Unnamed Aircraft System (UAS) Service Demand 2015 - 2035

Literature Review & Projections of Future Usage

Technical Report, Version 0.1 — September 2013

DOT-VNTSC-DoD-13-01

Prepared for:
United States Air Force
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13. ABSTRACT (Maximum 200 words)

This report assesses opportunities, risks, and challenges attendant to future development and deployment of UAS within the National Airspace System (NAS) affecting UAS forecast growth from 2015 to 2035. Analysis of four key areas is performed: technology, mission needs, economics, and existing or anticipated challenges to routine use in NAS operations. Forecast effects of emerging technologies as well as anticipating new technological innovations in areas of airframes, powerplants, sensors, communication, command and control systems, and information technology and processing are evaluated. Anticipated mission needs include intelligence, surveillance and reconnaissance (ISR), as well as new areas such as stores delivery, cargo transport, search and rescue, and pilot augmentation; example business case models are developed for each of these areas. Challenges to routine UAS usage in the NAS include: absence of legislation and regulations for safe flight in integrated airspace; pilot training and certification; regulatory, policy, and procedural issues; social issues, such as privacy and nuisance concerns; environmental issues, such as noise and emissions; and safety.

Provided these challenges are largely mitigated, the following are projections of UAS fleet size by user in 2035: Department of Defense ~14,000, with additional ~5,000 having optional pilot augmentation (Air Force ~3,500; Navy + Marines ~2,500; Army ~10,000); Public Agencies (Federal, State, & Local) ~70,000. Total UAS vehicles will approach ~250,000 by 2035, of which ~175,000 will be in the commercial marketplace. UAS operations are expected to surpass manned aircraft operations, for both military and commercial domains, by 2035.

14. SUBJECT TERMS
Unmanned Aircraft Systems (UAS), Unmanned Aerial Vehicles (UAV), Remotely Piloted Vehicles (RPV), Ground Based Sense and Avoid (GBSAA), Airborne Sense and Avoid (ABSAA), Communications, Command, and Control (C^3), Sensors, Information Technology, Airframes, Powerplants, Mission Needs, Economic Barriers, Market Development, Commercial Markets, Business Models, Regulations, Policies, Procedures

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

***SI = International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)**

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The intent of this report is to provide the USAF AFLCMC/HBAG with an initial comprehensive industry literature review and survey in support of (1) developing informed projections of future UAS service domains and demand, and (2) recommending opportunities for future UAS research and exploration. Generation and refinement of this report's contents was a joint government-industry effort, drawing on UAS subject-matter expertise from personnel at the Volpe Center, Mosaic ATM, Inc., and Aviation Management Associates, Inc.

Version 0.1 of this report is subject to revision based upon government and industry feedback. Any questions and/or comments attendant to this report should be submitted to Jason Glaneuski (Jason.Glaneuski@dot.gov) and Mark Strout (Mark.Strout@dot.gov) of the Volpe Center's Air Traffic Management Systems Division (RVT-73) no later than close of business (COB) Friday, December 20, 2013.

The Volpe Center wishes to thank the USAF AFLCMC/HBAG for their continued support towards mission-critical UAS research and analysis.

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List of Abbreviations

Abbreviation	Term
1090ES	1090 MHz Mode S Transponder Extend Squitter
4G	Fourth Generation
AAM	Air-to-Air Missile
AATD	Army Aviation Applied Technology Directorate
ABSAA	Airborne Sense and Avoid
AC	Advisory Circular
ACAS	Airborne Collision Avoidance System
ACAT	Acquisition Category
ACTD	Advanced Concept Technology Demonstration
ADC	Analog-to-Digital Converter
ADS-B	Automatic Dependent Surveillance Broadcast
AECV	All Environment Capable Variant
AEODRS	Advanced Explosive Ordnance Robotic System
AFR	Autonomous Flight Rules
AFS	Flight Standards Service (FAA)
AGL	Above Ground Level
AI	Airspace Integration
AIAA	American Institute of Aeronautics and Astronautics
AIR	Aircraft Certification Service (FAA)
ALM	Additive Layer Manufacturing
ALSM	Airborne Laser Swath Mapping
AMA	Academy of Model Aeronautics
AMRDEC	Aviation and Missile Research, Development and Engineering Center
AMUST	Airborne Manned/Unmanned Systems Technology
ANP	Airborne Nuclear Power
APU	Auxiliary Power Unit
ASIC	Application Specific Integrated Circuit
ASM	Air-to-Surface Missile
ASTM	American Society for Testing and Materials
ASW	Anti-Submarine Warfare
ATC	Air Traffic Control
ATO	Air Traffic Organization (FAA)
ATS	Air Traffic Services
AUVSI	Association for Unmanned Vehicle Systems International
AvGas	Aviation Gasoline
BA	Battlespace Awareness
BAMS	Broad-Area Maritime Surveillance
BMA	Business Model Archetype
C3	Communications, Command, and Control
CA	Collision Avoidance

Abbreviation	Term
CAI	Composite Affordability Initiative
CAIV	Cost as an Independent Variable
CAP	Combat Air Patrol
CBO	Congressional Budget Office
CBP	Customs and Border Protection
CCD	Charge Coupled Device
CCDR	Combatant Commander
CDL	Common Data Link
CFR	Code of Federal Regulations
CFRP	Carbon Fiber Reinforced Polymer
CIA	Central Intelligence Agency
CNO	Chief of Naval Operations
CNSI	California NanoSystems Institute
CNT	Nitrogen Doped Carbon Nanotube
COA	Certificate of Authorization
CONEMP	Concept of Employment
CONOPS	Concept(s) of Operations
CONUS	Continental United States
DARPA	Defense Advanced Research Project Agency
DC	Direct Current
DHS	Department of Homeland Security
DME	Distance Measuring Equipment
DMLS	Direct Metal Laser Sintering
DoD	Department of Defense
DSA	Detect. Sense and Avoid
ECU	Engine Control Unit
ELEV	Extremely Long Endurance Vehicle
EO/IR	Electro-optical Infrared
EPA	Environmental Protect Agency
ESA	Electric Speed and Altitude
ESSP	Efficient Small Scale Propulsion
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FCS	Future Combat System
FEMA	Federal Emergency Management Agency
FIS-B	Flight Information System Broadcast
FL	Flight Level
FOIA	Freedom of Information Request
FOTC	Flight of the Century
FTI	Federal Aviation Administration Telecommunication Infrastructure
FTC	Federal Trade Commission
GBSAA	Ground Based Sense and Avoid
GIS	Geographic Information System

Abbreviation	Term
HART	Heterogeneous Airborne Reconnaissance Team
HEETE	High Efficiency Embedded Turbine Engine
HYDROICE	Hydro Internal Clean Engine
IARPA	Intelligence Advanced Research Projects Agency
IFR	Instrument Flight Rules
IM	Instant Messaging
IMC	Instrument meteorological conditions
IMU	Internal Measurement Unit
ISR	Intelligence, Surveillance, and Reconnaissance
IT	Information Technology
ITAR	International Traffic in Arms Regulations
ITU	International Telecommunication Union
HALE	High Altitude Long Endurance
J-UCAS	Joint Unmanned Combat Aircraft System
JUAS COE	Joint Unmanned Aircraft System Center of Excellence
LIDAR	Light Detection and Ranging
LOV	Low Observability Vehicle
LSA	Light Sport Aircraft
LTA	Lighter Than Air
LSTAR	Lightweight Surveillance Target Acquisition Radar
MALD	Miniature Air-Launched Decoy
MALE	Medium Altitude Long Endurance
MAV	Micro Air Vehicle
MCTR	Missile Technology Control Regime
MEMS	Micro Electromechanical System
MOA	Military Operations Area
MSL	Mean Sea Level
MTCR	Missile Technology Control Regime
MWIR	Midwave Infrared
NanoSAR	Nano (scale) Synthetic Aperture Radar
NAS	National Airspace System
NIST	National Institute of Standards
NGIA	National Geospatial Intelligence Agency
NTZ	Non Transgression Zone
NVG	Night Vision Goggles
NVS	Federal Aviation Administration National Voice Switching Systems
PBR	Particle Bed Reactor
PC	Personal Computer
R and D	Research and Development
RC	Radio Controlled
RF	Radio Frequency
RFID	Radio Frequency Identification Device
RPA	Remotely Piloted Aircraft

Abbreviation	Term
RPV	Remotely Piloted Vehicle
RTCA	formerly Radio Technical Commission for Aeronautics
RVSM	Reduced Vertical Separation Minimum
S&T	Science and Technology
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SBIR	Small Business Innovative Research
SFC	Specific Fuel Consumption
SLAR	Side Looking Airborne Radar
SNTP	Space Nuclear Thermal Propulsion
SOFC	Solid Oxide Fuel Cell
SWIR	Shortwave Infrared Sensor
SUAS	Small Unmanned Aircraft System
TCAS	Traffic Alert and Collision Avoidance System
TOC	Total Cost of Ownership
TIS-B	Traffic Information System Broadcast
TRACON	Terminal Radar Approach Control Facility
UAS	Unmanned Aircraft System
UAV	Unmanned Aircraft Vehicle
UAT	Universal Access Transceiver
UCLA	University of California, Los Angeles
UCLASS	Unmanned Carrier Launched Airborne Surveillance and Strike Aircraft
UHF	Ultra High Frequency
U.S.	United States
UT	University of Texas
V&V	Verification and Validation
VAATE	Versatile Affordable Advanced Turbine Engine
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VFR	Visual Flight Rules
VOIP	Voice Over Internet Protocol
WAAS	Wide Area Augmentation System
WARC	World Administrative Radio Conference

Executive Summary

This report assesses opportunities, risks, and challenges attendant to the future development and deployment of Unmanned Aircraft Systems (UAS) within the National Airspace System (NAS) affecting UAS forecast growth from 2015 to 2035. This report also contains recommendations for future research considerations to address some of the challenges to entry that may stifle or prevent the introduction and growth of UAS in the NAS. The goal of this report is to provide a better understanding of UAS that will lead to better decisions related to UAS development, deployment, and operations.

Analysis of four key areas was instrumental in developing sound forecasts for UAS demand over the period 2015 to 2035. These areas are: technology, mission needs, economics, and existing or anticipated challenges to routine UAS use in NAS operations.

1. Technology

The global defense industry is currently investing heavily in research and development, which has led to the development of technologies to enhance the endurance, survivability, and usability of UAS. This paper identifies five major UAS subsystem technologies that are seen as enablers for both military and commercial Unmanned Aircraft Vehicle (UAV) market development and growth: airframe; power plants; sensors; communication, command, and control (C^3) systems; and information technologies (IT). Each of these subsystems will be driven at varying paces, depending upon research and development investments coupled with the financial viability of emerging markets. Some of these technologies, such as IT, are rapidly developing because of the high growth in user demand and the development of web-based services.

Some of the many mission characteristics and requirements that will drive future UAS development include: light weight (composite structures), long endurance, high payload carrying capacity, and interchangeability between standardized payload modules. Continuing microminiaturization, sensor fusion, C^3 standardization, and infrastructure integration will result in smaller and more capable UAVs. They will also be more efficient and less costly. In other words, more capability at less cost encourages more market growth.

2. Missions

While technology enables, it is the cost effective delivery of capability that meets the need that drives UAS markets. Identification of mission needs is foundational to forecasting future types and number of UAS. This report considers major mission requirements to continue to be in intelligence, surveillance and reconnaissance (ISR), as well as new areas such as stores delivery, cargo transport, search and rescue, and pilot augmentation. Mission need is tightly coupled with technology, meaning that technological developments are mission enablers in the same way that mission requirements drive technological changes.

Historically, UAV use has been primarily by the military in war zones, and in restricted airspace within the U.S. As such, UAV designs did not fully consider longevity or robustness which is important for operation in the NAS. New domestic missions and vehicles present a totally different picture. The anticipated expansion of UAS into a myriad of public, private, and commercial missions routinely using the national airspace alongside other air traffic has highlighted both operational needs and public concerns associated with UAS operations.

3. Economics

A business model tells the story of the business and how the elements of that business work together to produce value that a customer would want. The model also describes how the business differentiates itself from other competition in the same product area.[1] This report relies upon research from a Massachusetts Institute of Technology team, who in 2005 examined the business models of the largest 1,000 U.S. firms[2]; the MIT research team found that business models were a better predictor of operating income than existing business segment classifications. If this is the case, then a business model can be used to test a range of approaches for generation of revenue for UAS applications. If a business is to receive financing to start up (the case with nearly all civil applications using UAS) then a good business model must consider customers, cost, revenue, and the value proposition for the product or service being delivered.

4. Challenges

At the moment, there are major constraints to the use of UAS due to the underlying number and complexity of issues regarding operating UAS in the NAS. To this point, initiatives to promote and facilitate the use of UAS in civilian applications have been relatively uncoordinated and *ad-hoc*. Another challenge is pilot training and certification. Future users of UAS have to prove that they can operate (piloted from the ground or autonomously) safely. The military has been leading the training and certification process, including rules, pilot certification processes, and training and simulation requirements. The military anticipates leading the future of UAS operation training and certification into the NAS.

Additional challenges to UAS market growth for operations within U.S. include: regulatory, policy, and procedural issues; social issues, such as privacy and nuisance concerns; environmental issues, such as noise and emissions; and safety. While existing restrictions and procedures for the operation of UAS in the NAS mitigate safety concerns for other air traffic and persons and property on the ground, the Federal Aviation Administration (FAA) is currently developing regulations for safe and routine UAS operations in the civilian NAS. A final key area is the perceived concern for privacy. Even when the technical and safety concerns are overcome, there is still a growing challenge to widespread use of UAS in the NAS brought on by the public's privacy concerns. This is due to the widespread belief that only use for UAS is intelligence, surveillance, and reconnaissance (ISR). Most stakeholders, including FAA, recognize the time and cost challenges these policies and procedures place in the way of achieving UAS benefits. As a result, efforts are underway through the RTCA Special Committee 228 to address a myriad of issues associated with integration of UAS into the NAS. Timely deployment of UAS into the NAS is dependent upon reducing, circumventing, and eliminating these and other challenges.

[1] Joan Magretta. “Why Business Models Matter”. Harvard Business Review, May 2002, pp. 3-8.
[2] Peter Weill, Thomas W. Malone, Victoria T. D’Urso, George Herman and Stephanie Woerner. “Do Some Business Models Perform Better than Others? A Study of the 1000 Largest U.S. Firms”. Sloan School of Management, Massachusetts Institute of Technology, MIT Center for Coordination Science Working Paper No. 226, 2005.

Market Forecasts for UAS: Methodology, Development, & Trends

In order to provide realistic forecasts of future UAS markets, the "S" curve model of technology-driven market development over the last 50 years is utilized. The "S" curve is represented by a number of key phases in product development and deployment starting with technological innovation. If this innovation is coupled with emerging wants, needs, or desires, market growth follows predicated upon economic benefits balanced against costs. Further insight into the S-curve is generated from one of the most commonly used tools known as the Diffusion of Innovations Model[3] that identifies and analyzes the different phases of growth, saturation, and decline of a certain product, technology, new idea, or innovation. This valuable model helps forecasters make long term plans and design strategy around existing product portfolios and new product launches.

A number of short-range forecasts that address Department of Defense (DoD) planned investments in UAS are performed. Coupled with past acquisition trends, these forecasts provide an opportunity to lay a foundation for future UAS development and deployment in Federal, state and local government organizations as well as a potential commercial market. For other UAS markets identified by this report, the DoD baseline is biased to the forecast effects of emerging technologies as well as anticipating new technological innovations in areas of aircraft: airframes; powerplants; sensors; C^3 systems; and information technology and processing. A robust commercial market contributes to cost effective innovation as well as economies of scale that bring economic benefits back to the DoD.

Part of the effort to identify UAS technologies and market trends has been a 5-year data collection and analysis effort that serves to track the developments and deployments of UAS around the world. This 1,500-entry database archives media reports, press releases and documentation from government and industry sources and provides insight into UAS trends that are forecast to drive non-DoD UAS markets. The database is segmented to address: accidents and incidents; Congressional activities; regulatory activities, including policy and procedures; missions; vehicles; training, research and development; and economic and contract issues.

Ultimately, all of the factors above are considered and evaluated to develop the U.S. UAS forecasts 2015 to 2035. These forecasts are viewed as most probable given the political, economic and regulatory environment to date. Validation of these forecasts, which rely upon regression analysis and other statistical forecast methods, will eventually come as the non-DoD markets begin to develop and UAS is deployed within the NAS.

1. ***Forecast for DoD UAS***

The DoD expects its inventory of aircraft, both conventionally manned as well as unmanned, to grow to 27,000 vehicles by 2035, including 8,000 traditional aircraft, 14,000 UAS of all sizes and types, and 5,000 new aircraft with UAS technologies for pilot augmentation or optional pilot replacement. This growth is paced by the introduction of new and more capable unmanned or optionally manned aircraft accomplishing broader DoD missions. The DoD projects that the percentage of unmanned vehicles will

[3] George P. Boretos. "S-curves and their Applications in Marketing, Business, and the Economy". Marketing Research Association *Alert!* Magazine, Volume 52, No. 2. February 2012.

grow from 25 percent in total today to 70 percent of the DoD fleet by 2035, including new, optionally manned or pilot augmented aircraft.

The Air Force currently operates about 5,400 aircraft. Less than 5 percent of this total represents unmanned aircraft, and none are optionally manned aircraft. The Air Force projects that its fleet could grow to some 5,800 aircraft by 2035, with almost 60 percent optionally manned or unmanned. For example, replacement of the traditional long-range manned bomber fleet is under discussion to be replaced by an initial new fleet of 80 optionally manned aircraft at a cost of some $100 billion. The Air Force also expects that its large unmanned aircraft fleet will grow to about 750 vehicles, leaving the bulk of the Air Force fleet modernization focused on optionally piloted vehicles satisfying broad mission needs.

The shift in the Navy and Marine's assets toward optionally manned and unmanned aircraft will likely parallel that of the Air Force, although the Navy will also employ smaller UAS Carrier Launched Airborne Surveillance and Strike System (UCLASS) shipboard tactical vehicles for surveillance and weapons ordinance delivery. In addition, the Marines will increase the use of tactical UAS for both ISR and weapons ordinance delivery. This should increase the naval and marine aircraft inventory from 3,700 vehicles today to some 4,800 by 2035, including as many as 2,500 UAS vehicles. A much more significant change is expected in the Army in terms of the development and deployment of UAS.

Currently, 55 percent of the Army's aircraft are represented by some 6,200 predominantly Small UAS. This number is expected to grow to some 10,000 UAS representing more than 75 percent of Army aviation assets. As optionally manned aircraft will drive Air Force UAS development and investments, tactical UAS platforms that can effectively deliver ordinance will be a notable driver in the future for the Army. This is not unlike the introduction of aircraft in WWI when the initial reconnaissance mission developed into combat roles, both attacking ground targets and air-to-air combat. In addition, the Army is advancing its requirements for larger UAS vehicles, such as the Grey Eagle, for "regional theater" activities and in some cases may overlap with Air Force missions and vehicles.

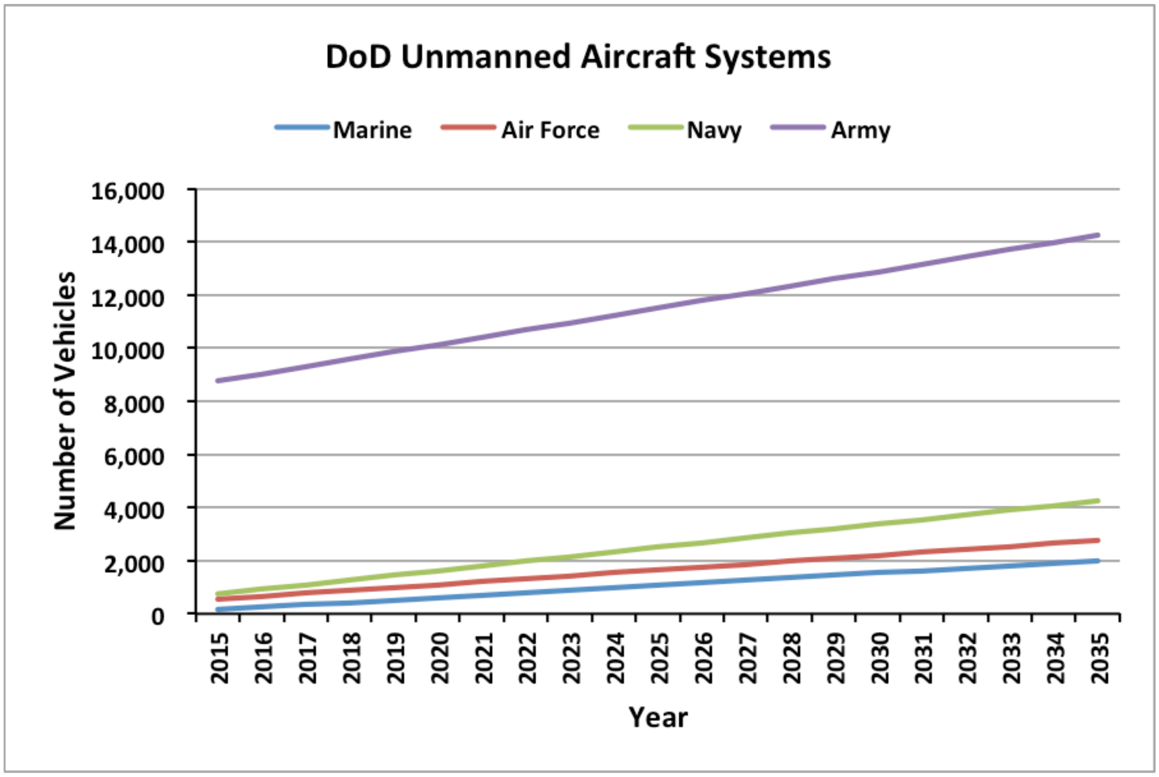


Figure ES-1 - DoD UAS Forecast 2015 - 2035

2. Forecast for Public Agency UAS

Currently, a number of federal agencies, including the Central Intelligence Agency (CIA), Homeland Security, Department of Justice, Department of the Interior, Department of the Treasury, and National Aeronautics and Space Administration (NASA) operate some 125 UAS for a variety of missions. Assuming existing FAA regulatory challenges can be significantly mitigated by 2015, it is expected that federal agencies will begin to acquire UAS to meet their mission needs in a more cost-effective manner. In addition to the agencies currently using UAS, it is expected UAS will play notable support roles for the Department of Agriculture, Department of Commerce, and the Department of Energy.

Between 2015 and 2035, it is expected that federal agency UAS fleets will grow from a few hundred to approximately 10,000, with over 90 percent of these vehicles categorized as Nano, Micro, or Small UAS. Ultralight, Light Sport, and Medium sized UAS will find a role with a number of agencies, such as Bureau of Land Management or Coast Guard, who need to survey large tracts of land or water for a variety of missions. In all cases, the UAS is the transport for the payload, be it sensors or cargo. The number and type of UAS developed, acquired, and deployed will be driven by mission needs and costs.

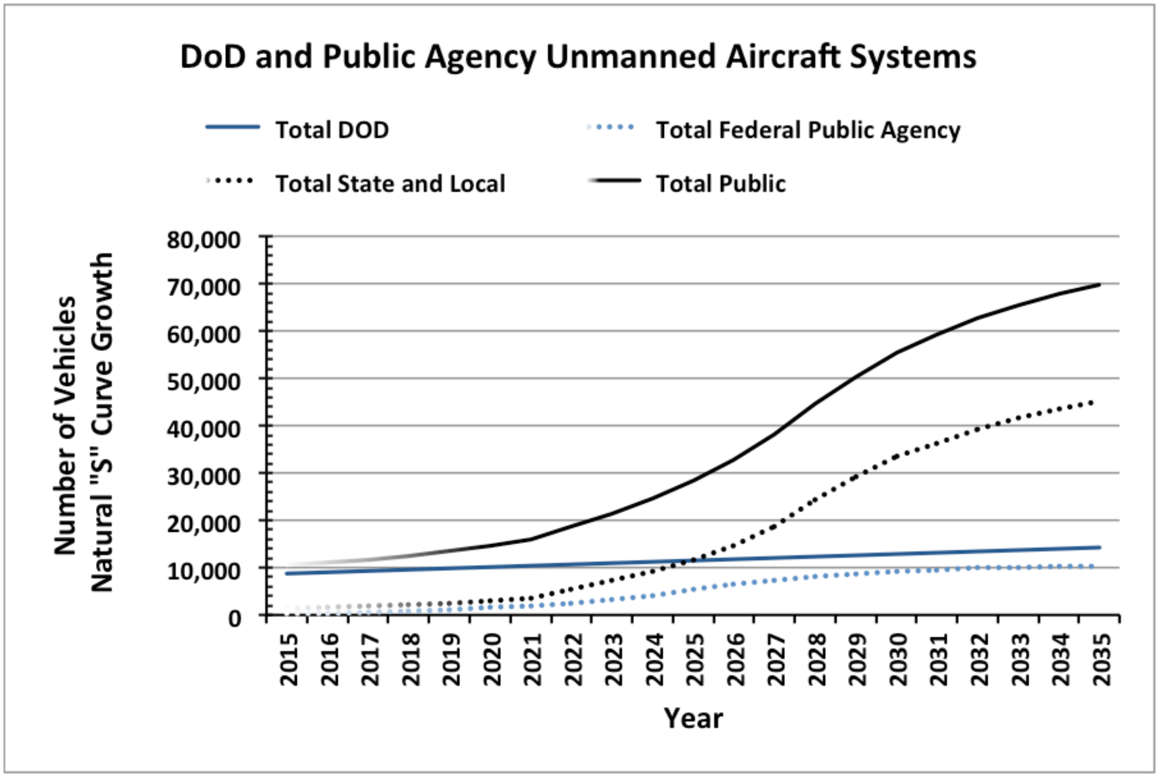


Figure ES-2 - DoD and Public Agency UAS Forecast 2015 - 2035

In addition to the non-DoD federal public sector, there are 50 states and other U.S. territories and possessions that will find great potential benefits in adopting and using UAS technologies. The pace of acquisition and use is expected to parallel the federal public sector since many states have programs aligned with very similar federal interests. From the modest acquisition of a few hundred UAS in 2015, state UAS inventories are expected to grow to 10,000 vehicles by 2035. These estimates include modest UAS inventories at colleges and universities.

