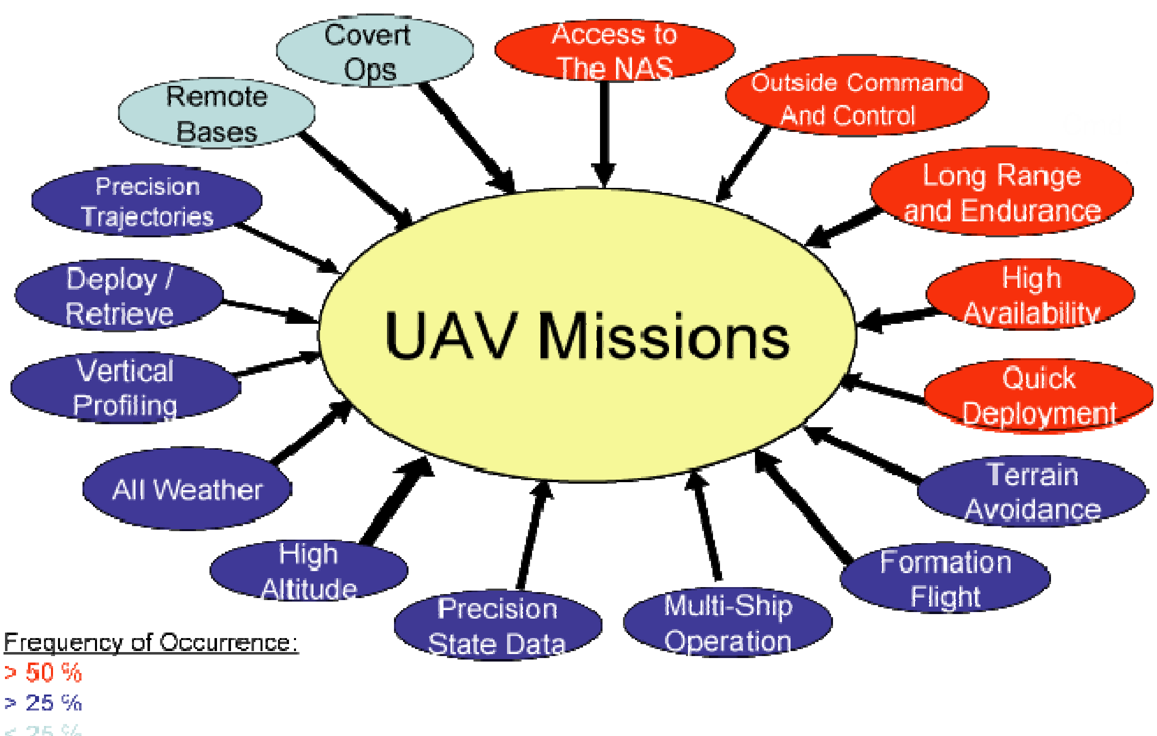


Figure 4.2 - Key Capabilities Identified in Documented Missions

4.3 Technologies

Appendix E contains sections that describe each technology in detail. Where available, summaries of development programs and forecasting maturation over the next 10 years are presented. A determination of when the technology will have matured enough to support the capabilities identified from the missions is provided where appropriate. Within each technology section, a first-cut estimate of the need of that technology or capability is given. If the technology 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". Again, rating does not imply priority. The technologies required to perform the missions described in this document include:

- Autonomous Mission Management
- Collision Avoidance
- Intelligent System Health Monitoring
- Reliable Flight Systems
- Sophisticated Contingency Management
- Intelligent Data Handling and Processing
- Over-the-Horizon Communication
- Network-Centric Communication
- Open Architecture
- Power and Propulsion
- Navigation Accurate System Technology
- Enhanced Structures

As part of the technology forecast, the Team established Technology Working Groups (TWGs) to assist in the technology forecasts. The TWGs utilized templates that were designed for consistency in reporting to establish forecasts for each of the technology areas. To gain an independent view of the technology forecasts, the Team engaged the University Space Research Association (USRA) to evaluate the templates from the TWGs and to add depth where required. All of the templates and the USRA inputs are contained in the addendum to this document.

4.4 Mission Readiness Summary

This section provides information summarizing civil UAV mission readiness based on technology maturation forecasts that meet or exceed the desired, or required, capabilities identified by the user community. Figure 4.3 presents a notional summary of the capabilities in terms of the predicted range in time when its supporting technologies are expected to become mature. The technologies listed at the bottom of the figure that are annotated with an asterisk (*) are shown within the figure with maturation forecasts based on development targets expressed in the DoD's UAV Roadmap document. Although much of the diagram is generally notional, i.e., not supported totally by data, future updates will have real data based on analysis and feedback from the TWGs. The purpose of the chart is to be able to identify when the capability to fly a particular mission can be expected as a function of time. For example, Access to NAS requires several technologies with differing expected maturation dates. If that capability is required for a mission, it is not currently expected to be available until the 2015 timeframe. If the decision makers wanted this capability earlier, then the technology that is the pacing item can be addressed. Note that the length of the bar is indicative of the uncertainty of the forecast timeframe. The left-most end is the least probable and the right end the most probable timeframe. Refer to Appendix D for comprehensive capability content definitions.