All told, the federal and state sectors are forecast to be collectively operating some 36,000 UAS vehicles by 2035. This number is comparable to the Nano, Micro, and Small UAS forecasts for local governments; especially including some 18,000 metropolitan police departments and other first responders. The number of UAS vehicles forecast for first responders jumps from a few hundred in 2015 to a number almost equal to all others except the commercial sector - some 34,000 UAS vehicles by 2035. This means an expected population of 70,000 state and local public UAS by 2035.

3. *Forecast for Commercial Market UAS*

It is expected that the overwhelming majority of commercial UAS will fall into the Micro and Small UAS categories. The majority of these vehicles will be low-cost and dedicated to specific new and emerging tactical market applications. The source of supply of these vehicles will come initially from the Radio Controlled (RC) type vehicle makers as opposed to the suppliers of DoD and public agency aircraft. After an initial surge or upswing in commercial sales, reduced growth is expected as needs for early adopters and innovators are met. As UAS usage becomes more mainstream, DoD suppliers are expected to seriously enter the commercial marketplace which will encourage changes in business models, especially emphasizing a service model where professional organizations offer routine ISR and other services wanted, needed, or desired by business and individuals. These changes should again accelerate market growth through 2035.

As markets are defined and refined, it is expected that beginning in the 2022 to 2023 period commercial sales of UAS vehicles, including products and services, will experience accelerated growth with total UAS vehicles approaching 250,000 by 2035, of which 175,000 will be in the commercial marketplace.

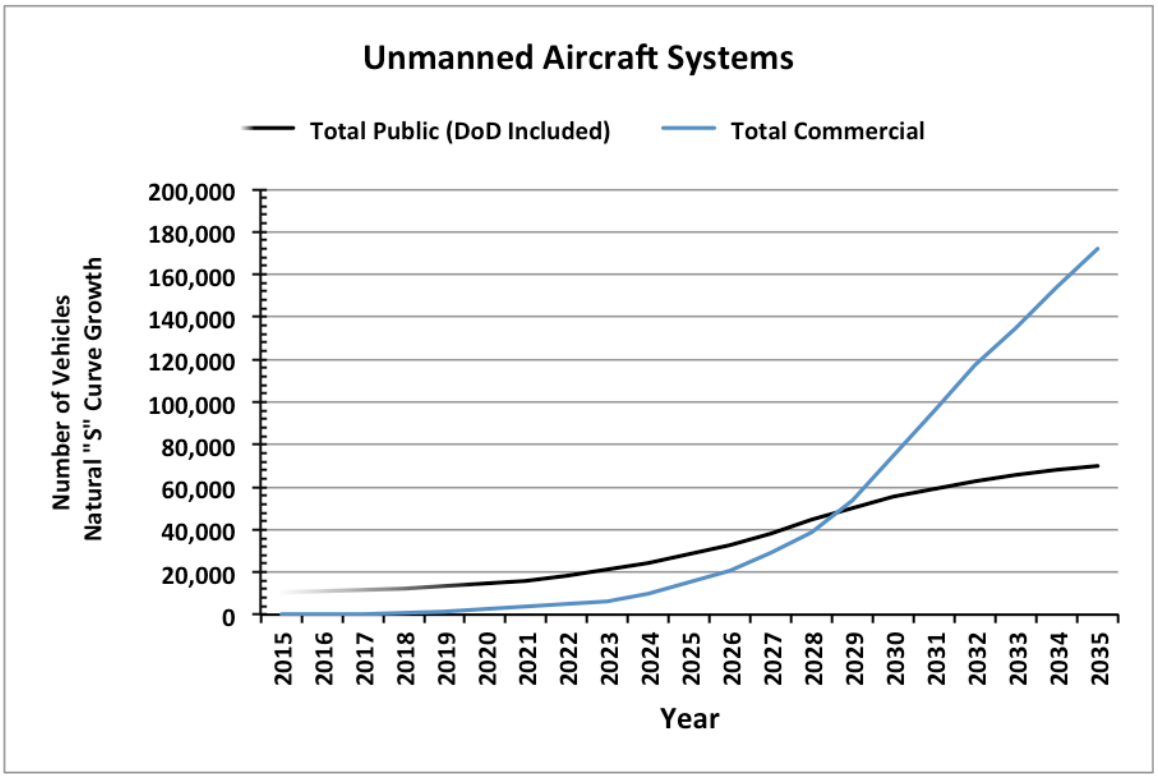


Figure ES-3 - Total UAS Forecast 2015 - 2035

Conclusion and Considerations

UAS operations are expected to surpass manned aircraft operations, for both military and commercial domains, by 2035. The technologies needed to support this transformation are developing rapidly, costs are diminishing, and applications are growing. However, there are considerable challenges to UAS market growth for operations within U.S. that must be overcome to realize the full economic and social benefits of UAS; these challenges primarily include regulatory, policy, and procedural considerations; social issues, such as privacy and nuisance concerns; environmental issues, such as noise and emissions; and safety.

A number of proposed research needs and considerations attendant to advancing routine UAS usage in the NAS in response to the aforementioned challenges are presented below. These proposed research areas are offered for consideration to UAS stakeholders, both government and industry alike. A more expansive discussion of many of these considerations is provided in the body of this report.

The following set of proposed research needs and areas to facilitate UAS operations in the NAS is offered to the FAA for consideration:

(1) Develop a VOIP communications infrastructure to provide ground-to-ground communications links from an air traffic controller to a pilot/operator.

(2) Establish and maintain the spectrum identified in (1), including providing standards for radio equipment on the aircraft as well as on the ground, to ensure acceptable communication availability and performance.

(3) Support both voice and data to enable “Instant Messaging” between multiple parties.

(4) Determine performance and functional standards for portable and fixed communication data links.

(5) Research speech recognition and encoding and decoding for both controller and pilot/operator, which should be enabled over any communications channel capable of carrying data.

(6) Modify UAT to provide two-way data link for both piloted and remotely piloted aircraft. Currently only a modest portion of the UAS bandwidth is used for ADS-B, Traffic Information System Broadcast (TIS-B), and Flight Information System Broadcast (FIS-B). This UAT link could easily serve potential communication, command, and control functions related to ATC.

(7) Perform research to reduce vertical separation between manned and unmanned aircraft above 18,000 feet to 500 feet, especially when speed differentials are considered. As with Reduced Vertical Separation Minima (RVSM), this research should focus on improved aircraft altimetry and flight control systems.

(8) Consider and adopt appropriate categorical exclusions with only operational constraints for small Micro and Nano vehicles under 4.5 pounds. These operational constraints would follow the lines of the current Advisory Circular for Model Radio Controlled Aircraft AC-91-57 to stay at or below 400 feet above ground level and more than 3 miles from a public airport, unless approved by air traffic control. Given the continuing developments in UAS integrated micro-miniaturization and the growing endurance and range of Nano and Micro UAS vehicles, this FAA action would reduce unnecessary regulatory burdens on the FAA and the general public affecting tens of thousands of smaller UAS.

(9) Expedite the issuance of the Notice of Proposed Rulemaking for Small UAS. Accepting public comment is essential, and the FAA must publish an acceptable final rule that can lift policy burdens on the social and economic benefits of new technological applications.

(10) Research and establish standards for unique UAS colors and lighting to enhance visibility for pilots to see-and-avoid in addition to any other work pertaining to sense-and-avoid.

(11) Explore UAS nominal kinetic energies to determine ground hazard risks for persons and property to assess vehicle safety needs driving regulatory requirements. Frangibility should also be part of this consideration.

(12) Establish and adopt standards and procedures for ground-based sense-and-avoid (GBSAA). This entails the use of three-dimensional primary radar that can detect non-cooperative aircraft

targets and provide both emergency multicast broadcasts of UAS activities on aviation frequencies as well as provide collision avoidance maneuvers to a UAS pilot or automated commands directly to a UAS vehicle.

(13) Consider the benefits of better managing UAS controller workload and complexity afforded by increasing the workforce in En Route Centers and Terminal Radar Approach Control Facilities (TRACONs) to handle UAS mission planning and approval, as well as complex UAS coordination and communication tasks.

(14) Review aviation weather requirements as they may apply to various classes and types of UAS vehicles. Current aviation weather needs and requirements have been predicated on a pilot's ability to determine inflight weather conditions. This "left seat" perspective is no longer available for UAS. FAA should undertake an effort to determine if weather-related FAA procedures, rules and requirements can be met by remotely piloted or semi-autonomous or fully autonomous UAS vehicles and their operational constructs.

(15) Research and address public privacy concerns for UAS and consider adopting a policy, or create a proposed rule, enabling a process of web-based operator and/or vehicle registration with rapid approval for operating authorization for Small UAS and larger UAS vehicles. Not only might this allow tracking of UAS vehicles, operators, and markets, but it provides a method to withdraw operating approval from those who have been convicted of violating local, state, or federal law, including the illegal invasion of privacy.

(16) Research and assess certifications (FAA Aircraft Certification Service (AIR)), standards (FAA Flight Standards Service (AFS)), and operational (FAA Air Traffic Organization (ATO)) approaches to accommodate UAS. This may eventually mean new, separate, and distinct FAA Aviation Regulations, FAA airmen requirements, and FAA operational guidelines and rules to accommodate UAS.

(17) Evaluate risks attendant to UAS use, given there are no humans onboard and many missions can be profiled to avoid persons and property. A prime factor of risk for airborne and ground collisions is the kinetic energy (i.e., velocity and mass) and the frangibility of a UAS vehicle. For example, a Micro vehicle of foam and balsa construction weighing less than 4.5 pounds traveling less than 20 miles per hour poses little if any collision risk to airborne aircraft or persons or property on the ground. The FAA should consider these factors of kinetic energy and frangibility, especially in addressed categorical exclusion of UAS vehicles operating below 400 feet above the ground.

The following proposed research need and area to facilitate UAS operations in the NAS is offered to the DoD for consideration:

(1) Leverage DoD-operated domestic air traffic control facilities to research communication, command and control concepts, functions and systems between UAS pilots/operators and air traffic control personnel. This would also allow DoD to develop procedures and validate standards and requirements for timely recommendations to the FAA supporting civil UAS integration into the NAS.

Given the notable performance differential between many unmanned and manned aircraft, segregation of aircraft with divergent operating characteristics should be a first consideration to facilitate access to the NAS. Providing spacing, sequencing, and separation to a diversity of aircraft with differing operating characteristics imposes a notable workload on an air traffic controller and can decrease capacity and erode safety margins. Establishing rules and procedures for segregating and integrating slow moving VFR aircraft from high-speed commercial jet transports has been a basic policy and design paradigm since the inception of air traffic control.

The following set of proposed research needs and areas to facilitate UAS operations in the NAS is offered jointly to the FAA and DoD (and industry stakeholders, where appropriate) for consideration:

(1) Consider both satellite and terrestrial spectrum frequencies to be designated for UAS activities within protected spectrum bands as a communication link from the UAS to the pilot/operator.

(2) Consider that surveillance of High-Altitude, Long-Endurance (HALE) and Medium-Altitude, Long-Endurance (MALE) UAS should rely upon Automatic Dependent Surveillance Broadcast (ADS-B). Any class, size, or type of UAS above a given size and weight should be required to carry a dual link 1090 Extended Squitter (1090ES) and a Universal Access Transceiver (UAT) ADS-B transceiver for Air Traffic Control (ATC) identification and surveillance. Given the one-megabit-per-second bandwidth of UAT at 978 MHz, it should be used to satisfy the need for protected spectrum as well as available and needed data bandwidth.

(3) Research, develop, and integrate a coordinated mission planning and related ATC conformance monitoring mechanism for UAS. The objective is to build a detailed, low-risk, four-dimensional flight profile, including lost link and other contingencies, avoiding areas of high population density, critical infrastructure, and heavily used airspace. This UAS mission profile (a.k.a. flight plan) could be filed 24 hours in advance with an FAA radar control facility and reviewed at a position enabling fast time simulation. Appropriate changes could be made by the FAA and retransmitted to the operator for further negotiations or acceptance. This mission flight plan could be activated and executed within an approved 15-minute window. In essence this creates a 24-hour "file and fly" approval in lieu of a Certificate of Authorization (COA).

(4) Research the feasibility of introducing a UAS position into an FAA facility, manned by a qualified FAA controller or DoD controller or pilot, while being either "worked" or "watched" by an air traffic controller with cognizant control area responsibility. This would enable workload-intensive communications and coordination to be handled primarily by the "monitor" position relieving potential workload for the primary controller. This is similar to the longstanding en-route controller teams (i.e., tracker, radar controller, manual controller) that share workload responsibilities.

(5) FAA, DoD, and industry stakeholders research, develop, and apply new remotely piloted aircraft design and build standards for categories of UAS aircraft certification larger than 4.5 pounds. This will be an important consideration in improving safety of UAS vehicles to a level acceptable to the FAA and the public as criteria to access the NAS. According to a 2012 Bloomberg Report, UAS accident rates of DoD UAS have been in continuing decline and are now approaching that of DoD manned fighter aircraft. For example, in 2011 Predator accident rates were 4.86 per 100,000 flight hours compared to F-16 accident rates of 3.89 per 100,000 flight hours. In many cases marginally higher UAS accident rates are associated with human factor issues as well as software, hardware, and equipment failures attributable to system design or build factors that may not meet established minimum FAA aircraft certification standards.

1. Background

1.1 Problem Statement

This report assesses opportunities, risks, and challenges attendant to the future development and deployment of Unmanned Aircraft Systems (UAS) within the National Airspace System (NAS) affecting UAS forecast growth from 2015 to 2035. This report also contains recommendations to address some of the operational, procedural, and technical challenges that may stifle or prevent the introduction and growth of UAS in the NAS. The potential economic and social benefits of UAS are also significant and should not be unreasonably or unjustifiably delayed. The goal of this report is to provide a comprehensive understanding of UAS considerations that will lead to better and timelier decisions related to UAS development, deployment and operations.

1.2 Historical Perspective[4]

The earliest recorded attempt at a powered unmanned aircraft vehicle was A. M. Low's "Aerial Target" of 1916. Nikola Tesla described a fleet of unmanned aircraft combat vehicles in 1915. A number of remote-controlled airplane advances followed during and after World War I, including the Hewitt-Sperry Automatic Airplane, the first scale RPV (remotely piloted vehicle), developed by the film star and model airplane enthusiast Reginald Denny in 1935. More were made in the technology rush during World War II; these were used both to train antiaircraft gunners and to fly attack missions. Nazi Germany also produced and used various unmanned aircraft vehicles (UAV) aircraft during the course of WWII. Jet engines were applied after World War II, in such types as the Teledyne Ryan Firebee I of 1951, while companies like Beechcraft also got in the game with their Model 1001 for the United States Navy in 1955. Nevertheless, they were little more than remote-controlled airplanes until the Vietnam Era.

1.3 Early Development[6]

In September 1916, the Hewitt-Sperry Automatic Airplane, otherwise known as the "flying bomb" made its first flight, demonstrating the concept of an unmanned aircraft. They were intended for use as "aerial torpedoes" an early version of today's cruise missiles. Control was achieved using gyroscopes developed by Elmer Sperry of the Sperry Gyroscope Company. Military applications continued to grow from World War I and throughout the late 1940s. Applications included utilizing unmanned airframes as:

- Target aircraft for ground based gunners and airborne aircraft, and
- Sensor Platforms - It was in 1941 that the first sensors were placed on a drone. The Naval Aircraft Factory assault drone "Project Fox" installed an RCA television camera in the drone and a television screen in the TG-2 control aircraft.

However, even though there was considerable success and excitement around unmanned vehicles, political and ideological disagreements arose within the DoD concerning the relative advantages of proposed programs for full-scale combat implementation versus traditional use of aircraft. Assault drones remained an unproven concept in the minds of military planners through major allied advances of 1944.

[4] "History of Unmanned Aerial Vehicles". http://en.wikipedia.org/wiki/History_of_unmanned_aerial_vehicles

After World War II, use of pilotless vehicles continued, especially as target aircraft. As aircraft became faster, drone technology required change. By the late 1950s combat aircraft were capable of Mach 2 which required the development of faster targets to keep pace. Northrop designed a turbojet-powered Mach 2 target in the late 1950s. This target drone was a slender dart with wedge-shaped stubby wings, swept conventional tail assembly, and a GE J85 turbojet engine, like that used on the Northrop F-5 fighter.

In 1946, eight B-17 Flying Fortresses were transformed by American airmen into drones for collecting radioactive data. They were controlled at takeoff and landing from a transmitter on a jeep, and during flight by a transmitter on another B-17. They were used on Bikini Atoll (Operation Crossroads) to gather samples from inside the radioactive cloud.

The success of drones as targets led to their use for other missions. The well-proven Ryan Firebee was a good platform for such experiments, and tests to evaluate it for the reconnaissance mission proved highly successful. The U.S. engaged in covert surveillance operations in North Vietnam, Communist China, and North Korea in the 1960s and early 1970s used a series of reconnaissance drones derived from the Firebee and the Ryan Model 147 Lightning Bug series.

By late 1959, the only spy plane available to the U.S. was the U-2. Spy satellites were another year and half away, and the SR-71 Blackbird was still on the drawing board. Not surprisingly, work intensified on an unmanned drone that would be capable of penetrating deep into enemy territory and returning with precise military intelligence. Within three months of the downing of the U-2, the highly classified UAS (then-called RPV) program was born under the code name of *Red Wagon.*
From August 1964, until their last combat flight on 30 April 1975, the USAF 100th Strategic Reconnaissance Wing would launch 3,435 Ryan reconnaissance drones over North Vietnam and its surrounding areas, at a cost of about 554 UAVs lost to all causes during the war.

1.4 Modern Era Development

The U.S. military has entered a new era in which UAS are critical to signal intelligence with the UAS controlled and relaying data back over high-bandwidth data links in real time, linked to ground, air, sea, and space platforms. The use of UAS in conflicts such as Kosovo, Iraq, and Afghanistan, and humanitarian relief operations such as Haiti, revealed the advantages and disadvantages provided by unmanned aircraft. Long considered experimental in military operations, UAS are now making national headlines as they are used in ways normally reserved for manned aircraft. Conventional wisdom states that UAS offer two main advantages over manned aircraft: they are considered potentially more cost effective; additionally they minimize the risk to a pilot's life, and their missions are not bounded by human physiological limitations. For these reasons and others, the DoD inventory of unmanned aircraft increased more than 40-fold from 2002 to 2010.[5] Increased utilization and success of UASs for numerous missions include large and small airframes as strike, intelligence, surveillance and reconnaissance, as well as resupply; combat search and rescue, refueling, air combat and aircraft carrier basing.

[5] Jeremiah Gertler. "U.S. Unmanned Aerial Systems". Congressional Research Service, January, 2012.

2. Methodology

2.1 Technologies

This paper defines five major UAS subsystem technologies that are seen as enablers for UAS market development and growth. These are: airframe; power plants; sensors; communication, command, and control systems; and information systems. Each of these subsystems will be driven at varying paces depending upon research and development investments coupled with the financial viability of emerging markets.

Many technology driven markets of the last 50 years have been characterized by an “S” curve of deployment representing market developments and penetrations in volume or sales numbers reflecting the profile of technology adoption. Figure 2-1 shows this “S” curve of market penetration of mobile phones by households in the U.S. The “S” curve is represented by three key phases in product development and deployment starting with technological innovation. If this innovation is coupled with emerging wants, needs, or desires, market growth follows predicated upon economic benefits balanced against costs. At some point market saturation is reached based on costs and benefits as the “S” curve flattens with market maturity.

Further insight in the S-curve comes from one of the most commonly used tools known as the Diffusion of Innovations Model[6] that identifies and analyzes the different phases of growth, saturation, and decline of a certain product, technology, a new idea, or any innovation. It is a valuable model that helps forecasters make long term plans and design their strategy about existing product portfolios and new product launches.

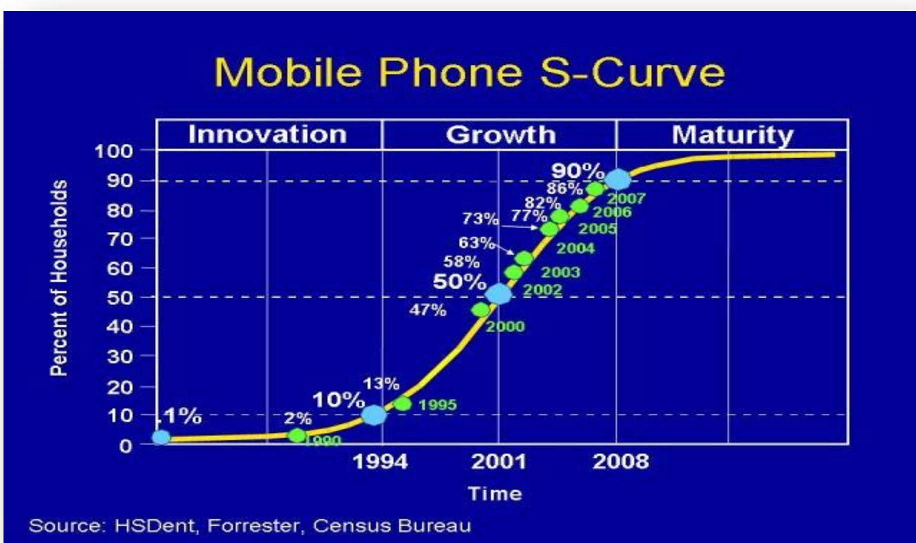


Figure 2-1 **- Growth of Mobile Phones**

[6] Boretos, 2012

In many cases, the "S" curve is represented by multiple cycles of technological innovations that can be disruptive to an established technology or business. This means finding a better, cheaper, or faster way to meet the same or similar needs for services and products. A good example of this phenomenon is shown in Figure 2-2, which shows continuing development supporting increased capabilities and resultant sales for mobile phones. Similar curves are found, for example, tracing the history of computer storage, integrated circuits, and the transition of desktop computer clients to portable tablets.

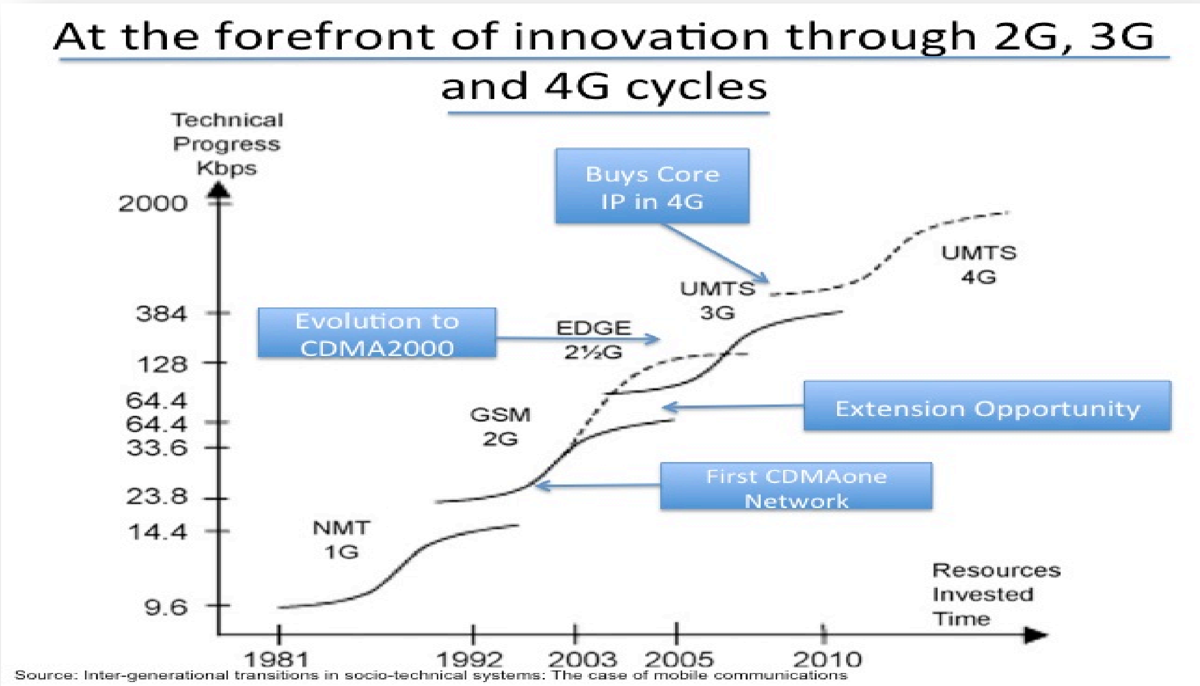


Figure 2-2 - Technological Innovation Producing Long-Term Market Growth

In order to obtain a better grasp of UAS potential, it is necessary to look at critical UAS subsystems to assess their current state and speculate on future technology developments that could meet current and future needs. For example, continuing micro-miniaturization, sensor fusion, and communication, command, and control standardization and infrastructure integration could result in smaller, more capable, efficient, and less costly UAS vehicles. In other words, more capability at less cost encourages market growth. Other elements portending future technological innovation and changes were also identified in hopes of improving the grasp of market opportunities. For example, the development of 3-D printing may reduce small UAS manufacturing costs while accelerating the time required to move UAS vehicles to customized market.