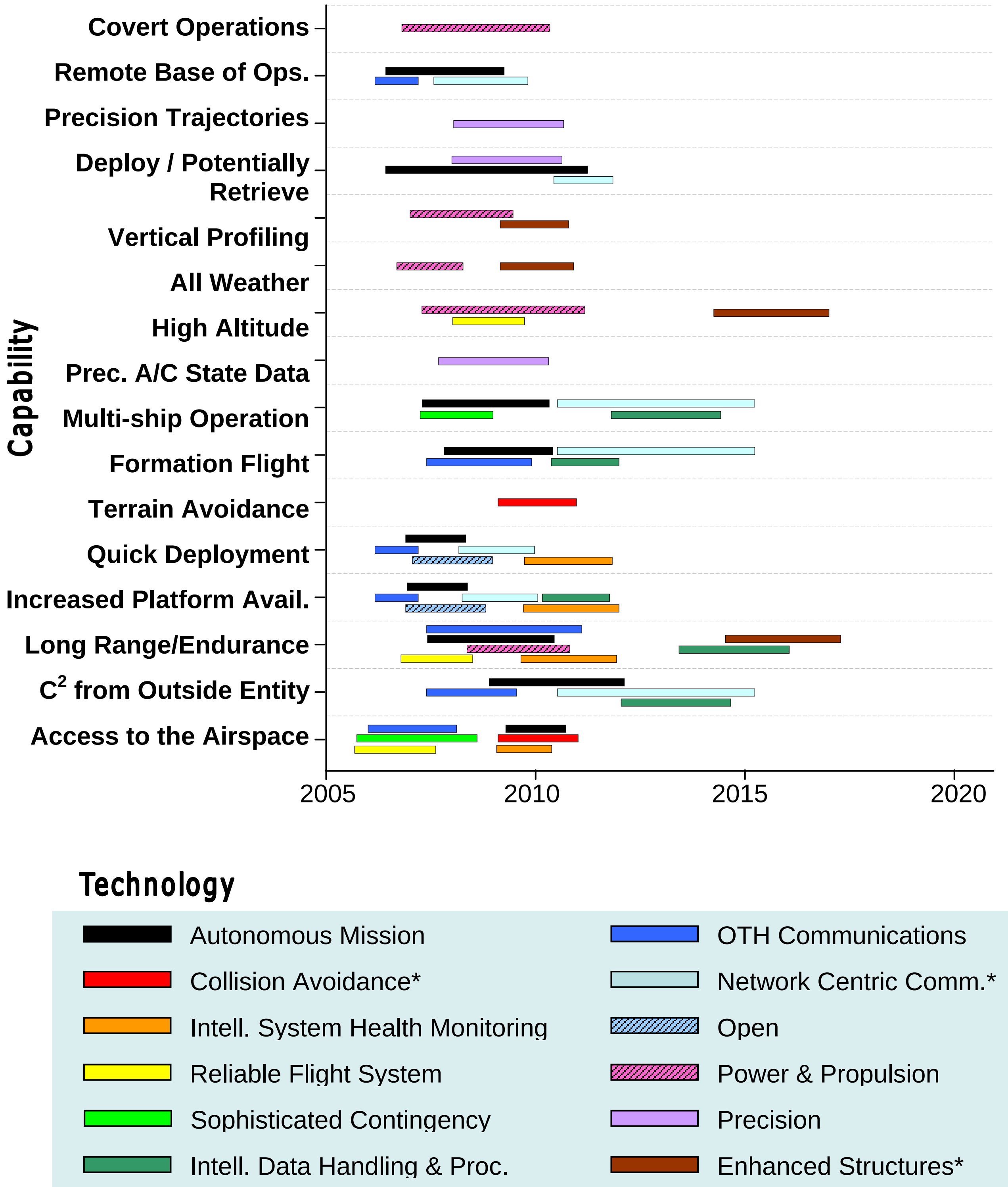


Figure 4.3 - Technology Maturation Summaries in Terms of Mission-Derived Capabilities

4.5 Identifying/Monitoring Relevant Policies and Break-Through Technologies

The information in this section describes the method by which potential technologies that could revolutionize the capabilities of UAV systems and their potential uses are identified and tracked. Evolving technologies are identified and tracked as well. The identified technologies are tracked and monitored by the Technology Working Groups (TWGs) and peer-reviewed by USRA.

For each of the technologies required, a working group composed of subject matter experts on that particular technology has been established. The main purpose of the TWGs is to identify, track and assess the maturation curves of each technology over time. The TWGs will identify, track and assess revolutionary technologies, policy issues, public perception issues, privacy issues, and anything else discovered that could have a significant impact on UAV system development.

The Information presented here will come from a variety of sources in addition each TWG's membership, including DARPA, NASA Small Business Innovative Research grants, universities, and the National Academy of Sciences. This section will also explore policy or other issues, which could drastically alter the landscape of UAV system development in either a positive or negative manner.

Appendix I contains inputs from the various TWGs which meet on a regular basis to update the state of their particular technology as needed. It is intended that the information contained in this Appendix will track technological progress as a function of time.

4.6 Payload Sensor Development: Autonomy and Miniaturization

Although not considered a focus of this version of the assessment, the proposed missions will 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 smaller "daughter" vehicles may carry a subset of payload sensors for specific data collection tasks. Thus some payloads may require miniaturization to support those missions. Until it becomes clearer which technologies will require this parallel development, they will not be included in the assessment.

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. Again, until it becomes evident which missions will require which payloads, it will not be included. However, the status and TRLs of payload sensor development will be included in the final version.

The TWGs will help to forecast these technology changes since each is 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 will develop time lines for various performance characteristics of the sensors including size and weight reductions and levels of increased performances. The results will 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 research and development (R&D) in those technology areas that appear weakest but necessary for mission success.

5.0 Interim Missions and Capabilities Analysis

This portion of the assessment will detail the analysis of the 53 proposed missions and 16 capabilities required as a group. Not all capabilities are required for all missions. For analytic purposes, the Assessment Team developed a matrix of missions vs. capabilities. Considering each mission and the data from the workshops taken collectively along with the inputs from subject matter experts, the weighted impact within each intersection of the matrix was assessed. This required that a set of "weighting" definitions be developed. The resulting matrix is followed by the series of weights and the definitions of each.

5.1 Output Matrix

Table 5.1 is the output matrix of the Mission vs. Weighted Capabilities developed by the Team using all of the proposed missions, the required capabilities and the weighting factors determined by each mission definition and profile as articulated in the previous section. Table 5.2 lists the weighting definitions for the capabilities. To understand the contents of the matrix, the reader will need to utilize the weighting definitions and to cross-reference Appendices C, D and E.

	Capability															
Mission Description	**Access to the airspace**	**C^2 from Outside Entity**	**Long Range/Endurance**	**Increased Platform Availability**	**Quick deployment**	**Terrain Avoidance**	**Formation Flight**	**Mon./control Multi-ship Op.**	**Precision A/C State Data**	**High Altitude**	**All Weather**	**Vertical Profiling**	**Deploy / potentially Retrieve**	**Precision Trajectories**	**Base of op's in Remote Area**	**Covert Operations**
Earth Science Missions	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Repeat Pass Interferometry	5	0	0	3	5	0	0	0	5	1	1	0	0	5	0	0
Cloud and Aerosol Measurements	5	5	3	0	0	1	3	5	1	1	5	1	0	0	0	0
Stratospheric Ozone Chemistry	1	5	5	1	0	0	1	0	1	3	0	0	0	0	0	0
Tropo. Pollution and Air Quality	5	5	3	1	3	0	3	1	0	1	0	1	0	0	0	0
Water Vapor and Total Water Meas.	5	5	5	1	0	0	0	1	1	3	0	1	0	0	0	0
Coastal Ocean Observations	3	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Fire, Emissions, and Plume Assess.	5	3	3	3	1	0	1	1	0	0	3	0	1	0	0	0
O2 and CO2 Flux Measurements	3	5	3	0	0	1	0	1	0	0	0	3	0	0	0	0
Vegetation Structure, Composition,	1	0	1	0	0	0	3	5	5	0	0	0	0	0	0	0
Aerosol, Cloud, and Precip. Dist.	5	5	2	1	0	0	0	1	3	1	0	5	0	0	0	0
Glacier and Ice Sheet Dynamics	3	1	1	3	3	0	0	0	0	0	0	0	1	0	0	0
Radiation – Vert. Profiles	5	5	0	1	0	1	3	5	0	1	0	3	0	0	0	0
Ice Sheet Thickness and Surface Def.	1	5	0	0	0	1	5	5	1	0	0	0	0	0	0	0
Imaging Spectroscopy	5	0	1	0	5	0	0	0	0	1	0	0	0	0	0	0
Topographic Mapping and Topo. Change	3	3	0	0	0	0	0	0	5	1	0	0	0	1	0	0
Gravitational Acceleration Measurements	0	0	0	0	0	0	0	0	5	0	0	0	0	3	0	0
Antarctic Exploration Surveyor	0	0	1	1	0	1	0	0	0	0	0	0	0	0	5	0
Magnetic Fields Measurements	0	0	0	0	0	0	0	5	1	5	0	0	0	0	0	0
Cloud Properties	5	5	3	0	5	0	3	3	5	3	0	3	3	0	0	0
River Discharge	3	3	0	1	1	0	3	0	1	0	0	0	0	3	0	0
Snow – Liquid Water Equivalents	5	1	1	3	1	3	0	0	3	0	0	0	1	3	0	0
Soil Moist. and Freeze/Thaw States	5	1	3	1	0	0	0	0	5	0	0	3	0	3	0	0
Cloud Microphysics/Properties	5	5	0	1	1	0	1	0	0	5	1	1	3	0	0	0
Focused Obs. – Extreme Weather	5	3	3	0	0	0	0	0	0	1	0	0	1	0	0	0
Forecast Initialization	5	5	3	0	3	1	1	5	0	1	5	0	5	0	0	0
Hurricane Evolution, and Landfall	5	5	5	0	3	1	1	5	0	1	5	0	5	0	0	0

Physical Oceanography	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**3**	**1**	**0**	**5**	**0**
Track. Transport and Evolution of Poll.	**5**	**5**	**5**	**5**	**5**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
Clouds/ Aerosol/ Gas/ Rad. Interactions	**3**	**3**	**3**	**0**	**0**	**0**	**3**	**3**	**0**	**5**	**3**	**3**	**1**	**0**	**0**	**0**
Long Time Scale Vert. Profiling of Atm.	**1**	**5**	**0**	**0**	**0**	**1**	**3**	**1**	**0**	**1**	**0**	**3**	**0**	**0**	**0**	**0**
Global 3D Continuous Measurement	**5**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**3**	**1**	**0**	**0**	**0**
Transport and Chem. Evolution in Tropo.	**5**	**5**	**3**	**5**	**3**	**1**	**1**	**1**	**0**	**1**	**0**	**3**	**1**	**0**	**0**	**0**
Land Mgmt. and Coastal Region	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'
Wildlife Management Pop. Count	**0**	**5**	**0**	**0**	**0**	**3**	**1**	**1**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**5**
Wildlife Management Telemetry Mission	**5**	**5**	**0**	**1**	**1**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**
Wildlife Habitat Change Mission	**5**	**1**	**1**	**1**	**3**	**1**	**0**	**3**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**3**
Precision Agriculture	**3**	**0**	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
Water Reservoir Management	**3**	**1**	**0**	**1**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Range Management	**1**	**0**	**0**	**1**	**1**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**0**
Urban Management	**5**	**0**	**0**	**1**	**1**	**5**	**0**	**0**	**5**	**0**	**0**	**0**	**0**	**3**	**5**	**1**
Coastal Water Quality	**5**	**3**	**3**	**3**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
ID and Tracking of Maritime Species	**5**	**3**	**3**	**5**	**5**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
Shallow Water Benthic Ecosystem	**0**	**1**	**0**	**1**	**1**	**1**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**5**	**5**	**0**
Carbon Dioxide Flux	**0**	**3**	**3**	**0**	**0**	**1**	**0**	**0**	**3**	**0**	**3**	**3**	**0**	**3**	**0**	**0**
Wildfire / Disaster: Real-time Comm.	**5**	**1**	**1**	**5**	**5**	**0**	**1**	**3**	**0**	**0**	**5**	**0**	**0**	**0**	**1**	**0**
Wildfire/Disaster: Predict, Measure	**5**	**3**	**3**	**5**	**5**	**0**	**1**	**0**	**3**	**0**	**5**	**0**	**0**	**0**	**3**	**0**
Wildfire: Fire Retardant Application	**5**	**5**	**0**	**5**	**3**	**3**	**5**	**1**	**3**	**0**	**5**	**0**	**0**	**5**	**0**	**0**
Wildfire/Disaster: Reducing Risk	**0**	**1**	**0**	**5**	**5**	**5**	**0**	**0**	**3**	**0**	**3**	**0**	**0**	**0**	**5**	**0**
Wildfire/Disaster: Pre- and Post-Event	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
Homeland Security Missions	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Marine Interdiction, Mon., Detection..	**5**	**5**	**3**	**3**	**5**	**1**	**1**	**1**	**1**	**0**	**1**	**0**	**3**	**1**	**0**	**1**
Tunnel Detection and Monitoring	**5**	**1**	**3**	**3**	**0**	**0**	**0**	**0**	**3**	**0**	**1**	**0**	**0**	**3**	**0**	**3**
Broad Area Surveillance	**5**	**1**	**3**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**
BORTAC Situational Awareness	**0**	**1**	**0**	**3**	**5**	**3**	**0**	**0**	**3**	**0**	**3**	**0**	**0**	**1**	**5**	**5**
Coastal Patrol	**3**	**1**	**1**	**0**	**0**	**0**	**1**	**1**	**3**	**1**	**3**	**1**	**3**	**0**	**0**	**0**