Generational Considerations
Many of the S-curve technological developments are paced by human generational considerations. Young innovators and early first adopters pioneer most of the significant migrations in technological paradigms. In many cases adoption by first the early and then the late majority pace a 20 to 25 year cycle of market maturity and saturation. This 25-year cycle of discovery, development and deployment is reflected in the lifecycle of many FAA programs from Traffic Alert and Collision Avoidance System (TCAS) to ADS-B as well as others. The pace of full UAS integration into the NAS should be along a similar cycle as the FAA develops and deploys the infrastructure of hardware, software, policies and procedures necessary for the safe integration of UAS into the NAS.

Market Baseline
A number of short-range forecasts have been completed that address DoD planned investments in UAS. These coupled with past acquisition trends provide an opportunity to lay a foundation for future UAS development and deployment in Federal, state and local government organizations as well as a potential commercial market. This report has used these public and private forecasts as a baseline upon which to build longer range forecasts through 2035.

UAS Development and Trends
For other UAS markets identified by this report, the DoD baseline is biased to the forecast effects of emerging technologies as well as anticipating new technological innovations in areas of aircraft: airframes; powerplants; sensors; communication, command and control systems; and information technology and processing. One example, as previously mentioned, is the continuing microminiaturization of vehicles and systems. Technology transfer from DoD no doubt salts initial commercial UAS development. Subsequently, a robust commercial market contributes to cost effective innovation as well as economies of scale that bring economic benefits back to the DoD.

Part of this effort to identify UAS technologies and market trends has been a 5-year data collection and analysis effort that serves to track the developments and deployments of UAS around the world. This 1,500-entry database archives media reports, press releases and documentation from government and industry sources and provides insight into UAS trends that are forecast to drive non-DoD UAS markets. The database is segmented to address: accidents and incidents; Congressional activities; regulatory activities, including policy and procedures; missions; vehicles; training, research and development; and economic and contract issues.

Forecasts
Ultimately, all of the factors above have been considered and evaluated to develop the U.S. UAS Forecasts 2015 to 2035. These forecasts are viewed as most probable given the political, economic and regulatory environment to date. In a nascent marketplace with such a dynamic environment, circumstances can change any number of factors that may significantly affect these numbers in the future. Validation of forecasts, which rely upon regression analysis and other statistical forecast methods, will eventually come as the non-DoD markets begin to develop and UAS is deployed within the NAS.

2.2 Mission Needs

Accurate and timely identification of user or consumer wants, needs, and desires that translate into viable markets are challenging at best - as evidenced by many failed companies and endeavors. These companies must realize that many needs, wants, and desires remain latent or hidden until unexpectedly discovered. The introduction and adoption of technology is best illustrated by Figure 2-3 that shows acceptance is dependent upon the timetable and enthusiasm of innovators and early adopters to bring technology to a critical stage of development and deployment. Many products and services fall into the chasm and out of vogue if they fail to capture a wider market interest. The perceived need weighed against costs and benefits will ultimately determine if a preliminary market exists. Even then the need that is fulfilled has to be determined to be of a significant priority to encourage additional research investments to introduce new approaches to meet these needs.

In many cases, success or failure will depend as much on "how" needs are met as "if" needs are met. This element focuses on human interaction of designs and functions. For example, in the UAS world the design, functionality, and human-computer interaction of a pilot work station will likely affect UAS markets.

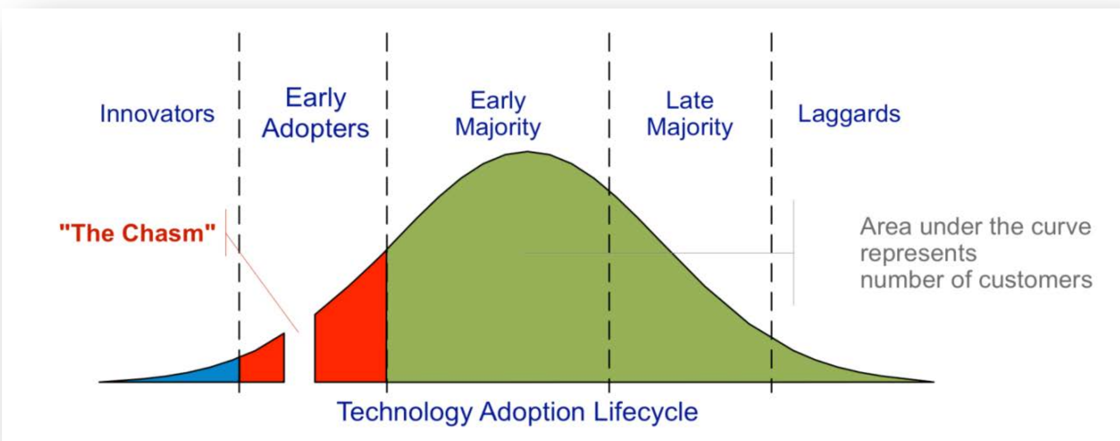


Figure 2-3 - Technology Adoption Lifecycle

Although developing technology often acts as its own engine for future innovation and markets with capabilities and applications not even imagined today, there are a number of identified near-term needs for UAS that continue to emerge. These are: intelligence gathering; continuing surveillance; dynamic reconnaissance; cargo transport; stores delivery; search and rescue; training; and pilot augmentation.

While the technology enables, it is the cost effective delivery of capability that meets the need that drives the markets. Identification of missions was foundational to forecasting future types and number of UAS aircraft. Mission need is also tightly coupled with the technology meaning technological developments are mission enablers in the same way that mission requirements drive technological changes. Appreciation of these facts is critical to generate any reasonable forecast numbers.

For example, FAA policy, implemented in May of 2012, permits first responders to operate UAS weighing 25 pounds or less below 400 feet above ground level and away from airports. With approximately 18,000 metropolitan police departments alone in the US, it is expected Small UAS fleets for first responders will grow to some 56,000 units by 2035. Other markets, such as farmland surveys of 150,000 farms that represent economically viable enterprises may result in an additional 100,000 vehicles used for crop surveillance and crop spraying. These types of large markets will stimulate product and service investments as new competitors enter the market and seek sales opportunities further reducing costs and expanding markets. In other words, the growing diversity and number of economically viable missions portend an upward trend in sales of UAS through 2035. Again forecasts must recognize these dynamics and synergies.

2.3 Economic Considerations

The convergence of technology and needs results in markets only if financial considerations align. Not only must apparent benefits to the consumer exceed their perceived costs, there must be suitable access and availability of financial resources throughout the entire supply chain. Additionally, successful business models must exist to provide the framework for products and services to reach the marketplace.

2.4 Challenges to Market Development

There are a considerable number of challenges facing the development of a UAS free market; these include regulatory, policy, procedural, social, and environmental concerns.

Notwithstanding the basic tenets of a convergence of enabling technologies, mission needs, and a viable economic climate, external or artificial barriers can range from minor inconveniences to major impediments affecting UAS development and deployment. Each barrier results in a delay of benefits and an escalation of costs. In some cases diminishing returns can terminate promising opportunities and significantly diminish markets.

2.5 Future Forecasts

The method for estimating future UAS development and deployment has relied upon work cross referenced and completed by other sources, such as the Teal Group, to build a baseline of Department of Defense forecast acquisitions. These relatively short-range forecasts were extrapolated into scenarios considering of a number of factors including technology trends, developing mission needs, economic issues, and challenges that would apply to the DoD markets. This resulted in a forecast range of markets. Forecasts were generated based upon the Diffusion of Innovations Model[7].

[7] Boretos, 2012.

Again, using the extrapolated DoD market as a baseline, identified factors referenced above were independently applied to address the opportunities and challenges associated with markets for non-DoD public agencies. This same process was used to assess commercial UAS markets as well. Recreational markets (i.e., radio-controlled model air vehicles and systems) were predicated upon current units and sales volumes. Again the factors of consideration as previously identified were applied to create a most probable identification of potential future markets segments.

2.6 Summary

The methods used to estimate the future development and deployment of UAS is dependent upon considerations addressed above for technologies, mission needs, economic incentives, and challenges to market development. While predicting future markets is relatively uncertain, an appreciation and understanding of key factors affecting market development is critical in being able to assess the potential of UAS in the future. As UAS markets begin to mature many of the factors of consideration may be better evaluated in the future in terms of a sensitivity analysis and their effects on market growth.

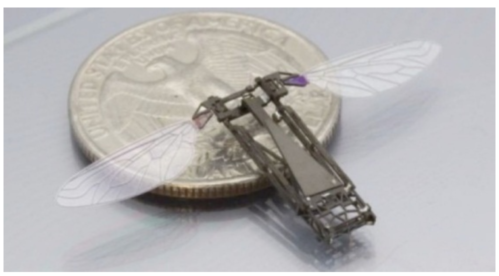
There is no question that there are very large potential markets in the future for UAS of all types. UAS are potentially more cost effective and efficient for a greater variety of missions than alternatives available today. Whether these markets will be attainable is dependent upon many of the factors identified, expanded, and explained in this report. A word of caution – the forecast work presented in this report is a first known effort to identify nascent UAS markets twenty plus years into the future. Fully understanding and appreciating the potential of new technology, such as UAS, has never truly been recognized in advance. The full forecasted development of UAS may be one of significant uncertainty.

3. Key UAS Technologies

The key to developing UAS markets is the ability to advance, enable and synergize technologies that identify and create new applications, define new missions and energize new markets. This in turn presses to develop or enhance even newer technological capabilities that lower costs and expand capabilities. This report identifies and addresses five key UAS subsystem technology areas that will play heavily in satisfying current needs and creating new markets and satisfying new demands for UAS. These are:

- Airframe
- Propulsion
- Communications, command and control
- Sensors
- Information processing

Each of these five areas is addressed to identify emerging technologies and/or capabilities that will contribute to future UAS market development.



Emulating the biology of a bee and the insect's hive behavior push advances in miniature robotics and the design of compact high-energy power sources; spur innovations in ultra-low-power computing and electronic "smart" sensors; and refine coordination algorithms to manage multiple, independent machines.
Image credit: Harvard University School of Engineering and Applied Sciences

These five UAS subsystem must support or contribute to meet user wants, needs desires and delights. UAS offers its greatest promise by removing the human from the aircraft or vehicle. No longer do aircraft systems have to be designed with a weight and systems complexity requirement driven by a human crew; this means greater vehicle efficiency and flexibility. No longer are missions compromised by human physiology; this means long endurance mission lasting days or longer can be accomplished and vehicle flight envelopes do not need to be constrained by human tolerances. Lastly, the use of UAS removes the human from dull, dirty or dangerous missions. These are the drivers that encourage the development and deployment of UAS.

It should be noted not all UAS will be developed at a similar pace. The greatest innovation is occurring and is likely to continue to occur in the very small UAS referred to as Nanos and Micros. The vehicles generally support surveillance missions and need low observability and in some cases biomimicry – looking and acting like insects or birds. Larger vehicles called Small UAS are driven by mission requirements of specific payloads and therefore vehicle size, weight and performance. Finally, large vehicles akin to manned aircraft are more traditional in terms of their airframe design and construction because they predominantly carry out missions similar to manned aircraft in the delivery of stores and cargo.

3.1 Airframes

Today, the common issue with virtually all UAS platforms is the need to optimize these aircraft to carry the most useful payload, which may consist of sensors, electronics, fuel, or weapons systems. The primary function of an unmanned aircraft is to get to a targeted location, perform a task, and then return in the most efficient and cost-effective way. Furthermore, without a pilot aboard, the return trip is optional.

[8]The implementation of innovative, low-cost manufacturing processes, along with consideration of manufacturing costs and sustainment throughout the design process, will be key to the development of UAS airframes. Processes that reduce the number of parts, simplify tooling, reduce energy requirements, and minimize waste will be preferred. Complicating the need for low-cost processes is that production quantities for some UASs will initially be small. Therefore, the primary criterion for the expanded use of polymeric composites in structural applications is the potential for low-cost manufacturing processes.

An important program was initiated in 1996 to reduce the processing costs of high-performance composites for aircraft. The Air Force, the Navy, and industry (Boeing, Lockheed Martin, and Northrop Grumman) jointly funded the Composite Affordability Initiative (CAI), which spanned 11 years of research until its conclusion in 2007. The objective of CAI was to "develop the tools, methodologies, and technologies necessary to design and manufacture a composite airframe utilizing revolutionary design and manufacturing practices to enable breakthrough reductions in cost, schedule, and weight". CAI benefited government and industry by developing technology applicable to a variety of aircraft. The program included (1) design integration, (2) design and manufacturing concepts, (3) fabrication technologies for unitized structures, (4) assembly processes for unitized structures, (5) development of performance standards for analysis methods, (6) element and subcomponent design and testing, (7) cost data, modeling, and analysis, (8) development of quality methods, (9) component scale-up and process validation, and (10) long-term technology development.

Analysis tools and design methodologies were developed to automate and improve predictions of the characteristics of composite components so that designs could be less conservative and the excess weight associated with overdesign can be avoided. The CAI investigated a range of innovative composite processes, including:

- Fiber placement
- Resin transfer molding (and vacuum-assisted resin transfer molding)
- Low-temperature/vacuum bag curing
- Through-thickness reinforcement (e.g., stitching/3-D weaving/Z pinning)
- Electron beam curing

Although polymeric composite structures will dominate future UASs, significant advances in the processing of high-performance metallic alloys will also be required. Although metallic structures will continue to be driven by traditional weight and durability considerations, cost is expected to become an even greater issue. Net-shape processing and integrated manufacturing techniques have the potential to

[8] "Uninhabited Air Vehicles: Enabling Science for Military Systems". National Academies Press, 2000.

reduce costs. Promising processes for producing metal airframe structures in small quantities at reduced cost include the following:

- Solid free-form fabrication
- Super-plastic extrusion
- Spray forming electron-beam physical vapor deposition
- Advanced sheet metal processes

More common materials, processes, and design features may also aid reducing the number of parts and lowering cost.

Finally, for the low-cost vehicle type, the suite of airframe materials should be expanded beyond those used for conventional aircraft. For example, the Miniature Air-Launched Decoy (MALD) Program took a Cost as an Independent Variable (CAIV)[9] approach to design by trading off performance for cost reduction. MALD is a small, inexpensive, modular vehicle that will replicate a jet aircraft kinematically and in terms of radar cross section on the battlefield. In addition to modular design and extensive use of existing commercial off-the-shelf components, the MALD program used very low-cost materials and processes to meet its cost targets. A key manufacturing technology used by the MALD program was compression molding of sheet-molding compounds to produce discontinuously reinforced composite components. These materials and processes are similar to those widely used in the automotive industry.

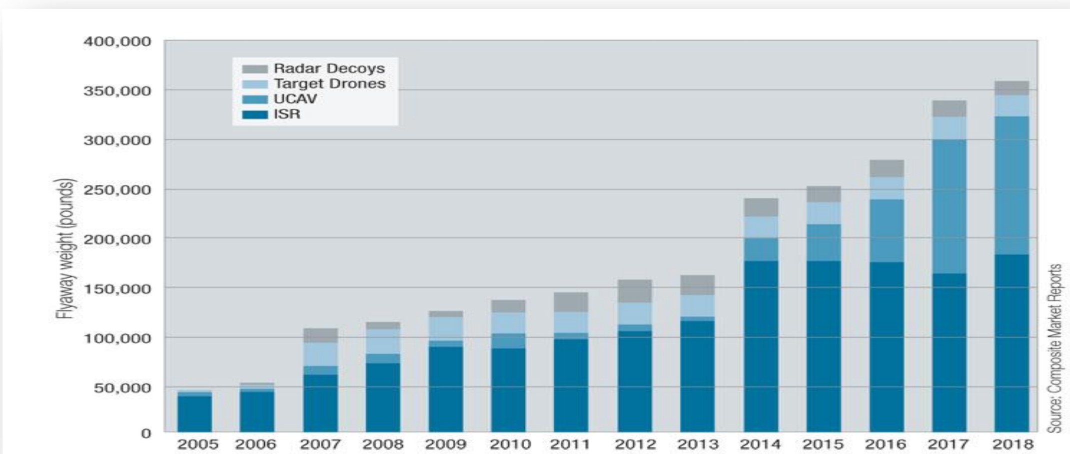


Figure 3-1 - Composite Airframe Growth (Source: Composite Market Reports)

It is thought that very low-cost materials and processing can also be used for small, expendable UASs, especially for components substructures, such as ribs and bulkheads, because of the shorter service life and lower reliability requirements of these UASs. Materials and processes, such as aluminum casting, high-speed machining of integral metal structures, and compression molding of low-cost materials (e.g., automotive sheet molding compounds), will also be considered.

[9] CAIV is a means of treating cost as the principal input variable.

[10]It is noteworthy that all of the UAS models considered in this report include composite parts in some form or another. Glass and quartz fiber composites are regularly employed in sensor radomes, nose cones, and small fairings. There are a number of cases where glass fiber composites were used in earlier medium-size airframes, but the demand for payload capacity, extended performance, and spiral development of unmanned systems have helped make carbon fiber reinforced polymer (CFRP) the primary materials used in construction of UAS airframes; and as the UAS market has grown, so has the need for advanced composites. With the outlook for unmanned aircraft focusing on maximizing payload capacity and endurance, the market for composite airframes in unmanned aircraft production is poised to grow over 300 percent into the year 2020.

Factoring in the various composite applications and their respective construction materials, it appears that CFRP accounts for 83 percent of the total market by volume. Manufacturing of UAS composite airframes represented $18.4 million to $20.0 million in 2007 (not including the value of Research and Development engineering, testing, and assembly). The market grew another 6 percent in 2008. As of 2009, expectations for market growth were an additional 10 percent, raising the estimated value by approximately $23 million. The Teal Group has forecast that UAS composite airframe manufacturing could account for $340 million over the next 10 years, reaching as much as $60 million annually by 2018.[11]

With the outlook for unmanned aircraft focusing on maximizing payload capacity and endurance, the market for composite airframes in unmanned aircraft production is poised to grow 300 percent over the next decade.

As an exciting new field, UAS promises significant new opportunities in aircraft airframe design, engineering and manufacturing. These opportunities are rapidly emerging with Nano, Micro and Small UAS focused on ISR missions. Larger vehicles that will carry stores and transport cargo will parallel manned aircraft development, such as the composite rich Boeing 787 Dreamliner.

The ISR mission demands the development of Low Observability Vehicles (LOV) with high endurance. These requirements are driving many new innovative approaches for both airframes and powerplants. Biomimicry is one on the most intriguing developments in low observability in efforts for UAS to mask themselves and emulate a biological species.

The design of Nano vehicles is particularly challenging and is garnering considerable attention in the academic and research community. Engineering parametrics of traditional aircraft design are simply not scalable to nano and even micro sized UAS. Therefore, new innovative concepts are being explored to do what airframes and powerplants must do as efficiently as possible – carry payload.

3D Printing

One of the most exciting emerging airframe manufacturing technologies is known as 3D printing or additive layer manufacturing (ALM). 3D printing allows for rapid computerized design development to be immediately manufactured. A 3D printed airframe can be tailored for changes in response to mission packages for powerplants, sensors, communications, command and control needs and requirements.

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[10] Chris Red. "The Outlook for Unmanned Aircraft". *High Performance Composites*, April 2009. http://www.compositesworld.com/articles/the-outlook-for-unmanned-aircraft

[11] "World Unmanned Aerial Vehicle Systems, Market Profile and Forecast 2012." The Teal Group, April 2012.

[12]3D printing is very cost-effective and may revolutionize aircraft design. [13]For example, researches at the University of Southampton believe that 3D printing will soon allow UAS to go from the drawing board to flight in a matter of days. No longer, they say, will one design of UAS be repeatedly manufactured on a production line. Instead, designers will be able to fine-tune a UAS for each specific application – whether it is crop spraying, surveillance or infrared photography – and then print a bespoke plane on demand.

3D Printed UAS
Photo Credit: University of Southampton

3D printing has been extensively developed since its origins as an expensive prototyping tool over two decades ago. It uses laser-assisted machines to fabricate plastic or metal objects, building up the item layer by layer, each slice just 100 micrometers thick. To do this, the 3D printer first slices up an object's computerized design into hundreds of easily printable layers. Each layer is then "printed" by training a laser beam on a bed of polyamide plastic, stainless steel or titanium powder – depending on the object being created – tracing out the entire 2D shape required for that layer. The laser's heat fuses the particles together at their boundaries. Once each layer is complete, more powder is scattered over it and the process repeated until a complete artifact is produced.

To create a stronger object that can withstand higher loads and stresses, an electron beam can be used in place of a laser to melt the powder particles completely. And because 3D printing involves no cutting or grinding of metal, it offers vast design freedom. "With 3D printing we can go back to pure forms and explore the mathematics of airflow without being forced to put in straight lines to keep costs down," notes one of the researchers at the University of Southampton.

The strength of 3D printed titanium can equal that of the traditionally machined metal, says Dan Johns, who is printing strong, lightweight metal parts for Bloodhound SSC, the rocket car aiming to break the land-speed record in 2013. To give a part the required strength, engineers can choose a metal – or mixture of metals and plastics – to suit their needs. For instance, an electron-beam-fused titanium/aluminum alloy elongates 10 percent before snapping, while laser sintered stainless steel elongates 25 percent. "There's almost always a way to get the properties your project needs," another University of Southampton researcher indicates.

[14]Two third-year engineering students at the University of Virginia (U. Va.) 3D printed and assembled a plane. When it successfully took off, their unmanned plane became just the third 3D printed aircraft to ever fly. 3D printing is a revolutionary technology, which some speculate could have an impact similar to

[12] Richard Meryn. "How the 3D Printed Aircraft Will Revolutionize Aircraft Design Economics". August 2011. http://www.industryleadersmagazine.com/how-the-3d-printed-aircraft-will-revolutionize-aircraft-design-economics/
[13] Paul Marks. "3D Printing: The World's First Printed Plane". *New Scientist*, August 2011. http://www.newscientist.com/article/dn20737-3d-printing-the-worlds-first-printed-plane.html?full=true
[14] Lorenzo Franceschi-Biccharai. "Students Build and Fly 3D Printed Plane". October 2012. http://mashable.com/2012/10/24/students-build-3d-printed-plane/

that of the personal computer. In fact, new potential applications for 3D printers seem to be appearing every week.

The U. Va. engineering students designed and assembled their 3D printed plane this year for the MITRE Corporation, a federally funded research and development center. The result of their work is a 6.5-foot wingspan drone, entirely built with 3D printed parts. The students proved that 3D printing could bring manufacturing cost down and still deliver a quality product. “To make a plastic turbofan engine to scale five years ago would have taken two years, at a cost of about $250,000,” an Engineering School alumnus and 20-year veteran of the aerospace industry who helped the two students said, “but with 3D printing, we designed and built it in four months for about $2,000.”

[15]A design engineer at Boeing has indicated that the Boeing Company been using 3-D printing for a decade to make parts such as electronics covers and air ducts that cool computer or electrical equipment. Printers can make ducts of varying shapes that fit through tight spaces or bend around structures, saving material costs. A duct can also be made without the need to first produce expensive tools. And it can be built as a single piece, rather than in multiple sections, eliminating assembly lines and cutting labor costs.

By using only necessary material and doing away with bolts and screws that meld parts together, 3D printing has reduced the weight of certain parts an average 10% to 30%, saving fuel costs. All told, 3D made parts have yielded 25% to 50% in savings, according to the Boeing design engineer. He also notes that the quality of 3D-printed parts is improving. For example, the layers form tiny ridges that can give parts a rough, textured feel. But as 3D printers put down larger numbers of thinner layers, surfaces have gotten smoother – critical, say, for a small, visible object in the first-class cabin. 3D made parts also have gotten stronger; "before, it didn't last. Now, it's comparable,” he notes.

In recent years, Boeing has dramatically increased the number of distinct parts it prints to about 300. And the technology has cranked out a total 22,000 pieces across 10 types of military and commercial aircraft, including the Dreamliner. Eventually, Boeing expects to use 3D to make an entire unmanned air vehicle and possibly even a commercial airliner, or at least a wing. "That's where the industry is trying to go," Hayes said.

[16]The European Aeronautic Defense and Space Company (EADS) has been delving into 3D printing to make fixtures and tooling for its Airbus planes, and applications in its other aero divisions, Eurocopter and Astrium. The EADS/Leeds UAS also was designed with larger open spaces on the fuselage and a larger profile wing, to take advantage of future propulsion systems – such as the lightweight hydrogen fuel cells currently under development at EADS Innovation Works (which operates the overall organization's Research and Development laboratories). These new fuel cells could triple the plane's continuous flight endurance to six hours versus existing battery systems.

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[15] Paul Davidson. “3-D Printing Could Remake U.S. Manufacturing.” *USA Today*, July 2012. http://usatoday30.usatoday.com/money/industries/manufacturing/story/2012-07-10/digital-manufacturing/56135298/1

[16] Industrial Laser Solutions Editors. “EADS, Leeds U Build Drone Aircraft with Additive Manufacturing”. July 2012. http://www.industrial-lasers.com/articles/2012/07/eads-leeds-u-build-drone-aircraft-with-additive-manufacturing.html

A flight capable metallic version of the UAS will be made at EADS Innovation Works in Filton, UK, using direct metal laser sintering (DMLS) technology, created with EADS proprietary "Scalmalloy" material – a modified alloy (aluminum, magnesium, scandium, and zirconium) designed to offer high strength and toughness with high fatigue properties and corrosion resistance.

Composites

[17]Lehigh University (Lehigh, Pa., USA) reports that one of its engineers has developed a carbon fiber composite wing for use on an unmanned aircraft being designed for high-altitude perpetual flight. The first uniquely designed carbon fiber wing has emerged from Lehigh's Composites Lab. The 6.5m/21.3-ft wing was made in a single molding process, complete with wing planks, spar caps to fortify the wings; six internal webs to carry shear loads and a trailing edge ready to accommodate wing flaps. The wing is made for an unmanned aircraft designed to fly at high altitude and generate power from the jet stream and the sun. The long-term goal of the project, led by a Lehigh mechanical engineer and computer scientist, is perpetual flight.

To keep an autonomous aircraft aloft for years at a time requires not just a source of power in the sky – in this case solar and wind – but a unique aircraft. The aircraft needs to have very low drag and long slender wings, as on manned gliders. But it also needs to be able to fly very fast. The wings must be stiff enough to avoid flutter and divergence (two phenomena of flight that become very important at high speeds), and strong enough to be able to perform hard, high speed turns. The present wing was designed to not fail before the aircraft sees 20G in the turns.

The Lehigh engineers seem to have met that challenge with a carbon fiber wing built as a single piece. Using this method they are able to eliminate the usage of nuts and bolts, effectively creating a wing with no weak points. The entire wing is made from thin layers of carbon fiber (0.6 mm thick) configured into complex geometric shapes and placed layer by layer in molds digitally designed and machined at Lehigh. The resulting wing has stronger-than-steel performance.

The engineers use carbon fiber reinforced epoxy, similar to the material used to build the Numerette, said to be the largest craft yet constructed with a composite sandwich hull. A team of researchers, engineers, and students fabricated the prototype and are now testing whether it stands up to extreme forces. The prototype took about two weeks to build.

The top wing skin is layered into the mold, followed by the placement of the internal webbing of carbon fibers, geometrically aligned by using flexible tubing and expanded polystyrene as placeholders to form the structure. Then the lower half of the wing skin is layered on top and the entire wing is cured in a 250°F/121°C oven, burning away the expanded polystyrene and tubing placeholders.

[17] "University Professors Pursue Perpetual Flight with Composites". *Composites World*, October 2012. http://www.compositesworld.com/news/university-professors-pursue-perpetual-flight-with-composites

Wing Morphing

[18]Engineers at the University of California San Diego (UCSD) are mimicking the movement of bird wings to help improve the maneuverability of unmanned aerial vehicles.

"Rotary wing aircraft may be able to land on a perch for surveillance, but are generally less efficient for cruising flight than a fixed wing solution," say the engineers. "A fixed wing aircraft capable of spot landing on a perch like the top of a pole, a building or a fence would be an ideal solution capable of efficient cruising and versatile landing for longer surveillance missions."

One UCSD student analyzed slow motion videos of birds morphing and flapping their wings as they landed on small perches. "One of the key behaviors observed in the birds was their use of wing sweep for pitch control in both forward flight and stalled landing approaches," she said. To study this observation, she the UCSD research team built a remote controlled plane with wing loading and airfoil characteristics similar to a bird, plus variable wing sweep.

Preliminary results are encouraging. "Their initial testing validated the concept of using wing sweep for pitch control of the aircraft," say the engineers. Future research could combine twisting, flapping, and other wing morphing. "Combining these aspects into a fully actuated, intelligent UAS would be the ultimate goal,' notes the student.

[19]In another effort a UAS that mimics the way a bat changes its wing shape in flight could make small, un-crewed vehicles far more agile. "Bat wings are highly articulated, with wing skeletons very similar to those of human arms and hands," says a researcher at the Polytechnic University of Madrid, Spain. "The way bats change the shape of their wings has great potential for improving the maneuverability of micro air vehicles."

The US military – which part-funded this research – is keen on drones that flap like birds because they can be far stealthier than faster, fixed wing aircraft. Researchers in Colorado, Madrid, and Brown University, have built a drone with a half-meter wingspan inspired by a species of bat called the grey-headed flying fox.

The "Batbot" replicates the way a bat changes the profile of its wing between the down stroke and upstroke. On the down stroke, a large wing surface area is required to generate lift and propulsion. On the upstroke, however, that large area would create drag, so the bat folds the wing inwards. On the robot, the up/down flapping motion of the soft silicone wing is performed by an electric motor in the bat's body - as it is with other bird-like, flapping drones. The difference is that the extension and contraction of the wing is controlled by shape-memory alloy wires that switch between two shapes when different currents are applied in much the same way as the human triceps and biceps do.

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[18] Andrea Siedsma. "Engineers Look to the Birds for the Future of Unmanned Aerial Vehicles". May 2011. http://ucsdnews.ucsd.edu/newsrel/science/05-27UnmannedAerialVehicles.asp

[19] Paul Marks. "Shape-shifting Wings Make Stealthy Batbot More Agile". *New Scientist*, May 2012. http://www.newscientist.com/article/mg21428665.600-shapeshifting-wings-make-stealthy-batbot-more-agile.html

Situated between the "shoulder" and "elbow" of the robot, these wires rotate the elbow, pulling in the "fingers" to slim the wing profile on the upstroke. The Batbot is not flying stably yet, but the director of the Swiss National Center of Robotics in Lausanne already considers it "a major step towards more agile and autonomous flying robots". "It is an example of how robotics is gradually moving from rigid mechanical components towards higher-agility bionic systems made from soft materials, elastic components and artificial muscles," he says.

Health Monitoring and Repair

Wright State University is designing a small UAS that can autonomously react to problems and repair itself in flight, according to the University. NASA has previously pioneered work to build automated command and control systems for aircraft to compensate for losses of flight control components without human intervention. This is only one aspect of aircraft health monitoring and repair. Other research has focused on imbedding carbon fiber nanotubes into airframe components to react to stress fractures and heal these. This is no doubt a burgeoning field in aeronautics design and manufacturing.

[20]Another area of control requiring research is the damage tolerance capability for UASs. This is crucial for UAS systems operating in very hazardous environments. The technologies for this capability need to provide virtually instantaneous, autonomous assessment of damage incurred, followed by an immediate response that alerts the flight-control system to compensate for the effects of that damage. The Joint Unmanned Combat Aircraft Systems (J-UCAS) program sponsored by DARPA is looking for a new approach to autonomously mitigate the effects of physical damage to aircraft in a combat environment. The areas of research include robust techniques for implementing damage tolerance and innovative strategies for avionics redundancy management.

Tekever AR4 Light Ray
Image credit: HIS Jane's

Frangibility

Frangibility is a significant consideration in determining an aircraft vehicle's potential for damaging property or injuring persons on the ground and is a major FAA safety concern. The factor of concern is the kinetic energy that must be dissipated upon a collision. The most rigid the vehicle, the more mass it has and the faster it flies all contribute to its potential hazard.

Mitigation of this kinetic energy concern, outside of mass and velocity, must rest in the design and construction of a UAS vehicle. Thus far there has been little focus on this hazards aspect of UAS design. Although some manufacturers have attacked this problem for reasons to promote vehicle cost effectiveness or efficiency, unlike automobiles design for occupant collision protection, UAS have not as yet had a design considered collision risk impacts. For example, light but reasonably frangible vehicles are made from balsawood and or foam but this is coincidental to their lightweight construction.

[20] "Case Study: Rockwell Collins Demonstrates Damage Tolerant Flight Controls and Autonomous Landing Capabilities".
http://www.rockwellcollins.com/sitecore/content/Data/Success_Stories/DARPA_Damage_Tolerance.aspx

[21]Some companies engineer their UAS to fall apart on landing. The Portuguese manufacturer Tekever says that unlike many other UASs of its class, the AR4's wings are specifically designed to detach when the aircraft lands on its belly, minimizing potential damage to the wings and airframe.

Wing Coating
[22]According to an article in New Scientist, coating the rigid wings of airplanes with artificial bristles that mimic feathers could make them more efficient. Researchers at the University of Genoa in Italy observed that a set of smaller feathers –called coverts – kept birds flying efficiently, and added synthetic coverts to a computer model of a 20-centimetre-diameter cylinder and put it in a virtual wind tunnel. In the simulation, as the wind speed increased the bristles started to vibrate in a similar way to real covert feathers, reducing the drag on the cylinder by 15%. The researchers explained that the feathers prevent low-pressure slipstreams from forming, and added that while artificial coverts could be added to aircraft or underwater vehicles to improve their efficiency, they may "need a self-cleaning system to mimic the way birds preen their feathers to ensure efficient performance." This program helps UAVs utilize thermals to save fuel.

3.2 Powerplants

3.2.1 Efficiency

The dramatic increase in the development and deployment of unmanned systems across the entire spectrum of air, ground, and maritime mission requirements has led to a concurrent increase in the demand for efficient, powerful, often portable, and logistically supportable solutions for unmanned system propulsion and power plant requirements.

For the purpose of this section, propulsion and power consist of the prime power to provide thrust and electrical power conversion, management, and distribution necessary for the operation of the electrically driven subsystems required to perform an unmanned vehicle's mission.

A wide array of propulsion systems are used in unmanned systems, including combustion engines powered by heavy gasoline and diesel fuels, jet engines, electric systems, fuel cells, solar power, and hybrid power systems. These propulsion systems can be divided into three groups according to vehicle size and mission: turbine engines, internal combustion, and electrical. The thresholds are not simple or clean cut, but are highly dependent on mission goals. Some of the parameters taken into consideration to determine the optimal propulsion system include size, weight, airflow, range, efficiency, and speed. Similarly, numerous power systems are in use or proposed, including batteries, engine-driven generators, solar power, and hybrid and nuclear systems.

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[21] Zach Rosenberg. "Tekever UAV Falls Apart Upon Landing, As Planned". *Flight Daily News*, July 2012. http://www.flightglobal.com/news/articles/farnborough-tekever-uav-falls-apart-upon-landing-as-planned-374109/
[22] Colin Barras. "Fake Feathers Could Take the Drag out of Flights". *New Scientist*, April 2009. http://www.newscientist.com/article/dn16923-fake-feathers-could-take-the-drag-out-of-flights.html

Issues driving power requirements endurance is perhaps one of the most compelling aspects of unmanned systems. While power and propulsion systems are much improved over comparable manned systems, the search continues for even more efficient systems to provide greater endurance, speed and range.

A primary long-term goal in aircraft propulsion is to reduce system-specific fuel consumption by more than 30 percent over current gas turbine engines. Technical challenges being pursued include efficient, high-overall-pressure-ratio compression systems; variable-cycle engine technologies; advanced high-temperature materials and more effective turbine blade cooling; and techniques to more efficiently recuperate energy while satisfying thermal and power requirements.
Miniaturization plays a large part in addressing weight issues in the UAS community. As technology begins to catch up with the requirement for more efficient and smaller parts to satisfy the weight requirement, the UAS community products will begin to cross over the mission requirement line currently being observed because of current standards for product supply.

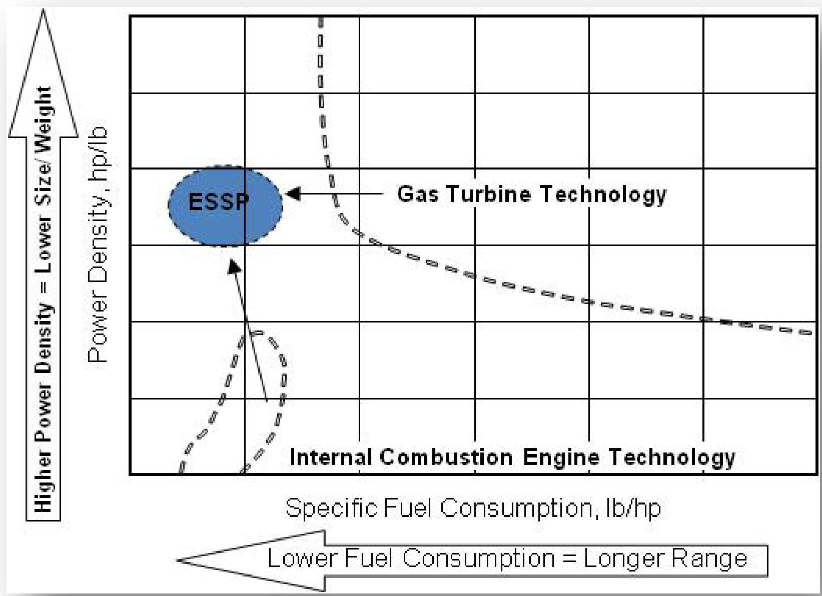

Figure 3-2 - Efficient, Small-Scale Propulsion (ESSP)

These challenges are currently being addressed for UAS applications under the highly efficient embedded turbine engine (HEETE) and efficient small-scale propulsion (ESSP) products, which are part of the Versatile Affordable Advanced Turbine Engines (VAATE) Program.
HEETE will demonstrate engine technologies that enable fuel-efficient, subsonic propulsion that supports future extreme endurance and range requirements with embedded engines incorporating complex inlets and exhausts. Covering the thrust class of 20,000 to 35,000 lbs, HEETE has two challenges: packing a high-bypass engine internally and delivering large amounts of electrical power regardless of throttle or flight condition.

The HEETE design provides very small, high-powered cores to enable high bypass within the diameter constraints of an internally packaged engine. Highly efficient fans designed with the distortion tolerance needed to run behind complex inlets provide the propulsive efficiency. The HEETE cores run at impressive pressure ratios, greater than 2.3 times the current state-of-the-art, and such ratios enable high tolerance of auxiliary power at HALE altitudes.
HEETE is associated with USAF ideas for an ultra-long-endurance, high-altitude, stealthy UAS called Sensor Craft. With the requirement to pack a high-bypass engine internally plus deliver a lot of electrical power at a point where the engine really wants to be loafing along with minimal fuel burn, the dynamics

present some clear engineering challenges to be overcome. HEETE clearly has an aggressively three-dimensional fan with lots of sweep and twist, to handle a lot of air in the smallest possible diameter, and the core runs at a mindboggling 70:1 pressure ratio for small size and high tolerance of auxiliary power off-take.

ESSP will cover a full spectrum of technologies for propulsion systems for vehicles ranging from 100 to 2500 lbs. These products promise game-changing system capabilities. The Science & Technology (S&T) challenge to meet the ESSP goals is the simultaneous combination of high power density with high efficiency (low specific fuel consumption) in a design space not typically addressed by either gas turbine or piston engine systems (see Figure 3-6 below). ESSP will conduct various demonstrations leading to reduced specific fuel consumption (SFC), increased power density, and a heavy fuel consumption capability. These demonstrations include a ducted fan, a nutating engine, a heavy fuel engine conversion, and a recuperator. ESSP is also designing and rig-testing high-pressure ratio compressors and high temperature capable turbine concepts aimed at long-term capability.

The ducted fan is the most complex of the near-term demonstrations. The two main technologies to be demonstrated are the high-bypass geared ducted fan and the variable turbine nozzle. The test demonstrates the capability to run the high-bypass ducted fan with airflow from two different distributed core gas generators for maximum power during takeoff and maneuvering and then turning off one core gas generator, as a variable cycle feature, at cruise to cut the fuel consumption. Conventional high-bypass turbofans would have to pull back the power setting to attain cruise condition, and this method would decrease engine speed, reduce the pressure ratio, and decrease component efficiencies resulting in increased SFC. The remaining core gas generator used to drive the ducted fan at cruise condition

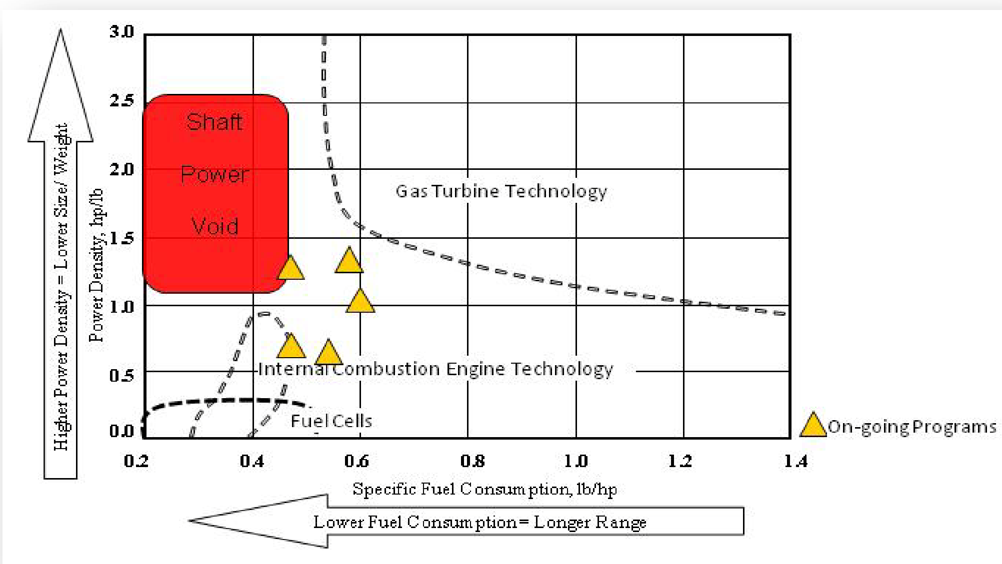

Figure 3-3 - Fuel Cell Efficiency

continues to operate at its design point for best cycle SFC. The variable turbine nozzle matches the airflow changes to maintain efficient turbine performance and drive the ducted fan.

The nutating disk engine leverages Small Business Innovation Research (SBIR) contracts for both the 4-inch and 8-inch disk engines. Both engines utilize derived advanced micro components to enable engine performance potential. The major technical challenges are the development of micro-fuel injectors and radial engine seals and the understanding of the thermodynamics process. Both sizes of disk engine have undergone initial testing and show a significant increase in power density, to 1.38. The nutating disk is scalable to multiple UAS platforms by scaling the disk size.

The heavy fuel conversion engine (i.e., the Rotax used in the Predator) runs on aviation gasoline (AvGas, 100 octane). The Rotax concept demonstration is aimed at running the engine initially with lower octane fuels and ultimately with JP-8 heavy fuel. Engine testing has been completed successfully with 70-octane fuel. Although octane level is not specified for JP-8 fuel, fuel analysis to date has shown variations between a 20 to 50-octane level. Testing was done to demonstrate the operation of the Rotax engine on JP-8. In parallel, there are SBIR efforts working to convert the Shadow UEL AR-741 engine to JP-8 fuel. Conversion efforts are aimed at maintaining engine performance levels while operating with JP-8 fuel.

The WTS126 turbo generator, developed by Williams International to drive the General Motors electric car, has a highly efficient recuperator, but is too heavy and large for installation into a flight vehicle. VAATE II studies indicated that a less efficient recuperator appeared to be the best balance among performance, size, and weight for a flight vehicle application. The WTS126 is an alternative heavy fuel propulsion system candidate for the Shadow. Testing and evaluation of the baseline WTS126 and the version with the less efficient flight weight recuperator are both underway.

For smaller platform applications, fuel cells offer an attractive alternative for internal combustion engines as field power generators, ground vehicle and aircraft Auxiliary Power Units (APUs), and primary power units for small UAS. Fuel cells are devices that electrochemically combine fuel and air to produce high-quality electrical power. Because these systems do not generate power via combustion processes, they offer significantly lower SFC rates relative to advanced heavy fuel engines or diesel power generators.

Solid Oxide Fuel Cell (SOFC) systems are a compelling power system option due to their high efficiencies, fuel flexibility, and low audible signature. Compared to other fuel cell approaches, the thermal environment and conductivity mechanism in SOFCs allow for a considerable improvement in fuel tolerance and provide a path forward for electrochemical logistic fuel operation.

3.2.2 Types

The overwhelming majority of UAS vehicles are powered by conventional engine technologies. This includes gasoline and diesel powered internal combustion engines as well as electric motors. In both cases the challenges are the weight and bulk of the expendable fuel source that affects vehicle designs and performance. Significant research and development has been accomplished to improve conventional powerplant efficiencies but the problem remains when the optimal UAS has unlimited endurance. Because UAS are freed from human physiological limitations the bar has risen for powerplants that can provide extensive persistence from days to week to months. This endeavor represents one of the most exciting technological challenges associated with UAS.

Conventional

[23]Goebler-Hirthmotoren KG (Hirth Motors) has launched a new UAS engine family that is based on Hirth's 4102 100cc 2-stroke EFI engine which has flown over 15,000 successful missions. The 4102 was developed from a base King engine, and Hirth is now developing a complete line of small EFI 2-stroke engines from base King engines to create a reliable engine for this UAS size class. This new line of 2-stroke air-cooled engines will utilize Hirth's advanced engine technology currently flying on other UAS applications. This includes increased efficiency due to electronic fuel injection, electronic throttle control, lightweight exhaust systems, shielded Engine Control Units (ECU) with military connectors, starter-generator solutions and advanced ignition systems. The family will initially include six engine configurations: 50cc (single), 70cc (single), 100cc (boxer), 140cc (boxer), 190cc (boxer) and 280cc (boxer).

[24]Orbital developed the Heavy Fuel Engine, nicknamed 'redback' by Orbital's staff, with AAI Corporation's Australian operation Aerosonde to power UASs, which will see service with the US Navy's Special Operations Command. The redback engine is a two-stroke; single-cylinder unit manufactured from lightweight materials, and is designed to run on heavier JP5 and JP8 military kerosene-based fuels. Orbital says that the miniature engine, which can fit into a shoebox, has advanced fuel injection systems that provide for greater reliability, longer endurance and larger payloads than existing UAS engines.

Disc Based Internal Combustion

[25]Flight International reported an internal combustion engine for UAVs that uses a disc rather than pistons is undergoing bench testing through the support of U.S. Army and U.S. Air Force Research Laboratory (AFRL). The target is to develop a 16.3kg powerplant that generates 77 hp. The engine's developers, Kinetic Research and Development and Baker Engineering, claim a nutating disc has a smaller contact area compared to a piston, will deliver a flatter torque profile, and provide 270 degrees of compression on the 360 degree rotation of the shaft. Designers claim that with a two-disc system the engine would be the equivalent of an eight-cylinder engine and the injection system design will be key for using heavy fuel.

Rotary Engine

[26]The Rotron Rotary UAS Engine Line features a revolutionary single-motor design. The Wankel cycle engine is a 4-stroke rotary engine, making it smaller, more fuel efficient, more powerful and more reliable than other equivalent piston engines. The revolutionary Rotron Rotary UAS engine is considerably smaller, lighter, and contains fewer moving parts than piston engines of equivalent power output. Every engine is fine-tuned to its optimum operating efficiency and safety levels before shipment. If your

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[23] "Hirth Motors Launches new UAV Engine Family at AUVSI". PR Web, August 2012. http://www.prweb.com/releases/2012/8/prweb9761774.htm

[24] "Aussie 'Redback' to Power US Navy UAVs". *Australian Aviation*, June 2012. http://australianaviation.com.au/2012/06/aussie-redback-to-power-us-navy-uavs/

[25] Rob Coppinger. "US Military Funds Pistonless Disk Engine". *Flight International*, June 2008. http://www.flightglobal.com/news/articles/us-military-funds-pistonless-disk-engine-224851/

[26] NWUAV Propulsion Systems. http://www.nwuav.com/uav-products/uav-rotary-engines.html

application requires a different power configuration but needs to keep the same package size, custom options are available to fit your needs.

[27]Another new engine type is the turbofan for UAS. The core propulsion technology being developed by one of the propulsion companies is the Micro-Turbofan™. The fundamental difference between the Micro-Turbofan™ and a conventional turbofan is that the power-turbine driving the by-pass flow is located in front of the combustor rather than at the engine exhaust. In its standard configuration, the Micro-Turbofan™ is ideally suited to engines producing less than 1,000 lb thrust and extending down to below 100 lb thrust. Fuel consumption for both configurations is comparable to conventional small turbofans and turbo shafts, but with improved thrust-to-weight and power-to-weight ratios. The Micro-Turbo shaft™ engine is ideally suited to low-speed UASs, while the Micro-Turbofan™ engine will allow higher performance for UASs and commercial light aircraft. Additional advantages are increased payload, reduced exhaust temperature, greater fuel flexibility, longer service interval and a simplified installation process.