Table 5.1 - Mission vs. Weighted Capabilities

5.2 Matrix Weighting Definitions

Access to Airspace
5: Mission requires "unconstrained" access to the NAS to accomplish the mission. For example, rapid response, or real-time re-tasking are absolutely required.
3: Mission allows flight with "constrained" access to the NAS and still accomplishes most of the desired mission. Mission schedule either allows time to file Certificate of Authorization (COA), has limited need to deviate from a filed plan, or event-driven response is not a priority.
1: Mission can probably fly with "very limited" access to the NAS and still accomplish most of the desired mission. Mission schedule allows time to file COA, and there is no re-tasking necessary.
0: No "file & fly" access to NAS necessary.

Command/Control from Outside Entity
5: Mission success requires that C^2 system respond to input from payload system (to track dynamic phenomena), another UAV (for coordinated flight), or any other non-human source (such as satellite weather data). (Note: the use of GPS satellite data is not meant to be included with this need for "satellite data").
3: Mission success is possible with some limited C^2 inputs from outside source such as the payload or another UAV. Mission probably still uses some limited operator interface into the C^2. (The need for terrain avoidance, or GPS input, is not considered in this classification.)
1: Mission can be fully accomplished with C^2 input from operator.
0: Mission can be fully accomplished with a preprogrammed mission manager. A commanded repeat of a portion of the mission is still considered a zero.

Long Range / Long Endurance
5: Mission lasts 14 or more days and/or requires a range in excess of 10,000 miles.
3: Mission lasts between 1 and 13 days and/or requires a range between 3,000 and 10,000 miles.
1: Mission lasts between 6 and 24 hours and/or requires a range between 1,000 and 3,000 miles.
0: Mission does not involve significant levels of either endurance or range.

Increased Platform Availability
5: Mission is characterized by purely dynamic events. This requires that the vehicle have maximum possible availability.
3: Mission incorporates the potential for dynamic events, or has some elements of a dynamic event involved, thus requiring high vehicle availability.
1: Mission does not involve a response to dynamic events, but calls for a high frequency of operations, and thus some advanced level of availability.
0: Mission has no trace of a dynamic event, or high frequency operation, and thus no need for elevated availability.

Quick Deployment
5: Mission involves a purely unpredictable event, and thus requires a maximum capability for quick deployment.
3: Mission involves an unpredictable event, but some forecasting (weather related), or for example, satellite monitoring, which mitigates the unpredictability.
1: Mission is event-driven, but the season or general timeframe of the event is well-known in advance
0: Mission is not event-driven and therefore does not require quick deployment.

Terrain Avoidance
5: Mission requires "below building-top elevation" flight in an urban area – thus requiring advanced terrain avoidance and a high-level of aggressive maneuverability.
3: Mission requires flight below 500' AGL in hilly or possibly mountainous terrain – thus terrain avoidance and aggressive maneuvering is required.
1: Mission calls for either flight above 500' AGL or flight below 500' AGL over generally flat terrain – thus low-resolution terrain avoidance with moderate maneuvering is acceptable. Missions that call for data flights down to the surface, even for a short time, would be considered in this category.
0: Mission does not require any terrain avoidance capability.

Formation Flight
5: Mission requires two or more vehicles flying in a tight formation - flying, essentially, as "one" vehicle, or in such close proximity as to be called a "swarm".
3: Mission can be performed with two or more vehicles flying in a coordinated fashion, but with considerable separation (and with probably some flexibility to the accuracy of their relative separation distance).
1: Mission can be performed by one "mother ship" vehicle that directs one or more "daughter" vehicles in some manner. Control of the distance or trajectory of the respective vehicles is not necessarily required.
0: Mission does not require any multi-vehicle coordination.

Monitor/Control Multi-Ship Operations
5: Mission requires that 4 or more vehicles be monitored and/or controlled simultaneously.
3: Mission requires that 3 vehicles be monitored and/or controlled simultaneously.
1: Mission requires that 2 vehicles be monitored and/or controlled simultaneously.
0: Mission does not require multi-ship operations.

Precision State

5: Mission requires highly accurate position (such as to DGPS resolution) and highly accurate vehicle attitude (such as ±0.25 deg. in all three axes) to perform such tasks as very accurate determination of ground-object position.
3: Mission only requires GPS-level accuracy of position, and relatively high accuracy of vehicle 3-axis attitude.
1: Mission can be performed with GPS-level position. Knowledge of the vehicle's 3-axis attitude may or may not be necessary.
0: Regardless of the vehicle's need or use of GPS for basic enroute navigation, the actual mission does not require any precision state information.