Turbine Alternator[34]

The micro-turbo alternator uses the same core turbo-machinery as the micro-turbofan, but instead of driving a fan to provide thrust, drives a light weight, permanent magnet generator provide electrical output. Using a compact recuperator to recover heat from the exhaust decreases the fuel consumption. This is six times the specific power, or 12-15 times the energy density, of lithium polymer batteries. Electrical output ranges from under 10 kW to over 100 kW. The micro-turbo alternator is ideally suited to the next generation of hybrid electrical UASs.

Distributed Propulsion[34]

Another source of power for UASs is the Distributed Propulsion concept, which is enabled by small, low thrust engines, such as the Micro-Turbofan™ and a compact lift fan. Contemporary small aircraft are typically limited to using one or two large engines, because there are currently no small engines with a suitable performance. Control is primarily provided by moving the aerodynamic surfaces, either flaps on fixed wing aircraft or rotor blades on helicopters. However, if the total thrust requirements of an aircraft can be met with a large number of small engines then differential throttle control can be used to control the aircraft. This approach has a number of benefits that are particularly suitable for low-speed aircraft operating in restricted environments; eliminating movable control surfaces and actuators greatly simplifies the construction of the airframe; multiple engines provide redundancy in the event of damage or failure; control via thrust is independent of speed and acts more directly.

Solar Turbine

[28]Another type of UAS power is being explored to provide more enduring power to unmanned aircraft. Airship Technologies Group has designed a solar turbine that will provide motive power for up to 90 days flying time. This new design will provide critical new capabilities in a reliable and more affordable manner, all while consuming no fossil fuels and emitting no carbon emissions. The turbine's reduced

[27] Metis Design. http://www.metisdesign.com/multidisciplinary-systems/propulsion-systems.html
[28] Gary Mortimer. "AirScape UAV Solar Turbine to Deliver 30 to 90 Days of Flying Time!" *SUAS News*, November 2012. http://www.suasnews.com/2012/11/19684/airscape-uav-solar-turbine-to-deliver-30-to-90-days-of-flying-time/

carbon footprint is defined by multiple stages: solar film nanotechnology; clean tech solar turbine manufacturing; and renewable solar electric power for long flying time

The Solar Turbine engine design is more efficient, non-polluting and inexpensive to use than any other small UAS propulsion system on the market. It is an industry game-changing revolutionary approach to ultralight UAS propulsion that eliminates the carbon footprint. The Solar Turbine reduces UAS aircraft weight and eliminates the need to carry onboard fuel because of the introduction of renewable solar energy with rechargeable ultra-capacitors.

Electric

[29] Wired's Autopia blog reported on the ElectraFlyerC as a small electric airplane that debuted at the AirVenture show in Oshkosh, Wisconsin. The aircraft, which received its airworthiness certificate in April, features a 5.6 kWh lithium battery with a projected lifecycle of 1,000 cycles and a recharge time of roughly six hours at 110 volts. The battery-powered motor drives a 45-inch superlight PowerFin propeller made of a foam core surrounded by an outer shell of carbon fiber and glass fabric. The aircraft's top speed is 90 mph, and it can fly for 90 to 120 minutes before the battery needs recharging. The manufacturer, Electric Aircraft Corporation, points out that the motor is nearly silent, “which means no earplugs for pilots, and brings the potential for flying into new sites." The company also estimates that 'refueling' the plane with a full charge of the battery will cost, on average, sixty cents. This engine remains an obvious and certifiable alternative for a UAS.

[30]An outfit called Flight Of The Century (FOTC) has flown a modified Rutan Long-EZ with which it plans to set electric-aircraft speed and altitude records en route to its goal of developing an "infinite-range" aircraft and attempting an all-electric transatlantic flight to demonstrate its technology. FOTC's ambition sounds similar to Defense Advanced Research Project Agency’s (DARPA) goal for its recently terminated Vulture "infinite-endurance" unmanned aircraft program – and there are other similarities.

FOTC's concept is to extend the range and endurance of an electric-powered aircraft by replacing battery packs in flight using a mid-air "refueling" technique. This would use "flying battery packs" – a UAS that would detach from the mother ship once the batteries are depleted and fly down to a recharging station while a freshly charged battery pack is launched to rendezvous and dock with the aircraft.

As steps toward its infinite-flight goal, FOTC says the range of an electric aircraft can be increased by the single in-flight jettison of a depleted battery pack – either by UAS or by parachute. Dropping half the battery weight 30-50% into the flight would reduce aircraft weight and extend range by up to 40%, the company says.

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[29] Dave Demerjian.”Plug and Fly: The Battery-Powered Plane Makes Its Debut.” *Wired*, August 2008. http://www.wired.com/autopia/2008/08/the-company-cla/

[30] Graham Warwick. “Electric Aircraft Promises Infinite-Range Flight”. *Aviation Week: Ares Defense Technology Blog*, July 2012. http://www.aviationweek.com/Blogs.aspx?plckController=Blog&plckScript=blogScript&plckElementId=blogDest&plckBlogPage=BlogViewPost&plckPostId=Blog%3a27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post%3a440cb322-d3e3-4c53-bfe0-a70a078e96a5

A greater than 90% increases in range could be achieved by sequentially dropping depleted battery-pack segments at regular intervals during the flight. Rather than a single, monolithic battery pack, FOTC reconfigures the same capacity into a series of smaller packs which are brought on line one by one, depleted individually, then dropped by parachute while the remaining packs are repositioned to rebalance the aircraft's Center of Gravity (CG).

Breaking current large battery packs into 10 smaller units, and making 10 drops at equal intervals during the flight, will double the range of today's electric aircraft, using today's batteries, says FOTC. The batteries would be dropped over collection stations to be recharged and reused.

Using today's battery technology, rather than waiting for promised advances in power density, is key to the company's approach. The modified "Long-ESA" (Electric Speed & Altitude) has the same 258 hp liquid-cooled permanent magnet DC motor and lithium-ion polymer prismatic pouch cells used to set a 200-mph+ world speed record for an electric motorcycle.

In addition to trying for speed and altitude records, the Long-ESA will test FOTC's technology for dropping and repositioning battery packs in flight. It will also test whether it is feasible to recover kinetic energy from the freewheeling propeller via its electric motor during descending flight.

Solar Electric[31]

A UAS vehicle known as *Silent Falcon™* is a solar-electric, all composite, modular Small Unmanned Aircraft System designed for both military and public safety applications. Silent Falcon™ has a solar electric propulsion system, rugged composite structure, and three interchangeable wing configurations.

UAS Technologies
Silent Falcon
Image Credit: Silent Falcon™ UAS Technologies

Hybrid[32]

Flight Global reported that Aeronautics Defense Systems plans to test a hybrid battery-piston engine inside its Aerosky 2 close-range tactical unmanned air vehicle. The system works by using the piston engine at the UAV's takeoff, and then switching to its battery system once it reaches its target area. The 80-kilogram UAV is expected to have an endurance of 10 hours. According to the company, the UAV's electric propulsion mode will reduce its noise signature at low altitudes.

CNT Fuel Cell[33]

Flight International reports, "Cost and performance limitations have kept fuel cell-powered unmanned air vehicles within the military domain, but new nitrogen-doped carbon nanotube (CNT)-based catalyst technology could see this situation end." The nitrogen-doped CNT catalyst, developed at the University of

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[31] Silent Falcon™ UAS Technologies. http://www.silentfalconuas.com/Silent_Falcon_spec_sheet.pdf
[32] Arie Egozi. "Aeronautics' Aerosky 2 to Test Hybrid Engine on 2 June". *Flight International*, April 2008. http://www.flightglobal.com/news/articles/aeronautics-aerosky-2-to-test-hybrid-engine-on-2-june-222999/
[33] Rob Coppinger. "Carbon Nanotube Catalyst to Improve Fuel Cell Endurance". *Flight International*, February 2009. http://www.flightglobal.com/news/articles/carbon-nanotube-catalyst-to-improve-fuel-cell-endurance-322628/

Dayton with support from the Air Force, could someday replace costly and less effective platinum-based cell types. Hopefully, this new technology will reduce the major cost of a fuel cell and create a “breakthrough toward commercialization of fuel cell technology for various applications," according to the Chairman of Nanomaterials at the Wright Brothers Institute.

Hydrogen Fuel Cell[34]
Wired News reports that Boeing is anticipating a big future for hydrogen-fueled aircraft and is developing an unmanned plane called the Phantom Eye that would use liquid hydrogen - the same fuel used in rockets - to reach altitudes topping 60,000 feet and stay there for days at a time. The plane is one of several alternative fuel aircraft that Boeing, which earlier this year tested a hydrogen fuel cell airplane, is working on. Although it is still a long way from meeting such lofty expectations, Boeing believes a liquid-hydrogen plane, which would have reconnaissance and atmospheric research applications, could solve many of the challenges inherent in designing so-called HALE aircraft.

The plane uses an internal combustion engine developed by Ford and adapted to burn hydrogen. The company says the engine ran for nearly four days in a test chamber, including three days in conditions that simulated an altitude of 65,000 feet."

Steam[35]
It is possible to create steam within seconds by focusing sunlight on nanoparticles mixed into water, according to new research. That observation, made by scientists at Rice University in Texas, suggests a myriad of applications in places that lack electricity or burnable fuels.

“We can build a portable, compact steam generator that depends only on sunlight for input. It is something that could really be good in remote or resource limited locations,” said an engineer and physicist at Rice who ran the experiment. The experiment is more evidence that Nano scale devices – in this case, beads one-tenth the diameter of a human hair – behave in ways different from bigger objects.

In the apparatus designed by the Rice team, steam forms in a vessel of water long before the water becomes warm to the touch. It is, in effect, possible to turn a container of water into steam before it gets hot enough to boil. “There is a disconnect between what happens when we heat a pot of water and what happens when we put nanoparticles in that water,” said a chemist and director of the California NanoSystems Institute (CNSI) at the University of California, Los Angeles (UCLA).

“This is a novel proposed application of nanoparticles,” says the director of the Lawrence Berkeley National Laboratory and a nanotechnology expert. “I think it is very interesting and will stimulate a lot of others to think about the heating of water with sunlight.”

In the Rice experiment, the researchers stirred a small amount of nanoparticles into water and put the mixture into a glass vessel. They then focused sunlight on the mixture with a lens. The nanoparticles —

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[34] Dave Demerjian. “Boeing Has Seen the Future, And It Includes Hydrogen”. *Wired*, December 2008. http://www.wired.com/autopia/2008/12/boeing-has-seen/
[35] David Brown. “Making Steam Without Boiling Water, Thanks to Nanoparticles”. *Washington Post*, November 2012. http://articles.washingtonpost.com/2012-11-19/national/35505658_1_steam-nanoparticles-water

either carbon or gold-coated silicon dioxide beads — have a diameter shorter than the wavelength of visible light. That allows them to absorb most of a wave of light's energy. If they had been larger, the particles would have scattered much of the light.

In the focused light, a nanoparticle rapidly becomes hot enough to vaporize the layer of water around it, and then becomes enveloped in a bubble of steam. That, in turn, insulates it from the mass of water that, an instant before the steam formed, was bathing and cooling it. Insulated in that fashion, the particle heats up further and forms more steam, eventually becoming buoyant enough to rise. As it floats toward the surface, it hits and merges with other bubbles.

At the surface, the nanoparticles-in-bubbles release their steam into the air. They then sink back toward the bottom of the vessel. When they encounter the focused light, the process begins again. All of this occurs within seconds. In all, about 80 percent of the light energy a nanoparticle absorbs goes into making steam, and only 20 percent is "lost" in heating the water. This is far different from creating steam in a teakettle. There, all the water must reach boiling temperature before an appreciable number of water molecules fly into the air as steam.

The phenomenon is such that it is possible to put the vessel containing the water-and-nanoparticle soup into an ice bath, focus light on it and make steam. "It shows you could make steam in an arctic environment," says the Rice engineer and physicist. "There might be some interesting applications there."

The apparatus can also separate mixtures of water and other substances into their components – the process known as distillation – more completely than is usually possible. For example, with normal distillation of a water-and-alcohol mixture, it isn't possible to get more than 95 percent pure alcohol. Using nanoparticles to create the steam, 99 percent alcohol can be collected.

The Rice engineer and physicist says the nanoparticles are not expensive to make and, because they act essentially as catalysts, are not used up. A nanoparticle steam generator could be used over and over. And, as James Watt and other 18th century inventors showed, if you can generate steam easily, you can create an industrial revolution.

HydroICE[36]

What two Missouri-based inventors are working on is something a little different. They want to take an internal combustion engine, and run it on water and solar-heated oil instead of gasoline. That engine could then be hooked up to a generator to provide clean electricity. While that may sound uncertain to some, these inventors have already built a small-scale prototype.

The duo has labeled the system HydroICE, which is short for Hydro Internal Clean Engine. Here's how they envision it working. To begin, mirrored parabolic solar collectors would be used to heat oil to a temperature of at least 400ºF to 700ºF (204ºC to 371ºC). This hot oil would then be injected into the cylinder chamber of the engine, just like gasoline ordinarily is. A few micro-droplets of water would then also be introduced, which would turn to steam immediately upon contact with the hot oil. The rapidly

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[36] Ben Coxworth. "HydroICE Project Developing a Solar-Powered Combustion Engine". *Gizmag*, November 2012. http://www.gizmag.com/hydroice-solar-powered-engine/25139/

expanding steam would serve the same purpose as exploding gas, driving the piston downward and turning the driveshaft. As the piston reached the bottom of its stroke, the spent steam and oil would exit the cylinder and be run through an oil/steam separator. They could then each be returned to their respective reservoirs, for re-use within the closed-loop system.

The inventors have converted a 31cc 2-stroke gas engine to run as a HydroICE engine. While it isn't clear if they've actually had the thing running yet, they have partnered with Missouri State University and the Missouri University of Science and Technology to develop all the necessary peripheral hardware (such as the solar collectors), and to test the engine's efficiency.

That efficiency is currently estimated at being at least 15 percent – about the same as the maximum efficiency of existing photovoltaic panels. The technology's big advantage, however, would be price. They're projecting that a HydroICE system would cost about a quarter of what an equivalent-output photovoltaic system would cost.

Magnetic Resonance[37]

A technology reporter for *New Scientist* writes that anyone with an energy-gobbling smartphone knows the pain of having your battery run out while off-grid, but while you can always charge up when you return home, getting power to sensors placed in remote locations is more difficult. Now researchers at the University of Nebraska-Lincoln in the U.S. have come up with a solution - a flying wireless battery mounted on a quadrotor UAS.

The team use a technique called strongly coupled magnetic resonances, in which current in a coil of wire on the UAS generates a magnetic field that resonates with a second coil in the sensor, inducing a voltage and allowing it to charge up. How much power can be transmitted depends on how far the UAS is from the sensor. When hovering at an optimal distance of 20 centimeters the system can transfer 5.5 watts with an efficiency of 35 percent, enough to power a small light. Once the juice runs low, the UAS can simply fly back to base and recharge.

The researchers say their system could be used to charge highway messaging systems, ecological sensors located in forests, or sensors shallowly embedded underground or in concrete. And with civilian drone usage taking off, UASs could soon be delivering power to pretty much anywhere.

Laser[38]

LaserMotive has demonstrated a power system that can keep Lockheed Martin's Stalker unmanned aerial vehicle going for more than 48 hours with laser light — but that's not the most amazing part. What's even more impressive is that the drone could have stayed in operation indefinitely, fed by laser beams.

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[37] Jacob Aron. "UAVs Fly Wireless Power to Remote Locations". *New Scientist*, June 2012. http://www.newscientist.com/blogs/onepercent/2012/06/uavs-take-power-to-remote-loca.html

[38] Alan Boyle. "Laser Beam Keeps Robo-plane Buzzing for Two Days Straight". *MSNBC Cosmic Log*, July 2012. http://cosmiclog.nbcnews.com/_news/2012/07/12/12690006-laser-beam-keeps-robo-plane-buzzing-for-two-days-straight?lite

The Stalker is a camera-equipped, hand-launched UAS that's been used by U.S. Special Operations Forces since 2006 to perform intelligence, surveillance and reconnaissance missions. The Stalker has also been tested for domestic applications such as border patrol and pipeline surveillance.

One of the craft's limitations has to do with how much time it can spend aloft. A battery-powered Stalker can stay up for more than two hours, and last year a Pentagon-funded project used propane-powered fuel cells to extend that hang time to eight-plus hours. But that's nothing compared to the laser system. During the test, laser beams sent energy over a distance of about 30 feet (9 meters) to a photovoltaic receiver on the Stalker. That energy was then converted into electricity to power the Stalker. At the end of the two-day test, the Stalker's batteries carried more of a charge than they did when the test began.

The LaserMotive team indicated that wireless power transmission via laser is a good way to keep devices like the Stalker going for days at a time — in fact, it may be the only way.

Propane Fuel Cells[39]

PRNewswire reports that Ultra Electronics, AMI recently delivered 45 fuel cells for use by the U.S. military in UAS. The delivery is the latest in a series of multi-unit manufacturing runs of small propane-fueled solid oxide fuel cell technology.

According to the AMI president, "Compared to other, larger UAS platforms, those powered by the ROAMIO D245XR fuel cells can fly further and longer, as well as carry more sensors and equipment with a much smaller logistical footprint. The ROAMIO D245XR weighs significantly less than a traditional battery pack or other power source, reducing the overall weight burden of putting advanced UAS payloads and flight duration capabilities into small squads and making it possible for the system to be operated by only one or two warfighters."

The ROAMIO D245XR is designed and tested for integration with UAS weighing less than 25 lbs and with wingspans of approximately 12 ft. The propane fuel cell system enables these UAS to be powered anywhere in the world by locally sourced fuels.

The Mars vehicle Curiosity carries a radioisotope power system that generates electricity from the heat of plutonium's radioactive decay. Because it does not rely upon solar cells it can roam the Red Planet for at least 697 days.
Image credit: NASA Jet Propulsion Laboratory, Mars Science Laboratory

Nuclear[40]

Defense Technology International reported that in March, Sandia National Laboratories released a summary of research it had conducted with Northrop Grumman's unmanned systems division concerning an "ultra-persistent propulsion and power system" for unmanned aircraft systems. The conclusion was that by using nuclear technology, UAS could be built with longer endurance and lower operating cost

[39] Ultra Electronics AMI. "Ultra Electronics, AMI Delivers 45 Fuel Cells for Use in Military UAS". July 2012. http://www.ultra-ami.com/2012/07/ultra-electronics-ami-delivers-45-fuel-cells-for-use-in-military-uas/
[40] Bill Sweetman. "Benefits of Nuclear UAVs". *Defense Technology International*, May 2012. http://www.aviationweek.com/awmobile/Article.aspx?id=/article-xml/DT_05_01_2012_p14-450521.xml&p=1

than with hydrogen or hydrocarbon fuel, creating “unmatched global capabilities to observe and preempt terrorist and weapon of mass destruction activities.”

An earlier Sandia study concluded that such a UAS could be tested within a decade. However, due to concerns regarding the safety of nuclear technology, these tests are unlikely to occur. But the technical and operational case is powerful.

Boeing's Phantom Works was involved with the design of the nuclear UAS, a high subsonic, blended-wing body. Propulsion was based on concepts that emerged from the Airborne Nuclear Power (ANP) program of the 1950s, which was intended to lead to a strategic missile carrier that would remain on continuous airborne alert for a week or more. The ANP program combined two turbojet engines with a reactor and examined two designs: “direct cycle,” in which the engine airflow cooled the reactor; and “indirect cycle,” in which a liquid-metal coolant carried heat from the reactor to the engine.

The 2000 era UAS enjoyed three advantages over ANP, which struggled to reach a performance level where the aircraft could fly. Two stemmed from the fact that it was a UAS, which could take advantage of the propulsion system's endurance. Planners envisioned features such as magnetic engine bearings to eliminate oil. Importantly, more than half the weight of the ANP propulsion system was radiation shielding, which could be reduced in a system that would not run at full power near humans. (In the Sandia studies, the engines burned jet fuel for takeoff and landing.) A USAF study of a Global Hawk with a nuclear engine indicated it might need only 2,700 lb. of shielding.

The third advantage was improved reactor technology. Air Force interest in Extremely Long Endurance Vehicles (ELEV) coincided with the decline of the Space Nuclear Thermal Propulsion (SNTP) technology program, in which Sandia was also involved. SNTP started in 1987 as the Strategic Defense Initiative Office's Project Timberwind, aimed at producing a nuclear-thermal rocket (developing thrust by superheating hydrogen) for a missile interceptor, but was canceled after the Cold War. A Timberwind rocket engine would have incorporated a particle bed reactor (PBR), with some designs weighing as little as 2,000 lb., using carbon-carbon and ceramic-matrix composites.

New reactor designs are safer. They “would only hurt you if they fell on you,” it has been suggested, because of specially fabricated and shielded fuel elements and robust “poison” systems to perform an emergency shutdown. It is not known whether a PBR or a different modern reactor technology was the basis for the ELEV concept or the Sandia-Northrop Grumman study, which covered eight heat sources, three power conversion systems, two dual-cycle propulsion systems and an electrical generation system. However, it was stated in 2001 that the propulsion system would power the aircraft while delivering several hundred kilowatts to onboard radar, communications and electronic attack systems. Conventional turbine engines optimized for range and fuel consumption and sized for typical UASs struggle to deliver 50+ kW at altitude.

Hydrogen Storage[41]

L2 Aerospace, a maker of air and space-based products, has teamed with Cella Energy, a leading developer of hydrogen storage systems, have partnered to create a hydrogen storage system. The system will be designed to be used with small, hydrogen-powered unmanned aircraft. The duo has already fabricated a prototype system using a concept design that was on display during the Farnborough International Airshow. If the system proves successful, it may be modified to be used with larger aircraft in the future.

In March, L2 received an AeroVironment RQ-11 Raven UAS from the U.S. government. The UAS is used as a demonstrator for the Cella Energy's hydrogen storage technology for the duration of the project. The UAV normally powered by a lithium-ion battery and can operate for up to 90 minutes. L2's goal for the project is to at least triple the operational duration of the UAS through the use of a hydrogen fuel cell and Cella Energy's hydrogen storage technology.

L2 plans to modify an existing hydrogen fuel cell to work with the UAS as opposed to designing a new energy system from scratch. Cella Energy with is responsible for the creation of the hydrogen storage system as well as the materials that will be used for storing the UAS's hydrogen fuel. Cella Energy claims that the hydrogen storage system will be ready for operation by 2013, with a test flight of the hydrogen-powered UAS to occur later that year.

Magneto Hydrodynamics[42]

New Scientist reports on the University of Georgia, who is working to create a micro air vehicle (MAV) that uses magneto hydrodynamics for propulsion. The discipline involves passing a current or magnetic field through a conducting fluid to generate a force. New Scientist notes, "Numerous aerospace engineers have tried and failed to exploit this phenomenon...as an exotic form of propulsion." One engineer's design uses a saucer shape covered with electrodes that ionize air to create a plasma. This plasma is then accelerated by an electric field to push air around and generate lift. The design uses helium to reduce the MAV's weight, and is efficient enough to be powered by onboard batteries.

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[41] Bill Carey. "L2 Aerospace, Cella Energy Pursue Hydrogen Storage for UAVs." *AINonline*, July 2012. http://www.ainonline.com/aviation-news/2012-07-09/l2-aerospace-cella-energy-pursue-hydrogen-storage-uavs

[42] Justin Mullins. "Invention: Plasma-powered Flying Saucer". *New Scientist*, May 2008. http://www.newscientist.com/article/dn13840-invention-plasmapowered-flying-saucer.html

3.3 Communications, Command and Control

[43]In general, there are four main areas of concern when considering UAS Command, Control, and Communications (C^3) links. Inadvertent or hostile interference of (1) the uplink control data, (2) the downlink information transfer and health status data of the vehicle, (3) the navigation data link (e.g., GPS) to the UAS and/or ground operation centers, and (4) the availability of reliability of command and control links for air traffic control.

The forward "up" link controls the activities of the platform itself and the payload hardware/software. This command and control link requires a sufficient degree of security to ensure that only authorized agents/operators have access to the control mechanisms of the platform. The return "down" link transmits critical data from the platform payload to the warfighter or analyst on the ground or in the air, as well as transmitting the UAS health and status data to the ground control centers. System health and status information must be delivered to the operator without compromise, so a high degree of encryption is needed. Figure 3-4 shows the possible C^3 links for an UAS system. Not shown are the critical links to air traffic control needed for operations within civil domestic airspace managed by the FAA.

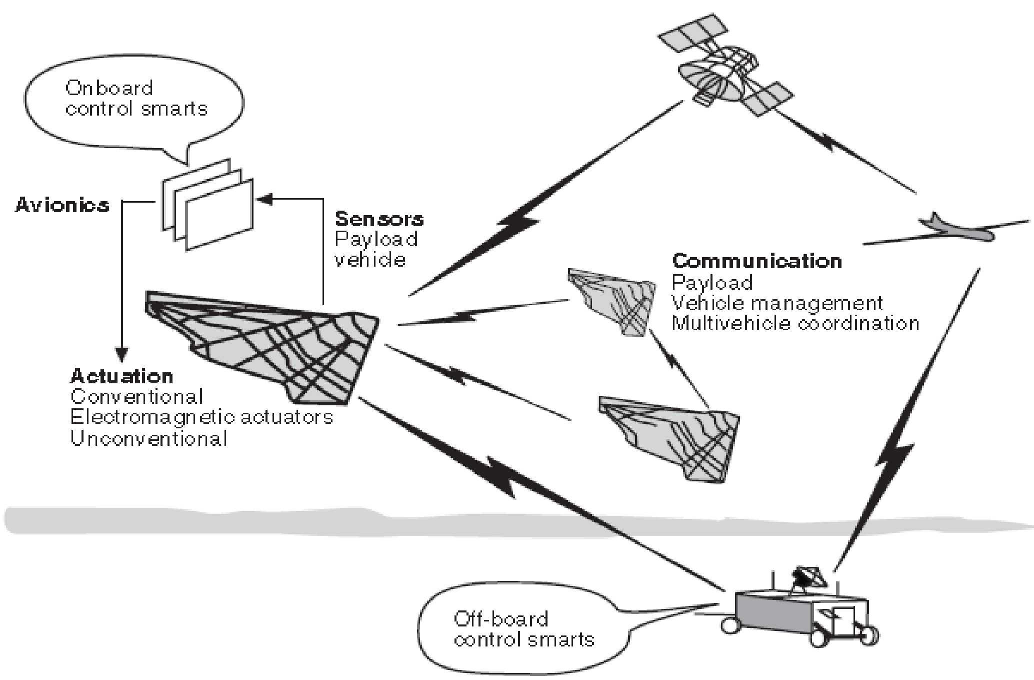

Figure 3-4 - Possible UAS C^3 Links

[43] "Unmanned Systems Roadmap: 2007-2032". Pg. 129. Office of Defense Acquisition, Technology, and Logistics. Washington, D.C., December 2007.

3.3.1 Communications

All communication links require frequency assignments. Those for navigation signals are already allocated and assigned. Effective frequency spectrum allocation and management is key to reducing inadvertent interference of the digital data or analog voice links.[50] While the International Telecommunication Union (ITU) World Administrative Radio Conference (WARC) has allocated terrestrial spectrum bands, provisional and permanent in 2012, currently there are no particular frequencies of the radio frequency spectrum assigned exclusively to civil UAS operations. For current operations, access to suitable areas of the frequency spectrum is granted, according to availability, by the local and national authorities, on an *ad hoc* basis. The assignment of appropriate frequencies of the spectrum, for UAS C^3 links continues to be an agenda item for the ITU WARC. Hopefully the next WARC will finalize assignment of terrestrial spectrum and allocate a satellite communication spectrum for UAS.

Communication is the backbone of air traffic control; its availability, reliability and integrity are critical to the safe, orderly and expeditious movement of aircraft. The current air traffic control communications air-to-ground radio infrastructure is dated and harkens to radio communication architectures and technologies of the 1950s and 1960s. The ground communication infrastructure is also dated from the 1980s and 1990s.

While the FAA has plans to add limited air-to-ground data communications (i.e., ADS-B for surveillance and Data Comm for limited controller-pilot communications), neither replaces the primary and current VHF two-way radios. The FAA has moved forward to create a dedicated fiber optic ground communications infrastructure for voice and data and is also contracting for initial but limited VOIP capability for ATC facilities and controller workstations. Full implementation allowing functions, such as instant text messaging between controllers or between pilots and controllers, are not even on the drawing board.

FAA's current infrastructure technologically falls short of DoD capabilities used to operationally manage its resources and responsibilities. The question is how UAS assets and their use, which relies so heavily on a modern communication infrastructure, can fare given FAA's conceptually antiquated communications architecture and infrastructure remains in question.

These conditions will seriously inhibit the rapid deployment of UAS into the NAS where timely critical data and voice communications must support ATC command and control capabilities. For example, the FAA in developing UAS operational concepts have characterized UAS as acting like manned aircraft relaying information through the UAS remotely to the pilot and from the pilot back through the UAS. Not only is latency an issue, but also security as well when communicating critical aircraft maneuvers over a "clear channel" available with multiple nodes of single point failure to anyone in the air or on the ground that wants to listen with minimal equipment investment. This simply continues the issue of "ghost controllers"[44] and their associated safety risks.

The large volumes of data that can be gathered by airborne sensors provide unique challenges and opportunities. The sheer volume of video and other sensor data transmitted will require significant

[44] "Ghost controllers" are radio broadcasts to aircraft by unauthorized individuals spoofing air traffic control

communications bandwidth. For military users, military and commercial Ku-band satellite resources, as well as airborne relays for very high capacity link requirements currently provide it. To meet the challenges associated with large data transfer rates, it is only logical to consider performing data processing and data discovery, to the maximum extent possible, on-board the UAS platform. Current research on on-board data reduction algorithms appears viable and promising. These advances, in concert with promising future processing technologies, such as nanotech and quantum computing, can alleviate much of the communications bandwidth needed for unprocessed data.

[45]It is expected that commercial satellite service providers (e.g., Inmarsat) will also continue to increase their global satellite communications capabilities for both the military and the anticipated commercials users of the UASs. Inmarsat's Global Xpress Ka-band satellite service is in fact in anticipation of the future increase in intelligence, surveillance, and reconnaissance data from all UAS markets.

The Inmarsat's $1.3 billion Global Xpress constellation scheduled to be initially deployed in 2013 will offer Ka-band satellite services to government and commercial users around the world. The full global operation is expected at the end of 2014. This trend is expected to continue by other commercial satellite providers, worldwide.

It is also anticipated that some UASs themselves will become high data link communications relay platforms to serve the needs of other UASs for data transmission. An airborne relay can effectively connect ground and UAS assets requiring high communications bandwidths. The trend in UASs providing communications relay platforms is expected to grow over the next decade.

3.3.2 Command

The uplink control links and the associated navigation links are essential parts of UAS operations. These links require a high degree of availability and security, in particular for military users.

The Command subsystems will require built-in intelligence designed into onboard and off-board processing elements of the UAS. Also important is the allocation of tasks and construction of interfaces between humans and automated processing capabilities. The capacity, security, and robustness/availability built into command links are of paramount importance. This includes the robustness and availability of the navigation signals against intentional or unintentional interferences. The GPS receivers may be vulnerable to jamming. GPS signals can also become the target of hacking attacks, known as "spoofing," that can send out false time signals and disrupt the flight pattern in undesired manners. GPS supplemental and/or backup systems such as FAA's WAAS, DME/DME or inertial reference systems need to be more closely considered.

[46]Researchers at Radionavigation Lab at the University of Texas at Austin have recently successfully spoofed the commercial GPS receivers to take control of a small helicopter drone using GPS spoofing equipment available to purchase on-line. The UT at Austin team used only about $1,000 worth of

[45] Jefferson Morris. "Inmarsat Sees Growing Market for UAV Data Relay, Despite Drawdowns". *Aerospace Daily & Defense Report*, July 2012. http://www.aviationweek.com/awmobile/Article.aspx?id=/article-xml/asd_07_05_2012_p03-01-473472.xml
[46] Brian Benchoff. "Spoofing GPS and Getting Your Own UAV". July 2012. http://hackaday.com/2012/07/01/spoofing-gps-and-getting-your-own-uav/

commercially available equipment to take control of an autonomous drone and pilot it away under unauthorized control. Clearly, the U.S. Military has a huge interest in technologies that may be used to spoof GPS signals; Iran gained a U.S. drone late last year under mysterious circumstances.

UAS technologies are developing so quickly that the FAA has not had enough time to implement regulations to safely accommodate routine UAS operations within the NAS. Current ATC equipment has not yet been optimized to command UAS traffic with the same safety standards as piloted aircraft. The 2,000 feet No Transgression Zone (NTZ) between parallel landing flight paths is a good example of the human performance buffer. If the controller could control the aircraft manned or unmanned directly, these buffers could be significantly reduced, adding both safety and capacity to the air traffic control system. This does make a case for the use of ADS-B UAT as a command and control mechanism to permit an air traffic controller to command as well as control a UAS to make a separation maneuver directly in lieu of going through a remotely stationed UAS pilot. Of course this is a revolutionary new air traffic control paradigm. Notwithstanding, it needs to be explored.

3.3.3 Control

The method of control of the UAS mission is a highly discriminating element. This control refers to the degree of human involvement in the real-time accomplishment of the mission. Control is broken into the following sub-categories:

- Remote human *pilot*. A pilot controls the position, attitude, and performance of the UAS throughout its flight in real time for the purpose of accomplishing the mission. The pilot's sensory information and control inputs are similar to being in the aircraft itself, but are remote from the aircraft and the operation. Piloting skills are required for control of the vehicle.
- Remote human *operator*. In this sub-category, the human is involved in causing the flight to begin and end, and in determining and directing the navigation and the temporal and operational aspects of the mission, but not manipulating the flight controls of the vehicle itself to maintain its attitude and stability. Those functions are "built-in," leaving higher order control of the mission to the human operator.
- Human controlled initiation and termination, autonomous mission execution. In this mode, the mission is entirely pre-programmed, or provided with artificial intelligence, enabling the UAS to adapt to conditions encountered during the mission. The operator monitors the mission to extract the data collected but not to influence its objectives during the operation.
- Automated operation after human initiation. A button is pushed to start the mission but no further action is taken during its accomplishment. The mission is fully robotic. When complete, the user receives the data, the payload, or the message that the mission is complete.

Using a net strung between a swarm of three quadrotors, researchers deployed algorithms that not only allow the bots to toss a ball both to themselves and to another team of hovering quadrotors, but also allow them to learn in real-time. When their accuracy fails them, the quadrotors learn from their mistake and adjust their trajectory on the next try. So after a series of failed tosses, the robots eventually compensate to get it right; the machines are learning.
Image credit: Popular Science, "Swiss Quadrotor Robots Throw and Catch". October 2012.

- Swarm control. In this sub-category, cooperative mission accomplishment is controlled among the vehicles themselves through autonomous intercommunication. This may be through "master/slave" relationships or through pre-programmed "roles" of each UAS in the mission, or a number of other cooperative paradigms. The primary difference in this category is the simultaneous cooperative behavior of multiple vehicles in accomplishing the mission.

An important area of research for future UAS operations is the area of autonomous capability to "Detect, Sense, and Avoid" (DSA). In the NAS, the community has also coined the term "Sense and Avoid" (SAA) and now "Detect and Avoid" to describe such technical capability that could be developed to mitigate the lack of a "See and Avoid" capability. DSA consists of two major components:

- Self-separation, and
- Collision avoidance

Two solutions are being studied: (1) a sensor located on the ground that can sense airborne targets surrounding the UAS GBSAA; and (2) an airborne sensor(s) located on the UAS (Airborne-Based Sense-and-Avoid - ABSAA). Clearly, both schemes require C^3 assets but with GBSAA demanding more communications bandwidth than ABSAA. GBSAA is anticipated to be more of a mid-term solution whereas the ABSAA will be a longer-term solution. This is because ABSAA will require sophisticated DSA algorithms with significant on-board processing and memory storage capabilities.

Progress has been made in DSA technology development and the future will undoubtedly bring more advances in automated algorithms. However, the metrics for testing have not been established and are not yet available to certify a DSA System. A key question is: What level of efficiency is sufficient to satisfy the "comparable to manned aircraft" level of safety requirement for collision avoidance for UAS? Clearly, regulatory issues have a large impact in this research area, especially the FAA's willingness to accept electronic means with equivalency of human sensing.

[47]New Scientist reported on a system being developed to help unmanned aerial vehicles "harness upward-moving thermal air currents to keep them aloft for hours" by using software that identifies regions of rising air. The program first analyses video of the sky taken by an on-board camera in order to seek out nearby thermal currents. This information is combined with real-time weather forecasts and computer simulations of air flow across the local terrain to predict the locations of further thermal currents. The system also uses software information from anecdotal reports by expert gliders, highlighting areas of rising air in specific locations and in various weather conditions. New Scientist explains, "the software uses all of this data, together with the aircraft's GPS coordinates, to plan a route that passes through as many thermals as possible."

Puzzlebox Orbit brain-controlled helicopter

Image Credit: Gizmag

[48]The innovation for UAS control is cutting edge and quite imaginative. For the last few years, Puzzlebox has been publishing open source software and hacking

[47] "Robot Aircraft Will Ride Thermals to Save Fuel". *New Scientist*, August 2008. http://www.newscientist.com/article/mg19926705.500-robot-aircraft-will-ride-thermals-to-save-fuel.html

guides that walk makers through the modification of RC helicopters so that they can be flown and controlled using just the power of the mind. Full systems have also been custom built to introduce youngsters to brain-computer interfaces and neuroscience. The group is about to take the project to the next stage by making a Puzzlebox Orbit brain-controlled helicopter available to the public, while encouraging user experimentation by making all the code, schematics, 3D models, build guides and other documentation freely available under an open-source license.

3.4 Sensors

Many of the most promising application areas for UAS relate to the gathering of information that can be remotely sensed. This ranges from visual range cameras gathering data for surveillance of various kinds to meteorological instruments, to geologic surveying and crop analysis among a wide variety of other existing and potential applications. In this section we discuss the current state of sensors as they apply to UAS applications, the trends that will impact the widespread growth of sensor equipped UAS and the data that they will be able to gather. We will also discuss the communication, processing, and exploitation of this data today and factors that will either hinder or assist in the future growth of UAS sensor-based services.

3.4.1 Sensors Today

[49]The UAS market is able to draw on a well-developed set of sensors that for the most part are already in use in manned airborne platforms, in satellites, and even in radiosonde balloons. UAS remote sensing functions include electromagnetic spectrum sensors, gamma ray sensors, biological sensors, and chemical sensors. A UAS's electromagnetic sensors typically include visual spectrum, infrared, or near-infrared cameras as well as radar systems. Other electromagnetic wave detectors such as microwave and ultraviolet spectrum sensors may also be used, but are uncommon. Biological sensors are sensors capable of detecting the airborne presence of various microorganisms and other biological factors. Chemical sensors use laser spectroscopy to analyze the concentrations of each element in the air.

3.4.1.1 Visual Range Detectors (Cameras)

Remotely operated cameras have proliferated to an amazing degree in the last thirty years with the advent of wireless technology and microprocessors. In UAS applications these cameras are made useful and highly adaptable by the addition of gimbals for pointing and stabilization software for removing distortions caused by aircraft vibration and atmospheric buffeting. Companies such as UAV Vision Pty Ltd[50] offer a wide variety of complementary hardware (visual and infrared range cameras and UAS-capable gimbals) and software components to enable UAS use of remote visual sensing technology.

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[48] Paul Ridden. “Puzzlebox Orbit Brain-controlled Helicopter is Flying into Production”. *Gizmag*, November 2012. http://www.gizmag.com/puzzlebox-orbit-brain-controlled-helicopter/25138/

[49] “Unmanned Aerial Vehicle Remote Sensing”. http://en.wikipedia.org/wiki/Unmanned_aerial_vehicle#Remote_sensing

[50] http://www.uavvision.com/

[51]In 2001, Hi Cam released Micro 100, the world's first 4.8V CCD-based high-power micro video system designed specifically for aerial applications. This has now evolved into the new MV500. Commercial systems include 5.8GHz versions, enabling amazing picture quality and avoiding interference with 2.4GHz remotes. These systems have been operating in 30 countries, operating on blimps, helicopters, planes, rockets, gliders, balloons, kites, live birds, and research UAVs around the world.

[52]Goodrich has also demonstrated shortwave infrared (SWIR) Sensors for UASs as a miniaturized version of the SYERS II camera carried by USAF Lockheed U-2s for the past two decades and declassified roughly nine years ago. SWIR is adjacent to the visual spectrum, which means that individuals can be observed in reflected light rather than using thermal imaging and allows the camera to see people more realistically, but in low light conditions from a stealthy location.

[53]Companies such as Hood Technology, manufacture advanced stabilized imaging systems like the Alticam 11 EO/IR1 payload for small tactical UASs. The 4-axis stabilized payload for long-range imaging is also suitable for use in manned and unmanned land vehicles, ground vehicles, aerostats, unstable fixed mounts, and marine systems. The proprietary imaging system includes customized zoom EO for visible wavelengths and continuous-zoom for midwave infrared (MWIR) thermal imaging. Laser channels include NVG (Night Vision Goggles) compatible, 830 nm laser pointer, and eye-safe laser rangefinder. An additional laser designator channel is currently in development. The Alticam 11EO/IR1 payload is 10 inches (25.4 cm) in diameter and weighs less than 12.5 lbs (5.5 kg).

3.4.1.2 Infrared Detectors

A thermographic camera[54] or infrared camera is a device that forms an image using infrared radiation, similar to a common camera that forms an image using visible light. Instead of the 450–750 nanometer range of the visible light camera, infrared cameras operate in wavelengths as long as 14,000 nm (14 µm). This technology is now being used, often in conjunction with visual range cameras, in both manned and unmanned aircraft for a wide variety of applications. Typical of the recent UAS products being offered is the one below from Sierra Pacific Innovation Corporation (SPI).[55]

[56]The M1-D Thermal PTZ is a low-cost and lightweight EO/IR sensor package. It can be mounted on both fixed-wing and rotary craft UAS devices. The traditionally high costs of these devices and complex FAA licensing procedures have prevented use of these systems by other than the military.

Public safety agencies can expand their area of coverage and increase their effectiveness by mounting the M1-D Thermal PTZ on UAS vehicles weighing up to 25 pounds. The SPI system weighs 2 pounds and contains a daylight TV camera, a laser pointer, and a thermal sensor in a pan-and-tilt body. When

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[51] Hi Cam Aerial Video Systems. http://www.hicam.com/

[52] Andrew Doyle. "AUVSI: Goodrich Demonstrates Miniature SWIR Camera". *Flight Daily News*, August 2009. http://www.flightglobal.com/news/articles/auvsi-goodrich-demonstrates-miniature-swir-camera-330785/

[53] "Alticam 11 EO/IR1 Imaging System for UAVs". *imveurope*, July 2012. http://www.imveurope.com/products/product_details.php?product_id=1905

[54] "Thermographic Camera". http://en.wikipedia.org/w/index.php?title=Thermographic_camera&oldid=519367465

[55] SPI Infrared. http://www.x20.org/m1-d-micro-thermal-ptz-camera.

[56] Kalwinder Kaur. "SPI Introduces FAA-Compliant Lightweight Thermal PTZ Solution for UAVs." *Azo Robotics*, June 2012. http://www.azorobotics.com/News.aspx?newsID=2909

compared to previous thermal PTZ systems, the new M1-D Thermal PTZ is significantly less expensive, enabling wider usage.

3.4.1.3 Multispectral Sensor and Hyperspectral Sensors

[57]Recent advances in remote sensing and geographic information have led the way for the development of hyperspectral sensors. Hyperspectral remote sensing, also known as imaging spectroscopy, is a relatively new technology that is being investigated by researchers and scientists in the detection and identification of minerals, terrestrial vegetation, and man-made materials and backgrounds.

Physicists and chemists have used imaging spectroscopy in the laboratory for over 100 years for identification of materials and their composition. Spectroscopy can be used to detect individual absorption features due to specific chemical bonds in a solid, liquid, or gas. Recently, with advancing technology, imaging spectroscopy has begun to focus on the Earth. The concept of hyperspectral remote sensing began in the mid-1980s and to this point has been used most widely by geologists for the mapping of minerals.

[58]Hyperspectral imaging technology can distinguish between wavelengths outside of the visible spectrum. It has been used in agriculture and forest management to remotely identify the presence of harmful pests and to remotely measure the condition of water and crops. The camera's functionality is based on the wavelengths that emanate from certain natural substances that are not visible to the human eye. Each substance produces a different wave, and the camera is able to distinguish between the various waves. As a result, the camera could differentiate between a natural bush and a bush that produces irregular waves.

3.4.1.4 Radar

[59]Many of the most promising applications of radar-based sensing to UAS utilize Synthetic Aperture Radar (SAR). SAR is a form of radar which uses relative motion between an antenna and a target region to provide distinctive long-term coherent-signal variations, which are exploited to obtain finer spatial resolution than is possible with conventional beam-scanning means. SAR originated as an advanced form of side-looking airborne radar (SLAR).

SAR is usually implemented by mounting, on a moving platform such as an aircraft or spacecraft, a single beam-forming antenna from which a target scene is repeatedly illuminated with pulses of radio waves at wavelengths anywhere from a meter down to millimeters. The many echo waveforms received successively at the different antenna positions are coherently detected and stored and then post-processed together to resolve elements in an image of the target region.

[57] “Hyperspectral Remote Sensing”. University of Texas Center for Space Research. http://www.csr.utexas.edu/projects/rs/hrs/hyper.html
[58] “Israel Air Force Testing Hyper-Spectral Camera Technology”. *UAS Vision*, June 2012. http://www.uasvision.com/2012/06/15/israel-air-force-testing-hyper-spectral-camera-technology/
[59] "Synthetic aperture radar". http://en.wikipedia.org/w/index.php?title=Synthetic_aperture_radar&oldid=516730386

[60]The developer of synthetic aperture radar that is orders of magnitude smaller than other radars was awarded a $24 million contract from the U.S. Army Contracting Command in Natick, MA, to build a "lightweight, ultra-wideband" SAR for UASs for completion in 2017.

The system will be an "adaptation" of technology used in the company's current NanoSAR B and Leonardo low-power, high-resolution radar systems. The X-band NanoSAR B radar assembly, including gimbal, GPS, and inertial measurement unit, weighs just 3.5 pounds and operates at 30 watts of power. It has a standoff range of one to four kilometers (0.6 to 2.5 miles). Leonardo is Ku-band radar that weighs only slightly more, with an operational height of up to 6,000 feet above ground level. The X-band NanoSAR B Radar assembly has flown on the RQ-7 Shadow UAS. The company lists resolutions for both radars down to 0.3 meters (one foot).

The shoebox-size NanoSAR radar has been demonstrated on the Insitu "ScanEagle," Northrop Grumman Bat, Arcturus T-16, and other manned and unmanned platforms, according to ImSAR.

[61]Selex Galileo has test flown a Falco unmanned air vehicle in the UK with its PicoSAR miniature synthetic aperture radar payload. The Falco tactical air vehicle was equipped with the active electronically scanned array PicoSAR and an electro-optical/infrared sensor for the recent trials activity. The high-resolution SAR, coupled with change detection, makes the radar particularly useful for counter-IED missions, detecting disturbances in ground surface.

3.4.1.5 LIDAR

[62]LIDAR (Light Detection and Ranging, also LADAR) is an optical remote sensing technology that can measure the distance to, or other properties of, a target by illuminating the target with light, often using pulses from a laser. LIDAR technology has application in geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing and atmospheric physics, as well as in airborne laser swath mapping (ALSM), laser altimetry, and LIDAR contour mapping.

LIDAR uses ultraviolet, visible, or near infrared light to image objects and can be used with a wide range of targets, including non-metallic objects, rocks, rain, chemical compounds, aerosols, clouds, and even single molecules. A narrow laser beam can be used to map physical features with very high resolution.

LIDAR has been used extensively for atmospheric research and meteorology. Downward-looking LIDAR instruments fitted to aircraft and satellites are used for surveying and mapping.

Many demonstration projects and experiments are currently underway to develop UAS-based applications of LIDAR. See for example Wallace, Lucieer, Watson, and Turner's recent paper[63] on Airborne LIDAR

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[60] Bill Carey. "Developer of Miniature SAR Awarded U.S. Army Contract". *AIN Online*, June 2012. http://www.ainonline.com/aviation-news/ain-defense-perspective/2012-06-08/developer-miniature-sar-awarded-us-army-contract
[61] Craig Hoyle. "DSEi: Falco UAV Makes First Flight with PicoSAR Radar". *Flight International*, September 2009. http://www.flightglobal.com/news/articles/dsei-falco-uav-makes-first-flight-with-picosar-radar-331961/
[62] "LIDAR". https://en.wikipedia.org/wiki/LIDAR
[63] Arko Lucieer, Christopher Watson and Darren Turner. "Development of a UAV-LiDAR System with Application to Forest Inventory Luke Wallace" . School of Geography and Environmental Studies, University of Tasmania, May 2012. http://www.mdpi.com/2072-4292/4/6/1519.

remote sensing in the management of modern forest inventories. Recently, improvements in small-scale technology have enabled the use of UASs as an alternative remote-sensing platform offering a distinctive combination of very high-resolution data captures at a significantly lower survey cost. Current research into the use of UASs as a 3D data-capture platform includes archaeological surveys and vegetation monitoring.

Because of their high spatial and temporal resolution, together with low operational costs, UASs can provide a more targeted approach to forest monitoring and allow for the use of multi-temporal surveys such as forest health and canopy closure monitoring.

Until recently LIDAR use with UAS was restricted to UAS platforms that were too large and costly for many non-defense operational uses. Today Micro-Electromechanical System (MEMS) based Inertial Measurement Units (IMUs) offer an alternative option for positioning and orientation that is both lightweight and low-cost. These IMUs have been deployed for a variety of positioning and orientation tasks, including navigation, obstacle avoidance and land-based mapping[64.] This technology can be used as the primary orientation sensor within a GPS/IMU sensor framework to provide the high-rate estimates of position and orientation required for LIDAR mapping.