High Altitude

5: Mission requires an altitude capability in excess of 85K ft.
3: Mission requires an altitude capability between 66K and 85K feet.
1: Mission requires an altitude capability between 46K and 66K feet.
0: Mission is below 46K feet, and does not therefore require high altitude capability.

All Weather

5: Mission requires flight in very severe atmospheric conditions for an extended period of time. Very severe conditions would include flight into hail, lightning, the inner and outer bands of hurricanes, or through volcanic or wildfire smoke and particulate plumes.
3: Mission probably requires day or night flight in severe atmospheric conditions, such as rain, icing, and/or moderate turbulence.
1: Mission is likely to involve day-time flight in light rain or light turbulence.
0: Mission does not involve all-weather flight.

Vertical Profile

5: Mission requires that the vehicle perform a maneuvering vertical descent (and perhaps ascent) to gather vertical profile data over a period in excess of 24 hours. Accurate horizontal position control and timing, in concert with the changing vertical position, may also be necessary so that data is gathered along the same vertical axis.
3: Mission requires that the vehicle perform a maneuvering vertical descent (and perhaps ascent) to gather vertical profile data over a period less than 24 hours.
1: Mission permits the vertical profile data to be gathered either by the vehicle dispensing and monitoring Drop Sondes or by multiple vehicles in stacked formation.
0: Mission does not involve vertical profiling.

Deploy/Retrieve

5: Mission requires that the vehicle deploy one or more daughter ships. Retrieval and/or docking are highly preferred but not necessarily required. The use of expendable daughter ships (and perhaps even drop sondes) is acceptable as an operational option.
3: Mission requires that the vehicle deploy one or more daughter ships. These vehicles would either be recovered on the surface, or would be designed to be expendable. No airborne retrieval and/or docking is needed. The use of expendable drop sondes is acceptable as an operational option.
1: Mission requires that the vehicle deploy one or more expendable passive sensors such as drop sondes. No daughter ship deployment is needed.
0: Mission does not involve deployment of any devices.

Precision Trajectory

5: Mission requires that the vehicle follow a precise trajectory, absolute or relative, that must be based on better-than GPS accuracy. Trajectory is to be based on a position accuracy of better than ±15 ft. (±5 m.).
3: Mission requires that the vehicle follow a precise trajectory, absolute or relative, that is based on no-better-than GPS position data. Trajectory is to be based on a position accuracy of between ±15 ft. (±5 m.) and ±150 ft. (±50 m.).
1: Mission requires some sensitivity to vehicle trajectory, absolute or relative, but position accuracy can be less than ±150 ft. (±50 m.).
0: Mission does not involve precision trajectory.

Remote Operations

5: Mission requires flight operation from a location not intentionally suited for air operations. Such an area would typically be on a road, or on undeveloped, but cleared, land such as an empty field. Operations from a ship or a truck would be included here also.
3: Mission requires flight operations from a small, rural, uncontrolled airfield. Such a location is designed for non-commercial flight operations, and may only have a relatively short grass, dirt, or (in the case of the Antarctic shelf) ice runway.
1: Mission requires flight operations from a small airfield that could either be controlled or uncontrolled. However, such a facility would have one moderate-length asphalt runway
0: Mission does not involve operations from a remote facility.

Covert Operations

5: Mission requires the vehicle be inaudible at a distance of 300 ft at night. It may also be required that the vehicle be visually covert during daylight hours as well, which would dictate size constraints, color, and lighting.
3: Mission requires that the vehicle be relatively quiet at a distance of 300 ft and generally inaudible during the daylight hours. Visual covertness is still important, but not necessarily a requirement.
1: Mission requires that the vehicle be very quiet at a distance of 1000 ft. Visual covertness in not an issue.
0: Mission does not involve covertness in any way.

Table 5.2 - Capability Weighting Scale Definitions

From the matrix shown in Table 5.1, the following observations are noted:

- Of the 53 missions listed, the capabilities with the most missions at the weighted "level 5" (i.e., absolute requirement) are:
    - Access to the National Airspace (29 missions)
    - C2 from Outside Entity (19 missions)
    - Quick Deployment (10 missions)

- Of the 53 missions listed, the capabilities with the most missions at the weighted "level 0" (i.e., no requirement) are:
    - Covert Operations (45 missions)
    - Base of Operations in Remote Area (43 missions)
    - Precision Trajectory (40 missions)

- Of the 16 capabilities listed, the missions with the most required capabilities at the weighted "level 5" are:
    - Hurricane Genesis, Evolution, and Landfall (6 capabilities)
    - Forecast Initialization (5 capabilities)
    - Tracking Transport and Evolution of Pollution (5 capabilities)

- Of the 16 capabilities listed, the missions with the most required capabilities at the weighted "level 0" are:
    - Gravitational Acceleration Measurements (14 capabilities)
    - Magnetic Fields Measurements (13 capabilities)
    - Wildfire/Disaster: Pre- and Post-Event Monitoring and Assessment (13 capabilities)

When the above observations and other information from Table 5.1 are taken in conjunction with Figure 4.3, the basis for developing a funding prioritization methodology can be developed. Other issues including time horizon for technology availability, mission critical capabilities, and mission priorities will be needed to form a UAV roadmap.

5.3 Technology Readiness Level Estimates

As detailed earlier in this document, Technology Working Groups were established to help assess the various technologies required for successful Earth observation applications for UAVs. After each TWG completed the templates developed for acquiring the inputs, an independent review of these templates was conducted by the USRA. This peer review was to help the Assessment Team in its identification of the gaps in technology development as well as to suggest ways for improving the robustness of the effort. The USRA report is contained in Volume 3.