3.4.1.6 Acoustic Sensor

[65]One of the most common types of acoustic sensors is the acoustic wave sensor, which is an electronic device that can measure sound levels. They are called acoustic wave sensors because their detection mechanism is a mechanical (or acoustic) wave. When an acoustic wave (input) travels through a certain material or along the surface of a material it is influenced by the different material properties and obstacles it travels through. Any changes to the characteristics of this travelling path affect the velocity and/or amplitude of the wave. These characteristics are translated into a digital signal (output) using transducers. These changes can be monitored by measuring the frequency or phase characteristics of the sensor, and can then be translated to the corresponding physical differences being measured.

Acoustic sensors have long been widely associated with many remote sensing applications especially submarine applications such as sonar. However, systems are now being offered that provide acoustic sensor applications for UAS. For example, Micro Flown Technologies Inc. developed micro-electro-mechanical systems that uses acoustic vector sensors to cover the entire audio range and is working to develop systems to source the acoustic locations. [66] By using four such sensors, Micro Flown says it can localize and track up to 30 sound sources. Each source can be tracked in bearing and elevation. KU's radar band adaptation of the technology for airborne use for Force Protection[67] now has in process an application for a patent on its system.

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[64] Dr. Klaus Peter Schwarz and Dr. Naser El-Sheimy. "Mobile Mapping Systems - State of the Art and Future Trends". Department of Geomatics Engineering, University of Calgary, 2004. www.isprs.org/proceedings/XXXV/congress/comm5/papers/652.pdf

[65] "Acoustic Sensor". http://www.wikid.eu/index.php/Acoustic_sensor

[66] Microflown Avisa. http://www.microflown-avisa.com/.

[67] Tamir Eshel. "New Gunshot Detection Capability Expands the Role of Mini-UAVs in Force Protection". *Defense Update*, October 2011. http://defense-update.com/20111031_new-gunshot-detection-capability-expands-the-role-of-mini-uavs-in-force-protection.html.

3.4.1.7 Magnetometers

[68]UAVs can be used to perform geophysical surveys, in particular geomagnetic surveys, where the processed measurements of the differential Earth's magnetic field strength are used to calculate the nature of the underlying magnetic rock structure. Knowledge of the underlying rock structure helps trained geophysicists to predict the location of mineral deposits. Oil and gas exploration and production activities entail the monitoring of the integrity of oil and gas pipelines and related installations. For aboveground pipelines, this monitoring activity could be performed using digital cameras mounted on one, or more, UAVs. InView Unmanned Aircraft System[69] is an example of a UAS developed for use in oil, gas, and mineral exploration and production activities.

3.4.1.8 Meteorological Sensors – Barometers, Anemometer

Strictly speaking, barometers and anemometers are not remote sensors in that the instrument directly senses the phenomenon that they are observing. However, the use of a UAS enables the sensor to be deployed to a location in the atmosphere remote from the user of the sensed data. The National Weather Service and others have used radiosondes and manned aircraft to reach regions of the atmosphere remote from the ground observer. The use of radiosondes, however, is inefficient and costly.

3.4.2 Sense and Avoid Sensors

Of all the safety issues concerning the operation of UAS in the NAS, none is more difficult to overcome than the ability to safely maintain separation from all other traffic in the airspace. This is a normal function of the air traffic control system for separating from other IFR traffic, but in the United States, most of the airspace below FL180 is designated as Class E, in which VFR flight is permitted and separation responsibility rests with the pilots of all aircraft. Pilots separating themselves often use electronic aids and ATC advisory services to assist in this task, but it ultimately relies on the concept of "see and avoid", a pilot responsibility formalized in Federal Aviation Regulation (FAR 91.113 (b)). A UAS, not having a pilot on board to perform this function, has to "sense and avoid" other aircraft in order to provide an equivalent or better level of safety.

Two approaches have been taken in addressing the "sense and avoid" function for UAS; ground based sensing and airborne sensing. Ground based sensing uses radar and other sensors located on the ground to exercise surveillance in the airspace in which the UAS will operate and provide advisories to the remote pilot or UAS autopilot to maintain separation from all other aircraft in the vicinity. Airborne sensing uses sensors on the UAS to detect other aircraft in the vicinity so that on board algorithms can provide guidance to safely avoid any conflicting aircraft. Both approaches are addressed in the following sections.

[68] "Unmanned Aerial Vehicle." http://en.wikipedia.org/wiki/Unmanned_aerial_vehicle
[69] "InView Unmanned Aircraft System". http://en.wikipedia.org/w/index.php?title=InView_Unmanned_Aircraft_System&oldid=508766893

3.3.2.1 Ground Based Sense and Avoid

[70]Most of the funding for this approach has come from the DoD through the Army as the lead responsible service. They have recently completed a demonstration to validate this capability at the Redstone Arsenal in Alabama. This GBSAA fused 3D radar and ATC Airport Surveillance Radar (ASR-9) in real time. The Lightweight Surveillance Target Acquisition Radar (LSTAR) V3 was also used. Both live and synthetic testing was performed. They flew a synthetic UAS against a live traffic feed in downtown Salt Lake City and a live UAS against recorded Boston airspace data. The seven live and synthetic vignettes exhibited the system's ability to fly in numerous National Airspace System environments including Airfield Traffic Patterns, Lateral Transits, Military Operations Areas (MOAs) in Class D, E and G airspace. For sensing cooperative targets, both secondary radar (transponder based) and ADS-B are used in the ground based sensing schemes. Non-cooperative targets require optical or primary radar based sensors for detection. The primary drawback to the GBSAA approach is that the surveillance must be present in the entire operating area of the UAS. While this works well in limited space operating theaters, it is impractical for many UAS missions covering greater distances.

3.3.2.2 Airborne Sense and Avoid

[71]Even though more development effort has gone into airborne sensing, practical solutions for a wide range of UAS using ABSAA have been more elusive. Again, the cooperative sensors TCAS and ADS-B are used to provide the most reliable and data rich surveillance when it is available. Sensing of non-cooperative targets is done using electro-optical (visual) sensing, primary radar, or a combination of the two. The funding for this research has been broader, but is centered at the Air Force’s Aeronautical Systems Center at Wright Patterson AFB in Dayton, OH. In July 2012, they released a Sources Sought notice in anticipation of an RFP for the ABSAA program. The Aeronautical Systems Center is looking for a sensor fusion product that is agnostic both to the sensors and the UAS platform. This product would go between the sensors and the UAS's flight controls and operator interface. It needs to take TCAS, ADS-B, radar, and electro-optical/infrared (EO/IR) inputs while allowing easy integration of other sensor types in the future. Northrop/Grumman has already begun live calibration testing of such a system including TCAS, ADS-B, an electro-optical sensor and a "purpose built radar".

The difficulty in ABSAA has always been that airborne radar for detecting aircraft has historically been very expensive, bulky, and requires a large amount of energy to operate. Cameras can be small, light and cheap but while they are good at measuring a bearing to a target, they provide no distance information without time consuming tracking and lots of image processing. Thus there is a desire to fuse the visual with the radar technology to achieve both accurate range and bearing on a target. Carnegie Mellon University is one institution working this problem; Britain's Robot Plane is another using this technology. AeroSpy of Austria is bringing its sense and avoid technology to a joint venture with California's Advanced Defense Technologies, Inc. (ADTI). ITT Exelis has created an ABSAA radar operating in the

[70] Sofia Bledsoe. “Army Conducts Successful Demonstrations of the Ground Based Sense and Avoid System.” June 2012. http://www.army.mil/article/82821/Army_Conducts_Successful_Demonstrations_of_the_Ground_Based_Sense_and_Avoid_System/

[71] Gary Mortimer. “Detect Sense and Avoid Sensor Fusion Program Starts.” *sUAS News*, July 2012. http://www.suasnews.com/2012/07/17655/detect-sense-and-avoid-sensor-fusion-program-starts/

Ku band for the Navy's Triton UAS, but it weighs 50 pounds and is very expensive. This makes it a candidate only for very large UAS. The ABSAA radar has a field of view of plus or minus 110 degrees lateral and plus or minus 30 degrees vertical. That meets ICAO guidelines but is still vulnerable to the rear. Several European consortia are also working the problem using similar sensors but are not closer to a practical solution.

A couple unique designs have surfaced going beyond the traditional radar and EO approach that most are intriguing. A Cyprus, California company called SARA has developed an array of lightweight acoustic probes coupled to a signal processor that filters out wind noise in order to listen for and locate other aircraft in the sky. Flight Safety Technologies, Inc. was developing a lightweight, low cost and power solid-state radar using a "sing around" technology borrowed from the sonar world, with upper and lower antenna arrays that provided complete coverage of the sky, not just the forward field of view. But it is safe to say that the eventual solution is not likely to fit all UAS and will probably include a fusing of several sensor technologies. And while the FAA Administrator has professed confidence that the technical challenges can be overcome by the congressionally-mandated 2015 date for integration of UAS in the NAS, we are not there yet with respect to UAS ABSAA.

3.4.3 Sensor Trends

As a result of pioneering efforts in micro-miniaturization, including continuing development of micro electro mechanical devices (MEMS) and integrated computer application chips (ASIC), sensors will not only continue to be reduced in size and weight but will be functionally integrated to fuse multiple data sources. These efforts will continue to reduce the size and weight of unmanned aircraft systems and support the development and deployment of Low Observability Vehicles (LOV).

Many of the same technological forces that have acted on and enabled the information age in general are affecting sensor technology. These include:

- Miniaturization, including advances in materials sciences
- Memory and data storage growth
- Computing power
- Economies of scale – cost reductions
- Standardization – the development and wide adoption of data format, data bus, and other standards will be a great facilitator in driving down cost and increasing availability of a wide variety of plug and play sensors. Recall the impact on the cost of local area networks when inexpensive Ethernet cards replaced high cost proprietary IBM, Digital Equipment Corp. and other companies' unique data network protocols and equipment.
- Down marketing – adaptation of space-based and combat-hardened instruments to less demanding, low altitude civilian environments
- Laser advancement

3.4.4 Constraints and Concerns for Future Growth

While the growth potential for the use of UAS sensors is enormous, there are many obstacles that must be overcome in order to realize this potential. Some of these, such as safety and UAS regulatory issues, are covered in Section 6 of this report. We address several others below.

3.4.4.1 Privacy and Data Rights

Privacy

On February 14, 2012, The president signed Public Law 112-95, FAA Modernization and Reform Act of 2012. This new law instructs the FAA to release a proposed rule that will establish policies, procedures, and standards for a wide spectrum of UAS users and applications. There is a growing public concern that these new surveillance technologies can significantly intrude on individuals rights to privacy. Although the word "privacy" is actually never used in the text of the Constitution, there are Constitutional limits to the government's intrusion into individuals' right to privacy. The Fourth Amendment guarantees “the right of the people to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures”.

[72]For example, on May 30th, 2012, Reuters reported that cattle farmers complained on that a federal agency is "spying" on their operations by flying airplanes over Midwest cattle feedlots to see if they are complying with clean water regulations. The livestock producers and some members of Congress want to know why the Environmental Protection Agency (EPA) is using airplanes to monitor whether feedlots are obeying the Clean Water Act.

"The federal government has literally resorted to spying on producers," said a natural resources and environmental affairs director for the Nebraska Cattlemen. The association advised two U.S. senators and three members of the U.S. House of Representatives from Nebraska in drafting a letter to the EPA administrator on the matter. The Nebraska Cattlemen Association says the aerial surveillance raises privacy concerns and they question the statutory authority for the flights.

On August 1st, 2012, the House of Representatives Transportation and Infrastructure Committee held a hearing to approve the Farmer Privacy Protection bill (H.R. 5961), which sparked a lively debate about “drone” privacy. The bill would essentially prevent the EPA from using any type of aircraft from enforcing Clean Water Act provisions.

This expanding debate concerning privacy has delayed the release of a request for proposals to industry for UAS test locations directed by Congress to be released in August. On November 1st, 2012 the FAA administrator sent a letter to congress stating, “Increasing the use of UAS in our airspace also raises privacy issues”. The administrator went on to state, “the FAA will complete its statutory obligations to integrate UAS into the NAS as quickly and efficiently as possible. However, we must fulfill those obligations in a thoughtful, prudent manner that ensures safety addresses privacy issues and promotes economic growth.”

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[72] Kevin Murphy. “Midwest Cattle Farmers Complain of Government ‘Spying’”. *Reuters*, May 2012. http://www.reuters.com/article/2012/05/31/us-usa-environment-spying-idUSBRE84U03120120531

We have learned that there are upsides of technology as well as negatives; unmanned air systems have similar challenges. Today, most mobile phones have a camera that records still photos and video with sound. As a network-connected device, camera phones are playing significant roles in crime prevention, journalism and business applications as well as individual uses. [73] From a negative perspective, they can also be used for activities such as voyeurism, invasion of privacy and copyright infringement. From a positive perspective, because they can be used to share media almost immediately and have proved they are a potent personal content creation tool.

On January 17, 2007, the Mayor of New York City announced a plan to encourage people to use their camera phones to capture crimes happening in progress or dangerous situations and sends them to emergency responders. Ironically, the Mayor's response referenced a case in which police confiscated a witness' camera phone. This case was upheld by a Seton Hall Law Professor whose team released this statement: "We are pleased that the Newark Police Department has adopted a policy that clearly articulates and respects the constitutional rights of citizens to record police activity".

Different from the introduction of camera phones where usage was perceived to simply take pictures for individual use, the UAS ISR capability is well known and understood because of its application in the war zone. Because of this, the general population may be very concerned what the introduction of these vehicles into the NAS will mean to their privacy.

[74]On 20 Sept. 2012, the think-tank Heritage Foundation released a UAS privacy report entitled, "Drones in U.S. Airspace: Principles for Governance." The report concludes, "In the absence of congressional action, the executive branch should reluctantly proceed independently with the development of its own privacy and civil liberties policies for the use of drones. What should not happen – what couldn't be allowed to happen – is that domestic drones continue to proliferate without any consideration of privacy and civil liberties". However they went on to state: "what also must not happen is that Americans allow an unreasoned fear of hypothetical abuse to stampede the country into a blanket prohibition on the use of drones for domestic purposes, depriving all Americans of a wide range of benefits."

The Association for Unmanned Vehicle Systems International (AUVSI) released its Privacy Rights Statement that supports the expanded use of unmanned systems, and believes unmanned systems can be used lawfully and responsibly without infringing upon Constitutional rights provided adequate guidelines are adopted and applied. AUVSI continues to encourage an open dialogue at the national, state, and local level with all parties, including law enforcement, citizens and advocacy groups, to address concerns about the use of unmanned systems.

Additionally, the FAA has been caught up in the national privacy debate concerning UAS. In the past it has not been the FAA's charter or mission to address or regulate privacy issues; however, this could easily change given Executive Order or Congressional mandate. To avoid these alternatives, FAA may

[73] "Camera Phone". http://en.wikipedia.org/wiki/Camera_phone

[74] Paul Rosenzweig, Steven P. Pucci, Charles Stimson, and James Jay Carafano. "Drones in U.S. Airspace: Principles for Governance". The Heritage Foundation, September 2012. http://www.heritage.org/research/reports/2012/09/drones-in-us-airspace-principles-for-governance

need to be proactive to define means and methods of supporting established privacy laws – local, state and federal within their jurisdiction.

One suggestion has been to establish a national recurrent (e.g., every two to three years) Internet registration for UAS owners, operators, and their vehicles. This was a precedent established by the Federal Communications Commission (FCC) for selected radios many years ago. With registration an owner and operator would receive immediate authorization to operate the registered UAS as long as it was operated in conjunction with FAA rules and in compliance with any and all state, local or federal ordinances, including provisions for privacy. This allows law enforcement organizations to petition the FAA for a withdrawal of an operator or owner's authorization for operation. If a vehicle were operated without valid authorization from the FAA the owner and operator could face civil penalties and fines.

This approach imparts two additional benefits: (1) it allows FAA to maintain a fairly current inventory of UAS operators, owner and vehicles; and (2) it addresses current aircraft registration challenges of knowing owners but not operators of aircraft.

Data Rights

Many organizations, including the FAA, are struggling with data rights issues. The related questions are who collects the data, who stewards the data, who owns the data, and who can use and distribute the data and under what circumstances. The development of server farms, data cloud concepts and integrated databases for terabytes of data can create complexities in applying and implementing policies and procedures. While these issues are challenging for virtually all organizations, it becomes even more difficult for public agencies that may have very little legal protection and a lot of confusion surrounding data rights of public organizations.

For example, publications of publically funded organizations have no copyrights, although distribution of publications may be limited for some reasons (e.g., national security), generally they are available to the general public at little or no cost. The Congress has even provided for availability of federal public agency information under the provisions of the Freedom of Information Act (FOIA). This is indeed a case of the technology far outstripping society's ability to have sound policies and rules that deal with the confusion and contradictions of the extensive amounts of electronic data and information now available. The use of UAS will further amplify these data right discussions. The ISR capabilities of UAS to collect data and transmit data place the UAS communities in the middle of this debate. Generally the increased ability to gather and send information has had negative implications for retaining privacy. As large-scale information systems become more common, the sheer volume information stored in many databases worldwide creates a situation in which an individual has no practical means of knowing of or controlling all of the information. The concept of information privacy has become more significant as more systems controlling more information appear.

Privacy law is at the forefront of the data rights issues. The existing national and global privacy rights framework has also been criticized as incoherent and inefficient. Proposals such as the Asian-Pacific Economic Cooperation Privacy Framework have emerged, which set out to provide the first comprehensive legal framework on the issue of global data

[75]The Professional Surveyor Magazine stated, "Two issues – privacy and UAS – will have a more profound impact on the ability of some industries, such as aerial mapping firms that to operate in the U.S. market in the coming months than any technology change experienced in the past 20 years".

[76]In March 2012, the Federal Trade Commission (FTC) issued a final report, "Protecting Consumer Privacy in an Era of Rapid Change" providing recommended actions for business and policy makers to protect consumers' private information. The report seeks to regulate the collection, sharing, or use of "precise geo-location data" about a citizen, requiring the "affirmative express consent" or advance approval of each such citizen.

As government use of UAS transitions from military operations overseas to domestic uses by civil agencies, concerns for the privacy of U.S. citizens will continue to grow. Several legislative proposals have been introduced in Congress to restrict UAS surveillance by government agencies or contractors. One such bill (H.R. 972) states, "a person or entity acting under the authority of the United States shall not use a drone to gather evidence or other information pertaining to criminal conduct or conduct in violation of a regulation except to the extent authorized in a warrant" could affect crop monitoring, pollution, and other activities for which conventional aerial photography is now used.[77]

[78]In a possible precedent setting decision, its 1986 decision on manned aerial surveillance and enforcement, the Supreme Court in Dow Chemical Co versus United States (476 U.S. 227), the court found, "It may well be, as the Government concedes, that surveillance of private property by using highly sophisticated surveillance equipment not generally available to the public, such as satellite technology, might be constitutionally proscribed absent a warrant. But the photographs here are not so revealing of intimate details as to raise constitutional concerns. Although they undoubtedly give EPA more detailed information than naked-eye views, they remain limited to an outline of the facility's buildings and equipment. The mere fact that human vision is enhanced somewhat, at least to the degree here, does not give rise to constitutional problems".

Since that time, commercial remote sensing satellites and unmanned aerial surveillance platforms have entered the market and such imagery is "generally available to the public." Absent new legislation, the availability of imagery from a UAS and its use by a government agency or its private contractor (as was the case in Dow) may ultimately be settled in court.

Recommendations to address issues associated with data rights are beyond the scope of this report.

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[75] John Palatiello. "Aerial Perspective: Privacy & UAS". *Professional Surveyor Magazine*, Fall 2012. http://www.profsurv.com/magazine/article.aspx?i=71166
[76] "Protecting Consumer Privacy in an Era of Rapid Change: Recommendations for Business and Policymakers". Federal Trade Commission, March 2012. http://www.ftc.gov/os/2012/03/120326privacyreport.pdf
[77] "H.R. 972: Preserving Freedom from Unwarranted Surveillance Act of 2013". 113th Congress, 2013-2015. March 2013. http://www.govtrack.us/congress/bills/113/hr972/text
[78] "476 U.S. 227: Dow Chemical Company v. United States". May 1986. https://bulk.resource.org/courts.gov/c/US/476/476.US.227.84-1259.html

3.4.4.2 Export Restrictions

[79]According to an article published in the American Institute of Aeronautics and Astronautics (AIAA) November 2012 *Aerospace America*, technology restrictions on UAS exports to foreign countries are threatening U.S. manufacturers' worldwide leadership position in the UAS market. The coming years promise to be critical as major European countries, including Germany, France, and the Netherlands decide what to do about their requirements for MALE aircraft. Major prime contractors such as Boeing and Lockheed Martin have been increasing their shares of international sales for several years and see potential for increasing those sales further. However, leading UAS companies are concerned that U.S. International Traffic in Arms (ITAR) and other regulations, bureaucratic processes and international agreements, such as the Missile Technology Control Regime (MTCR), make it difficult to meet international demands at a time when the U.S. is leading the market and has an associated competitive advantage. Legislative challenges often develop according to Teal, such as a lawmaker delaying a sale of the Predator to Italy for two years.

According to the Teal Group, if export restrictions are not loosened, it will be difficult for the U.S. to take advantage of growing international market demand for military UAS projected at $3.4 billion by 2021. In fact in the last few years the U.S. export rates for UAS were only about 5% of its production.

A number of countries have begun to develop a wide range of unmanned aircraft vehicles and systems for home use as well as export. Israeli has been particularly successful with its leased Israel Aerospace Industries Heron and Aerostar and the Elbit Systems Hermes 450 as well as its low end targeting system MTCR compliant MALE Hermes 900. Other countries are rapidly coming onboard as UAS manufacturers including Russia (Sukhoi ZOND-2), Brazil (Harpias), China (Yi Long), Pakistan, Hungary (HM EI and CURRUS), South Africa (Hungwe), India, Columbia and Iran.

Any delay in U.S. UAS exports will erode the U.S. markets as foreign countries develop and deploy their own UAS. These foreign manufacturers, such as Israel, not only meet their own demand for UAS technologies, but also become competitors in the world's markets further eroding the U.S. market position internationally.

The most significant effect of a global heterogeneous UAS market is an erosion of a domestic manufacturing base that may not take suitable advantages of economies of scale as well as a loss of cost effective technology innovation and availability. The thought of the DoD seeking international markets for cost effective and technologically advanced UAS is not a comforting thought to many at the Pentagon.

3.5 Information Technologies

The deluge of data (video and other sensor data) from UAS will continue to increase through consumer demand. The U.S. National Geospatial Intelligence Agency (NGIA) projects that it could take an astounding 16,000 analysts to study the details of just the video footage from UASs and other airborne surveillance systems currently operational. Fortunately, there are many technologies available, or being developed, that can facilitate the efficient and timely process of data sorting and discovery for both the military and commercial users of UAVs in the future.

[79] "Export Hurdles Aid Foreign UAV Competitors". *Aerospace America: Industry Insights*, November 2012

3.5.1 Trends in Information Technology

Commercial information systems are increasing in complexity. There are greater volumes of data, users, processes, and transactions. There are greater interdependencies between components. The range of available storage, user interface, and computing devices is increasing at a rapid pace and has created a demand for high processing power along with high-capacity data storage solutions, both on the ground and on the UAS platforms.

The trends in information technology can be grouped in three categories:

- Computing power and memory growth
- Miniaturization
- Advanced algorithms for data discovery and management.

Use of these technologies in commercial market (i.e., due to growth of internet and smart phones) will also mean availability and lower cost for the UAS users. Although it is not accurate to forecast the specifics of information technology growth beyond a few years, the following sections will describe the trends and identify some promising technologies.

3.5.1.1 Computing Power

Where just a few years ago high computing power was only available at a high cost, it is widely available today thanks to "cloud computing." According to National Institute Of Standards (NIST), cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.[80]

The availability of cloud computing has given access to enormous computing power and data storage capabilities to the average consumer with significant reduction in total cost of ownership (TCO), with minimal initial capital expenditures, and low pay-as-you-use rates. Where supercomputing resources were available to only a few users in the past, today with "cluster computing" using cloud computing resources, one can achieve the same capability at affordable cost. These high processing capabilities will allow users the opportunity to exploit sophisticated data processing schemes to achieve efficient and timely data discovery and data management. This is opportune, since the trend in needs for both computing capability and data storage capability is geometric.

Clearly, the trend for use of cloud will ignite the growth in data processing for many commercial users of UASs and this in turn will cross over to military markets. Although currently there are some information security concerns with the use of public clouds, the provision of both physical and virtual private clouds, along with sophisticated data encryption technologies, is dampening those concerns.

[80] "Final Version of NIST Cloud Computing Definition Published". *NIST Tech Beat*, October 2011. http://www.nist.gov/itl/csd/cloud-102511.cfm

[81]Another fast developing area is the advent of quantum computing. As Moore's Law states, the number of transistors on a microprocessor continues to double every 18 months, the year 2020 or 2030 will find the circuits on a microprocessor measured on an atomic scale. Perhaps, the logical next step is to create quantum computers, which will harness the power of atoms and molecules to perform memory and processing tasks at a miniaturization level consistent with low power utilization, making them ideal for UAS platforms. The quantum key distribution systems are expected to allow for the utilization of completely random keys at a distance, thereby providing greater assurance for authorization through identification and authentication of UAS users. High processing power, miniaturization, with low power utilization makes this technology ideal for future UAS systems.