Table 5.3.1 is a summary-level comparison between the TRLs estimated by both the TWGs and USRA. The intent is to provide a general sense of the state-of-the-art of each technology that would support the capabilities identified earlier. The table is meant to be an overview of the technology recognizing that each may contain several sub levels. For example, Payload Sensors contains both active and passive categories and types within each. Since these technologies may be at different stages of development, they will have differing TRL estimates. Hence, there may be ranges of TRLs for TWG and USRA estimates.

	TRL Estimates		
Technology	**TWG**	**USRA**	**TWG Lead**
Autonomous Mission Mgmt. ** **Intelligent Vehicle Sys. Mgmt.** **Contingency Mgmt.** 3 broad, 8 sub, 8 sub-sub	3 - 6	2 - 5	ARC
Collision Avoidance 1 broad, I sub, 1 sub-sub	7	<7	DFRC
Intelligent Sys. Health Monitoring	3 -7	<6	ARC
Reliable Flight Systems 1 broad, 1 sub, 1 sub-sub	6	<6	DFRC
Payload Sensors 1 broad, 6 sub, 13 sub-sub	4 - 9	6 - 9	ARC
Intell. Data Handling and Proc. ** **Network-Centric Comm.** **Navigation Accurate Sys. Tech.** 3 broad, 5 sub, 4 sub-sub	3 - 9	4 - 6	LaRC
Over-the-Horizon Comm. 1 broad, 3 sub, 3 sub-sub	3	2 - 6	DFRC
Open Architecture 1 broad, 1 sub, 1 sub-sub	NE	NE	ARC
Power and Propulsion 1 broad, 6 sub, 11 sub-sub	4	1 - 7	GRC
Enhanced Structures 1 broad, 1 sub, 1 sub-sub	1 - 3	3 - 7	LaRC

**(combined TWG) NE=Not Estimated

Table 5.3 - TRL Estimates

The TWGs identified a total of 87 different technologies within the classifications and levels shown in the Table. For each, the number of sub and sub-sub levels is shown as well. The TWG and USRA data are contained in Volume 3.

5.4 Next Steps

One of the purposes for conducting this assessment of the role of UAVs in Earth observations was to provide the foundations for development of a comprehensive civil UAV roadmap. It is expected that the content of this report will be updated periodically as new information becomes available and used to assess the feasibility of future missions. The concept of a "living document" bests describes the philosophy of this effort. The development of the roadmap will begin with the completion and publication of this Assessment Document.

The Civil UAV Team's objectives were stated to be:

- To determine and document desired future Earth observation missions for all UAVs based on user-defined needs
- To determine and document the technologies necessary to support those missions
- To discuss the present state of the art platform capabilities and required technologies, including 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

The Team feels strongly that this report meets these objectives to the degree possible for this stage of the Roadmap development. As technologies mature and requirements become defined mission prioritization relative to funding to develop capabilities will be addressed as the process of this effort continues.

In addition, the Team feels that the roadmap will help influence funding decisions to develop those technologies that are considered enabling or necessary but are not contained currently within approved funding plan.

Appendix A

Acronyms, Abbreviations and Definitions

3D	Three Dimensional
AGL	Above Ground Level
ASA	Aerospace States Association www.aerostates.org
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
BORTAC	Border Patrol Tactical Team
CAMEX	Convection and Moisture Experiment
cm	centimeter
C	a frequency sub-band
C^2	Command and Control
C^3I	Command, Control, Communications and Intelligence
CDOM	Color Dissolved Organic Matter
Cnty.	County
CIRPAS	Center for Inter-Disciplinary Remotely Piloted Aircraft Studies (see Appendix B)
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
COA	Certificate of Authorization
DARPA	Defense Advanced Research Projects Agency
Dept.	Department
dGPS	Differential Global Positioning System
DHS	Department of Homeland Security
Dir.	Directorate
DoD	Department of Defense
DOE	Department of Energy

DOI	Department of the Interior
E_c	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
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
GOTChA	Goals, Objectives Technical Challenges and Approaches
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
HAB	Harmful Algal Blooms
HALE	High Altitude Long Endurance
hr	hour
Hz	Hertz
ITAR	International Traffic in Arms Regulations
ICE	Immigration and Customs Enforcement

IMU	Inertial Measurement Unit
IMM	Intelligent Mission Management
IMU	Inertial Measurement Unit
iNet	Integrated Network Enhanced Telemetry
INS	Inertial Navigation System
INST	Institute
IR	Infrared
ISR	Intelligence, Surveillance, and Reconnaissance
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
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://www.ghcc.msfc.nasa.gov/sparcle/sparcle_tutorial.html
LOS	line of sight
m	meter
mm	millimeter
M	Million
MALE	Medium Altitude Long Endurance
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 Airspace System
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
NO_2	Nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration
N_2O	Nitrous oxide
NOx	Nitrogen oxides
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
pH	Potential of Hydrogen, a measure of acidity
PRGNC	Precision Relative Guidance, Navigation, and Control
PSC	Polar Stratospheric Clouds
PV	Photovoltaic
R&D	Research and Development
RF	Radio Frequency
ROA	Remotely Operated Aircraft
RTCA	Radio Technical Commission for Aviation
SAR	Synthetic Aperture Radar
SATCOM	satellite communication
sec	Second
Serv.	Services
SIGINT	Signals Intelligence
SO_2	Sulfur dioxide
SST	Sea Surface Temperature
STOL	Short take-off and landing
TBD	To Be Determined
Tech	Technology

TF	Technology Forecasting
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 or Unmanned Aerial Vehicle
TUAV	Tactical Unmanned Aerial Vehicle
UCAV	Unmanned Combat Aerial Vehicle
UPS	United Parcel Service
U. S.	United States
US	United States
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VTUAV	Vertical Takeoff Unmanned Aerial Vehicle
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
VTOL	vertical take-off and landing
W	Watts

Appendix F

UAV Sector GOTChA Chart

Overview

As referenced in several places within the main body of the document, Figure F.1 is the GOTChA Chart. Many of the general and specific capabilities have been captured in NASA's UAV Sector "GOTChA" chart. The GOTChA used in this assessment is for illustrative purposes. It was developed by the UAV Sector of NASA's Aeronautics Research Mission Directorate. Because of organizational restructuring at NASA Headquarters, this organization does not exist. However, for purposes of defining a potential program, this example provides a wealth of information.

The GOTChA chart is a management tool that breaks down the Goals, Objectives, Technical Challenges, and Approaches of a project – in this example, improving the state-of-the-art for UAV missions to perform Earth science observations.

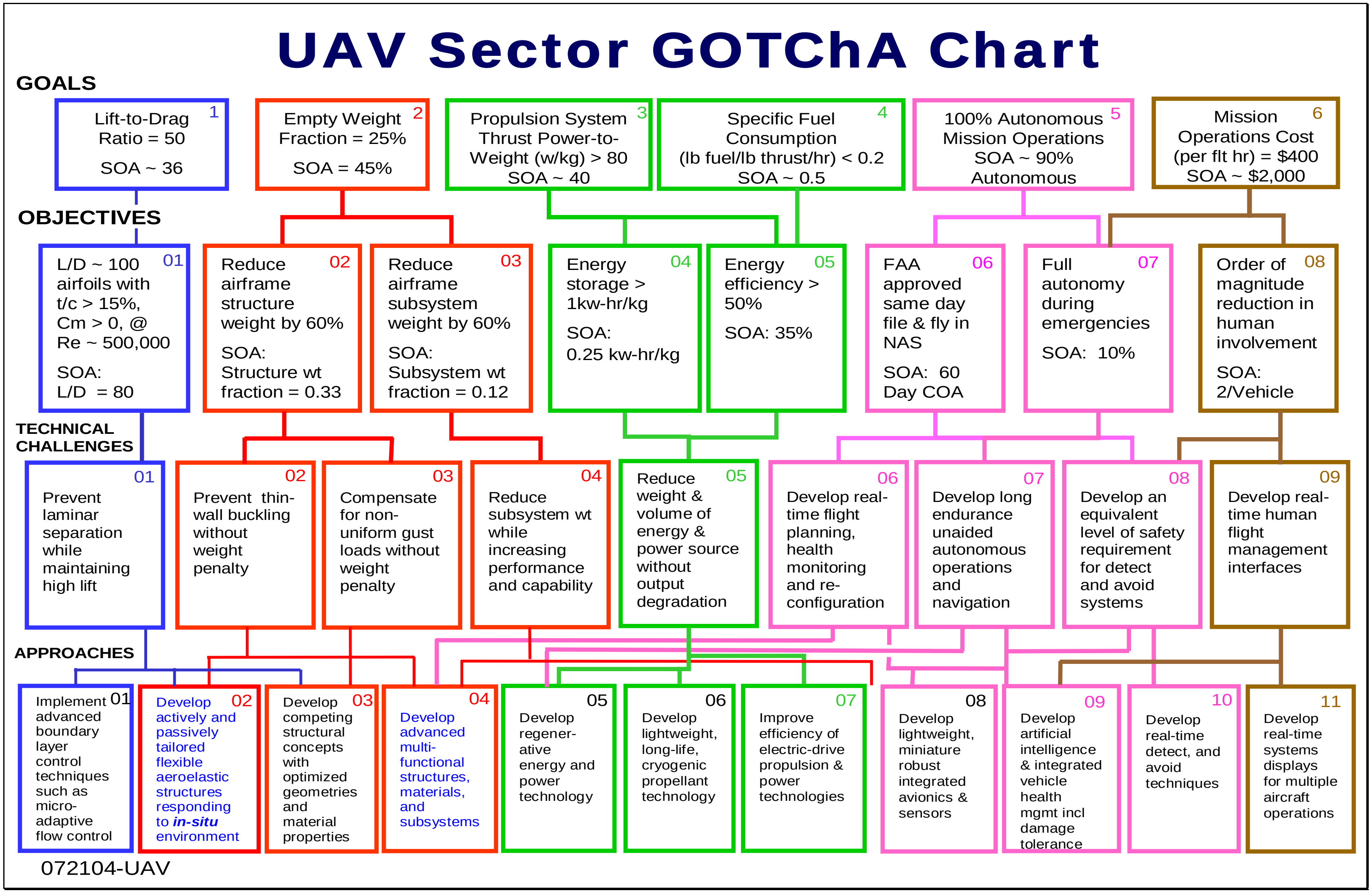


Figure F.1 UAV Sector GOTCHA Chart

Bibliography and References

Organizations/Agencies/Private Sector

The organizations represented at the various workshops and conferences along with those that participated in the interview process are articulated in this section. It should be pointed out that only the top organizational name is given. For example, although NOAA is listed once, the Team recognizes that participants from the many applicable divisions and laboratories were contacted for inputs. The Assessment Team has the rosters of all attendees at the workshops and of those that participated in the interview process.

- **Government Agencies**

Department of Defense
Department of Energy
Department of Homeland Security
Department of the Interior
Federal Aviation Administration
NASA AMES
NASA DFRC
NASA GRC
NASA GSFC
NASA HQ
NASA JPL
NASA LaRC
NASA MSFC
National Oceanic and Atmospheric Admin.
National Science Foundation
US Geological Survey
USDA National Forest Service

- **Academic Institutions**

California State Univ., Monterey Bay
California State University, San Diego
Colorado State University
Columbia University
Florida State University
Georgia Institute of Technology
Hampton University
Harvard University
Ohio State University
Penn State University
Purdue University
Universities Space Research Association
University of California, Davis
University of California, San Diego
University of Colorado
University of Denver
University of Illinois
University of Kansas
University of Maryland
University of Michigan
University of Southern California
University of Utah
Woods Hole Oceanographic Institution

- **Private Sector Organizations**

Bandwith Solutions, Inc.
EGG Technical Services
GTP Associates LLC
Longitude 122 West, Inc.
Lynne Carbon & Associates, Inc.

References

In articulating the following references, when available, a link to a website containing either the reference itself or the entire document will be given. In some cases, the materials are available to download. The references are presented in no order of preference or importance.

1. Office of the Secretary of Defense UAV Roadmap. http://www.acq.osd.mil/uas/.
2. Aviation Week and Space Technology, *"2005 Aerospace Source Book". January 17, 2005.*
3. NASA Civil UAV Assessment Team Website http://www.nasa.gov/centers/dryden/research/civuav/index.html.
4. Cost & Business Model Analysis for Civilian UAV Missions, Moiré Incorporated Issaquah, WA 98027, June, 2004.
5. Economic Forecasts: www.frost.com, www.forecastinternational.com, www.auvsi.org, www.uavworld.com, www.tealgroup.com .
6. Information on CAPECON: http://194.90.59.6/projects/capecon.htm
7. United States Government Accountability Office, UNMANNED AIRCRAFT SYSTEMS: New DOD Programs Can Learn from Past Efforts to Craft Better and Less Risky Acquisition Strategies, Report to the Committee on Armed Services, U. S. Senate, March 2006 GAO-06-447 Unmanned Aircraft Systems: New DOD Programs Can Learn from Past Efforts to Craft Better and Less Risky ...
8. Moire Inc. "Cost & Business Model Analysis for Civilian UAV Missions," August 2004. http://geo.arc.nasa.gov/uav-suborbital/

Technology Forecast References

1. ALLEN, T. J. *Managing the Flow of Technology.* Cambridge. MA: MIT Press, 1977.
2. AYRES, R. U. *Technological Forecasting and Long Range Planning.* New York: McGraw-Hill, 1969.
3. BLOHM, H., and K. STEINBUCK. *Technological Forecasting in Practice.* Lexington, MA: Lexington Books, 1973.
4. BRIGHT, J. R. A *Brief Introduction to Technological Forecasting.* New York: Pergamon Press, 1972.
5. BRIGHT, J. R., and M.E.F SCHOEMAN. A *Guide to Practical Technological Forecasting.* Englewood Cliffs, NJ: Prentice Hall, 1980.
6. BRODY, H. "Great Expectations: Why Technology Predictions Go Awry." *Technology Review,* July 1991.
7. BROWNLIE, D. T "The Role of Technology Forecasting and Planning: Formulating Business Strategy." *Industrial Management and Data Systems,* Issue 2, 1992.
8. CETRON, M. J. *Technological Forecasting: A Practical Approach.* Technology Forecasting Institute, 1969.
9. CETRON, M. J., and C. A. RALPH. I*ndustrial Applications of Technological Forecasting.* New York: Wiley-Interscience, 1971.
10. CHAMBERS, J. C., S. K. MULLICK, and D. D. SMITH. "How to Choose the Right Forecasting Technique." *Harvard Business Review,* July-Aug. 1971.
11. DUBLIN, M. 1989. Futurehype: The Tyranny of Prophecy. New York: Plume.

12. GARDE, V. D., and R. R. PATEL. "Technological Forecasting for Power Generation-A Study Using the Delphi Technique." *Long Range Planning,* Aug. 1985.
13. GOTTINGER, H. W. "A Strategic Management Decision Support Tool for Technology Management." *International Journal of Technology Management,* Issue 2, 1989.
14. HANKE, J. & REITSCH, A. 1992. Business Forecasting: Fourth Edition. New York: Simon & Schuster.
15. HENRY, B. *Forecasting Technological Innovation.* Norwell, MA: Kluwer Academic, 1991.
16. JONES, H., and B. L. TWISS. *Forecasting Technology for Planning Decisions.* New York: Macmillan, 1978.
17. KLEIN, H. E., and R. E. LINNEMAN. "The Use of Scenarios in Corporate Planning-Eight Case Histories." *Long Range Planning,* Oct. 1981.
18. LEE, J. C., K. W. Lu, and S. C. HORNG. "Technological Forecasting with Nonlinear Models." *Journal of Forecasting,* Apr. 1992.
19. LINESTONE, H. H., and M. TRUOTT. *The Delphi Method: Techniques and Applications.* Reading, MA: Addison Wesley, 1975.
20. MARTINO, J. P. "Looking Ahead with Confidence." IEEE *Spectrum,* March 1985,
21. MARTINO, J. P. *Technological Forecasting for Decision Making,* 2nd ed. Amsterdam: North-Holland, 1983.
22. MARTINO, J. P. "Technological Forecasting-An Overview." *Management Science,* Jan. 1980.
23. MILLETT, S. & HONTON, E. 1991. A Manager's Guide to Technology Forecasting and Strategy Analysis Methods. New York: Battelle Press.
24. MITCHELL, V. W. "Using Delphi to Forecast in New Technology industries." *Marketing Intelligence and Planning,* Issue 2, 1992.
25. MODIS, T. 1992. Predictions: Society's Telltale Signature Reveals the Past and Forecasts the Future. New York: Simon & Schuster.
26. MOGEE, M. E. "Using Patent Data for Technology Analysis and Planning." *Research-Technology Management,* July/August 1991.
27. NANUS B., "Visionary Leadership: How to Re-Vision the Future," *The Futurist*, September-October, (1992).
28. SCHNAARS, S. P. "Where Forecasters Go Wrong." *Across the Board,* Dec. 1989.
29. TALBOT, M. 1991. The Holographic Universe. New York: HarperCollins.
30. TOFFLER, A. et al. 1972. The Futurists. New York: Random House.
31. VANSTON, L. K., R. C. LENZ, and R.S. WOLFF. "How Fast Is New Technology Coming?" *Telephony,* Sept. 18, 1989.
32. VAN WYK, R. J. "The Notion of Technological Limits: An Aid to Technological Forecasting." *Futures,* June 1985.
33. WHEELER, D. R., and C. J. SHELLEY. "Toward More Realistic Forecasts for High-Technology Products." *Journal of Business and Industrial* Marketing, Summer 1987.