Researchers have already built basic quantum computers that can perform certain calculations, but a practical quantum computer is still years away.

3.5.1.2 Miniaturization

[82]Micro-miniaturization is resulting in smaller, more capable, and less costly electronic devices and UAV vehicles. The transistor has just celebrated its sixtieth anniversary and it has been about 50 years since it was first integrated into a silicon chip. The need for more and more computing power has pushed proportional amounts of transistors in the same silicon space. They demanded miniaturization, and in time they have become so small that shrinking them even more would be difficult. So far, however, Moore's Law has held.

Nanotechnology (nanotech) is a promising technology for miniaturization at atomic dimension capable of providing tremendous processing, data storage, and general miniaturization for UAS markets. Nanotech allows information exchange on the atomic scale that uses the wave nature of electrons instead of conventional wiring. The new phenomenon, called the "quantum mirage" effect, may enable data transfer within future nano-scale electronic circuits too small to use wires.[83]

As computer circuit features shrink toward atomic dimensions, which they have for decades in accordance with Moore's Law, the behavior of electrons change from being like particles described by classical physics to being like waves described by quantum mechanics. Quantum analogs for many traditional memory and processing functions will be available at extremely small sizes and low power utilization.

3.5.1.3 Advanced Algorithms for Data Discovery and Management

Information systems are rapidly increasing in complexity. This is evident by growth and capabilities offered by industry in data discovery and management. There are increasingly greater volumes of data, users, processes, and transactions with greater interdependencies between these components. Because the range of available storage, user interface, and computing devices is increasing, the need for advanced data processing and management systems is also increasing rapidly. Currently there are many advances fueled

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[81] Kevin Bonsor and Jonathan Strickland. "How Quantum Computers Work". http://www.howstuffworks.com/quantum-computer.htm

[82] Bogdan Botezatu. "Chips Are About to Reach Miniaturization Limits". Softpedia, December 2007. http://news.softpedia.com/news/Chips-Are-About-To-Reach-Miniaturization-Limits-74220.shtml

[83] Cheryl Ajluni. "Quantum Mirage Hints At Possible Atomic-Scale Communication

by Internet services growth. An example is Hadoop, with “map/reduce” algorithm, which distributes the application among many processors and databases Hadoop is “open source” software that enables distributed parallel processing of huge amounts of data across inexpensive, commodity servers. The value proposition of Hadoop is to “create solutions from big data.”

[84]The drivers behind all of this are the increasingly sophisticated demands of the user. Where workers were once content to engage in data environments for simple communications and number crunching, the norm these days is a highly collaborative, always-on experience in which the entire relationship between individual and work environment is defined by the level of access to IT resources.

[85]Current research is not focused on making more information available, but on conserving scarce human attention so that it can focus on the information that is most important and most relevant to the decisions that have to be made. To do this, the researchers are drawing upon artificial intelligence (AI) and using cognitive sciences to assess the information capabilities of human beings and how to best present the value-added data.

[86]For example, Northrop Grumman has introduced an unmanned air vehicle data management system to the European market to allow troops on the ground to "eliminate the tunnel-vision of the battlefield." The HART (heterogeneous airborne reconnaissance team) allows soldiers at small unit level without their own UAS to benefit from the plethora of assets overflying the battle space.

3.5.2 Summary

Although forecasting specific technologies in the next 20 years is not productive, it can be stated that an IT revolution (i.e., high processing power, large memory availability, along with advanced AI and cognitive-based data processing systems) will provide the technology enablers that UAS markets require for rapid market expansion into the commercial and military fields. Among the factors required to create an explosive UAS market worldwide are the regulatory enablers to allow efficient operation of UASs.

[84] Arthur Cole. “The Changing Face of Information Technology”. *IT Business Edge*, April 2012. http://www.itbusinessedge.com/cm/community/features/articles/blog/the-changing-face-of-information-technology/?cs=50198

[85] Herbert A. Simon. “The Future of Information Systems”. Annals of Operations Research, 1997, Vol. 71, Issue 0, pp 3-14. http://link.springer.com/content/pdf/10.1023/A%3A1018975616482#

[86] Dominic Perry. “DSEi: Northrop Launches HART UAV Data Management”. *Flight International*, September 2011. http://www.flightglobal.com/news/articles/dsei-northrop-launches-hart-uav-data-management-361968/

4. UAS Missions

In this section, the various UAS missions are described by their characteristics in a way that permits rapid identification of those traits required for mission accomplishment. UAS missions are so numerous in purpose and diverse in operational nature that it is best to describe their scope using a generalized and comprehensive classification scheme. The method set forth in this document first lists the descriptive dimensions of UAS missions at the highest level in the classification scheme. These dimensions are:

- User Class
- Mission Purpose
- Scale of Mission
- Control Paradigm
- Operational Characteristics

These high level categories are then broken into sub-headings to further describe the major components of each high level dimension. For example, the Dimension "User Class" is broken into:

- Military
- Public
- Commercial
- Private

At the third level, specific elements within each subheading are chosen to complete the description. For example, a UAS mission may be (1) military user, (2) payload delivery purpose, (3) small-scale, (4) real-time vehicle control, and (5) low-level straight trajectory to an unprepared operating area. Describing the mission further at the element level of detail, it could be an Air Force squadron delivering a single payload of supplies weighing between 25 and 50 pounds to a forward unit at an unprepared site, remotely piloted throughout the mission.

In this mission classification scheme, the first two high-level dimensions, User Class and Purpose, describe what is to be done and who is making it happen. This makes the classification method more valuable because while some missions are "looking for a UAS capable of performing them," other UAS, already highly developed, are looking for missions and users they can market to. This mission classification method may be used in either direction – for mission planners to describe the needed UAS capability or for UAS manufacturers to market a range of uses (missions) and users that could benefit from their existing UAS design having standardized characteristic definitions.

The classification breakdown is listed next, followed by expanded examples of each mission type in the following sections.

The highest-level dimensions of a mission have already been given above. The sub-headings for each dimension are:

4.1 Users

Military Users
This user class includes the Army, Navy, Air Force, Marines, Reserve and National Guard units, and the Coast Guard.

Public Users
This user class includes governments and government agencies at federal, state and local levels. For example, it includes the Departments of Homeland Security, Justice, Interior, Transportation, and FAA, the FBI, and others at the federal level. State police and militias are in this class, as are local law enforcement agencies. Environmental, public health, and other government services at all levels are in the class of public users.

Commercial Users
This user class includes all companies or business partnerships operating UAS or causing them to be operated in the course of their business. Non-profit corporations are also included in this class.

Private and Recreational Users
This class of users includes all individuals or groups of citizens operating UAS for recreation, competition, or any other private endeavor.

4.1.1 Purpose

Intelligence, Surveillance, and Reconnaissance
The ISR category is one of the largest purpose categories. It is first broken into the type of surveillance sensor, such as visual, infrared, radio frequency or other electromagnetic field measurements as described in Section 3. Then it is described by the field-of-view in the mission, such as large (bigger than a building) or small. Within these descriptors, large field-of-view missions may be sensed all at once (simultaneous) or sequentially. Small field-of-view missions are described as having a fixed or a moving objective, such as a person or vehicle. The update rate of the surveillance can range from a single snapshot to a high-speed motion picture and everything in between. The final descriptor is the latency of the data as the operator receives them. Does the mission require that the data be used in real time, can it be delayed a few minutes or hours, or can it be mailed after completion of the mission? The military use of UAS for ISR purposes has provided a myriad of well-publicized examples of this use of UAS. In civil use, pipeline patrol, wildlife survey, atmospheric aerosol sampling, border patrol, and pursuit of suspects are just a few examples of likely early civil ISR missions.

[87]Some vehicles can perform dual missions, such as the WineHawk. The WineHawk is a two-pound, autonomous drone that is centered on data collection. While there is a lot of great technology out there that analyzes and collects data, WineHawk carries a multi-spectral camera which can pick up imagery down to two millimeters per pixel. These are a lot higher resolution shots than can often be obtained via satellites or manned aviation.

[87] "WineHawk Rules the Sky with Precision". *AgWired: News from the World of Agribusiness*, November 2012. http://agwired.com/2012/11/08/winehawk-rules-the-sky-with-precision/

In addition, the system is largely autonomous. The WineHawk senses where to go and even comes back to its launch site and lands automatically before the batteries run out. Finally, the appearance of a hawk is intended to help scare away any birds that might eat crops, especially fruit crops.

WineHawk UAV
Image Credit: PrWeb

Payload Delivery
The Payload Delivery category, which includes cargo transport, also contains a number of classifying descriptors. First, a single point delivery may be to a fixed location, a moving location, or the mission may require it to "find and deliver." A military delivery of ordinance to a target that must be sought out is an example of the latter mode. A distributed delivery is a second classification of payload delivery. This may be to multiple fixed locations as via a cargo carrier, or it may be fixed area coverage of insecticide distributed over the landscape. "Find and deliver" also applies to the distributed class of payload deliveries.

Environmental
The Environmental mission purpose includes measuring, monitoring one or more parameters, or altering the environment in some fashion. Meteorological sensing, noise monitoring, climate monitoring, and the measurement of atmospheric aerosols are all examples of this mission purpose category.

Search and Rescue
Search and Rescue is a specialized mission that is now mainly search in support of a rescue mission. Eventually it will involve finding *and retrieving* persons or objects and returning them to a designated point. The mission itself implies values of the other elements of scale, control, and operational characteristics to be discussed below.

Training
The Training mission purpose cuts across all users, scales, and most control paradigms. Training hours may even exceed mission hours for some purposes that have very critical operational requirements. Training refers not just to the remote pilots of UAS but also to other "mission specialists" who will control aspects of the mission other than manipulating or directing the UAS vehicle itself. Things such as surveillance analysis, payload management, and data collection, storage, and forwarding during the mission all require training to proficiency. Maintenance training of the technicians who must keep all parts of the UAS up to specifications is also included in this category.

Pilot Augmentation
UAS technologies for controlling aircraft autonomously may be applied to manned aircraft in a manner to replace one of the pilots and still maintain the required safety in the event of incapacitation of the remaining pilot. This could significantly improve the safety of existing single pilot operations as well as provide large cost savings to current operations that now require two pilot crews. On air taxi aircraft with very limited seats, it would also offer additional revenue potential by adding a passenger seat in place of a crew seat. The augmented capability would permit the aircraft to safely fly itself to its destination or a

closer alternate in the event the remaining human pilot was unable to exercise those duties. The system could also raise a red flag to the human pilot if it detected some out-of-tolerance situation developing, such as descending below the applicable minimum safe altitude or flying in moderate to severe icing.

Communications Relay

The purpose of relay missions is to relay communications to or from a location that is otherwise incapable of communicating. The communication deficiency may be due to insufficient power or because of terrain or structures blocking the signal. This kind of mission might work cooperatively with the Search and Rescue mission in some circumstances.

Robotic

UAS may perform robotic control of remote agents. This could be to retrieve something that first has to be disconnected or to manipulate a remote object in some fashion to enable it to perform its function. This purpose could be called "find and fix." While this function is routinely used on spacecraft, lower-cost UAS could perform a myriad of terrestrial chores at remote, unmanned locations. While most of these may be on the surface and performed after landing at a site, some might be in the "airspace" such as changing the light bulbs on top of tall antennas.

Recreation

Many current RC Models built and flown by hobbyists are fully capable of carrying payloads that emulate UAS functions. These have become increasingly sophisticated over the years as all of the required technologies have matured and become smaller, lighter, and less expensive. Recreational flying and competition have contributed to advances in UAS technology for adaptation to other purposes, as well as for pure sport. Many of these models have found their way into research at universities and other research establishments. RC models, particularly helicopters, have become a large industry bringing the concept of UAS to millions of people, with the side benefit of reducing the potential societal resistance to increased UAS use in the NAS through familiarity.

Unique Specialized Mission

The Unique Specialized Mission category is a catchall for one-of-a-kind missions that do not fit well with the broader categories but are nonetheless important in their own right. Tethered high altitude windmills are one example and large or small airships for sky lift of various cargos, including placement of construction materials where conventional cranes are impractical, are some others. Just as the inventers of the Internet could not have foreseen all the uses to which it would be put, many of the missions that will use UAS in the future have not yet been conceived.

The final three High Level Dimensions of UAS missions relate more directly to the UAS needs and the operating characteristics necessary to achieve the mission capability. A potential user of UAS technology with a specific mission purpose would use these characteristics to further describe the mission and zero in on the particular UAS to fulfill the mission. Alternatively, a UAS manufacturer would use these categories to describe the system's capability to a potential customer with a stated mission fitting into the range of available UAS capability.

4.1.2 Mission Scale

Geographic Size

Geographic size describes the physical size of the area of operation or mission coverage. Example missions and corresponding operational ranges might include: inspecting a 300-mile section of transmission lines; scanning for fires in the entire western half of Montana; dousing a one-acre grass fire with retardant 50 miles from the operating base; or following a suspect in a two-city-block area and forwarding their position to law enforcement officers on the ground.

Temporal Extent

Temporal extent describes the timing aspects of the mission. Some missions may be "out and back" with no time spent at the destination other than to deliver the payload, collect the data, or make a marketing appearance. Other missions require a long loiter time waiting to detect an event or to monitor for a slow change in some observed variable. Some missions require the *simultaneous* sampling at many points in an extensive region of the atmosphere or over a broad area of the surface and therefore must be done with a swarm of dispersed aircraft in a temporally coordinated fashion. Defining this aspect of mission scale has the greatest impact on both the endurance requirements and the number of vehicles used in the application.

Payload Size

Payload size refers to the weight of anything carried by the UAS other than the lift and propulsion systems. More than anything else, this element will determine the physical size of the UAS. Whether the payload is something to be dropped off, picked up, or carried throughout the mission, such as sensing equipment, its weight is a key aspect of the mission description.

Mission Cost

The cost of the mission is that part of the cost/benefit equation that determines the economic viability of any UAS mission. Cost includes use of the vehicle(s), the supporting control and communications infrastructure, and the launch and recovery areas and systems. Sizing the cost of a mission is essential to determining its feasibility.

4.1.3 Mission Control

The method of control of the UAS mission is a highly discriminating element. Rather than the physical link providing command and control of the vehicle, this control refers to the degree of human involvement or automation in the real-time accomplishment of the mission. As mentioned in Section 3.3.3, control is broken into the following sub-categories:

- Remote human *pilot*. A pilot controls the position, attitude, and performance of the UAV throughout its flight in real-time for the purpose of accomplishing the mission. The pilot's sensory information and control inputs are similar to being in the aircraft itself, but are performed at a location remote from the aircraft and the operation. Piloting skills are required for this kind of control of the vehicle.
- Remote human *operator*. In this sub-category, the human is involved in causing the flight to begin and end, in determining and directing the navigation and the temporal and operational

aspects of the mission, but not manipulating the flight controls of the vehicle itself to maintain its attitude and stability. Those functions are “built in,” leaving higher order control of the mission to the human operator.

- Human controlled initiation and termination, autonomous mission execution. In this mode, the mission is entirely pre-programmed or provided with artificial intelligence enabling the UAS to adapt to variable conditions encountered during performance of the mission. The operator monitors the mission to extract the data collected but not to influence its objectives during the operation.
- Autonomous operation after human initiation. A human operator pushes a button to start the mission but takes no further action during its accomplishment. The mission is fully robotic. When complete, the user receives the data, the payload, or the message that the mission is complete.
- Swarm control. In this sub-category, cooperative mission accomplishment is controlled among the vehicles themselves through autonomous intercommunication. This may be through relationships, or through pre-programmed "roles" of each UAV in the mission, or a number of other cooperative paradigms. The primary difference in this category is the simultaneous cooperative behavior of multiple vehicles in accomplishing the mission.

4.1.4 Operational Characteristics

Multi-User Airport
The beginning and end of a UAS mission is a major determinant of its other operational characteristics. Many UASs resemble manned airplanes in size and performance and require similar takeoff and landing runway characteristics. Rather than incur the cost of separate airport facilities, some missions will seek to share existing runways on airports. Those missions that involve the transport of cargo or, eventually, people, will want to share the groundside infrastructure that already exists at current airports for handling and processing these payloads. Using shared airports also simplifies the often extensive and expensive approval processes required to gain access to new operating areas. Hanger and tie-down space and other aircraft support services, such as maintenance and fueling, already exist at most airports, both civil and military. For all these reasons dealing with the integration of manned and unmanned airport operations in many mission profiles will be worth the effort.

Private Use Short Takeoff and Landing (STOL) Facilities
For other missions, the overriding operational factor may be proximity to the mission’s operating area that doesn't happen to be near an existing airport. One class of such missions may require short, prepared takeoff and landing surfaces. With modest real estate requirements, a short field runway with supporting command and control facilities can be established to provide greater operational security without the complication of traffic integration at a joint use airport during launch and recovery operations. Such facilities can often be accommodated on the existing real estate of a potential UAS user with a corporate campus of sufficient size to support such operations.

Fling and Snatch
Some missions may use a vehicle that requires forward motion for generating lift, but may be catapulted into the air and snared during recovery without damaging the vehicle or its contents during a landing approach. This category of launch and recovery may be called "fling and snatch." Both fling and snatch

and true Vertical Takeoff and Landing (VTOL) missions greatly simplify the launch and recovery requirements of the mission, but are usually traded off against payload capability.

VTOL Unprepared Surface
Many other missions require the ability to take off and land vertically or to hover for the accomplishment of the mission itself. For these missions, the launch and recovery area may be nearly as small as the UAS itself, and not require a prepared launch and recovery area. This will be a requirement of most payload drop off and pick up missions. A version of this characteristic is called “perch and stare” requiring that the UAS be able to perch on a wire or a branch, like a bird.

Line of Sight
This operational characteristic requires that the vehicle be in sight of the operator throughout the mission. While simplifying control links and operational approvals, it severely limits the utility of most missions. Still, where it does not impose a limitation, it lowers the cost of the mission dramatically.

Autonomy
This operational characteristic describes how much command, control, and feedback is needed to accomplish the mission. The amount of telemetry required is often inversely proportional to the degree of autonomy of mission control described above. The more autonomous the UAS is in performing its mission, the lower the requirement for telemetry during the mission. In addition to reduced cost, this operational aspect also impacts the safety and security of the mission.

Autonomy as defined in this report means that a vehicle’s flight control system is automated and its flight profile is pre-programmed prior to departure or re-programmed from the ground while the autonomous UAS is airborne. In other words, an autonomous vehicle is not actively piloted (movement of the aircraft’s control surfaces or power).

Class A through Class E Airspace Operations
It is difficult for a UAS to know whether it is flying in visual meteorological conditions (VMC) or instrument meteorological conditions (IMC). Therefore, most missions will have to be presumed to be in IMC and operate under IFR when in controlled airspace. This operational characteristic places a tremendous burden on the UAS operator by having to participate in the ATC process, even when the launch and recovery of the mission is non-interfering. Still, current rules require UAS operations below Class A airspace to maintain VMC, further restricting the mission. One potential mitigating development is taking place at NASA called Autonomous Flight Rules (AFR). This capability, which is still being developed, would permit the autonomous operation of UAS (and manned aircraft for that matter) in mixed controlled airspace with safety and without the requirement for participating in the traditional ATC process. But since the missions will be in VMC most of the time, they will have to carry sense-and-avoid equipment to maintain safety with manned VFR flight on which the pilots are performing the same function. This is complicated by the fact that some aircraft are “non-cooperative” electronically, making visual or radar sensing of such targets a requirement.

Class G Airspace Operations
Mission operations carried out exclusively in Class G airspace face the smallest approval hurdles from the

standpoint of air traffic integration. It is legal even today to fly manned aircraft in IMC in Class G airspace without an ATC clearance. Practically speaking, there are very few manned operations now in Class G airspace between the surface and 700 or 1200 feet above the surface. Still, such UAS operations could pose a hazard to helicopter operations and some sense-and-avoid capability may eventually be required here as well.

Tethered Vehicles

Tethered vehicles may not, strictly speaking, be "aircraft" but another class of missions can use tethered air vehicles, attached to the surface by a wire or cable. Some may derive part or all of their lift from "kiting" in the wind, some may use lighter-than-air gases to create buoyancy, and others may have powered lifting devices installed to remain aloft and control maneuvering as required by the mission. This latter mission category may carry the fuel for the lifting energy aloft or be electrically powered through the tether itself. Some examples of missions where tethered vehicles offer a solution include:

- Power generation. Wind speeds at altitudes higher than surface windmills can reach are generally stronger, permitting greater mass efficiency of the wind turbines. In the extreme, jet stream winds of over 100 knots could provide a very high energy density, with the power delivered to the ground through the tether.
- Advertising/Marketing. When the message is up high, it attracts attention and is visible to greater numbers of people. Tethered vehicles may be "approvable" where low altitude flight is not.
- Water collection. It may prove feasible to coalesce the water droplets in clouds and drain them through a hollow tether to a drought-stricken farm or community on the surface. The collectors and tether may be held aloft through a combination of kiting and buoyancy with no direct expenditure of energy.
- Surveillance. Tethering can provide the lowest cost surveillance platforms for fixed areas such as beaches, parks, schoolyards, and parking lots. Control of the sensors can be provided securely through the tether itself, ensuring continued focus on the area of concern even from a moving (in the wind) platform.

Flying Wind Turbine UAS

Image Credit: National Geographic Daily News

With this simple classification, the mission can easily be placed with the proper UAS provider for fulfillment. Others have suggested standardized payload packages to place in a UAS for similar mission profiles. This scheme suggests a way of standardizing the classification of the missions themselves so that the best UAS for the mission can be quickly identified.

5. Economics

Business models are defined as a method of telling others what the business does and how it makes money at what it does. The model tells the story of the business and how the elements of that business work together to produce value that a customer would want. The model also describes how the business differentiates itself from other competition in the same product area. This story of business helps others understand the business, is useful in securing capital for business growth, and provides a way of categorizing a particular business relative to other businesses and its competitors.

In 2005, MIT researchers examined the business models of the 1,000 largest U.S. firms. In order to compare and contrast these 1,000 firms, each company was grouped into one of eight business models defined by the authors. They created a typology of how businesses differ based on two elements: (1) what the business does, and (2) how the business makes money doing these things. Their research created the MIT Business Model Archetypes (BMAs) that allowed the researchers to “bin” the various businesses so that they could then be compared.

What the MIT researchers found was that business models were a better predictor of operating income than existing business segment classifications. Selling use of assets to customers produced more profit and value than selling ownership of the asset. Business models that focused on non-physical assets were more profitable than those based on physical assets. In other words, the customer wants the product without the overhead of the physical assets needed to generate the product.

If business models are more predictive of revenue than other classical classifications of a business, then a business model can be used to test a range of approaches for generation of revenue for UAS applications. If a business is to receive financing to start up (the case with nearly all civil applications using UAS) then a good business model must consider customers, cost, revenue, and the value proposition for the product or service being delivered.

5.1 Unmanned Aircraft Systems (UAS) Business Model Development

Business models are used to describe a business, its market, expected expenses and revenues. Typically the model is used to test different approaches for conducting the business and for securing capital for development of the business.

5.1.1 Civil Businesses

With such a rapid growth in UAS for military applications, it is logical that many of the civil benefits will flow from military applications. However, over time, UAS will create its own unique civil applications.

For development of the civil business models, the following opportunities have been chosen:

- Direct Transfer of Military Application to Civil Use – Cargo delivery, where stocks are delivered to remote locations to support construction and where resupply is performed for offshore oil platforms.
- Modification of Military Application to Civil Use – Police operations, both in ISR and in supplement or replacement of civil flight operations by law enforcement.
- Modification of Civil Manned Application to Unmanned – Power line and pipeline inspections.
- Modification of Civil Terrestrial Activity to UAS – Agriculture crop monitoring for application of fertilizer, pesticides, and watering.
- UAS Unique Civil Applications – (1) Augmented flight assistance, leveraging optionally piloted aircraft technologies to improve safety and reduce the need for redundant pilot staffing, and (2) media communications relays at high altitude.

5.1.2 The Business Model Canvas©

[88]The Business Model Canvas documents nine attributes of a business:

- Key Partners – Who do we need involved in our business to be successful?
- Key Activities – What activities do we need to realize the Value Proposition?
- Key Resources – What resources does our Value Proposition require?
- Value Proposition – What value are we delivering to our customer?
- Customer Relationships – What types of relationships are needed to deliver the Value Proposition?
- Customer Segments – Who are we creating value for?
- Channels – Through what channels does our customer want to be reached?
- Cost Structure – What are the most important costs inherent in our business model?
- Revenue Streams – For what value are our customers really willing to pay?

These nine attributes have been used in this report to define a limited set of business models for civil use of UAS as a way of demonstrating the utility of business modeling. Each of these attributes is illustrative of a particular application or grouping of applications for use of UAS. For example, for police operations there may be modified military surveillance; highway patrolling that replaces manned operations, and new, unique communications applications linking tactical units with secure communications.

K-Max Helicopter
Image Credit: Armed Forces International, February 2010.

[88] "Business Model Canvas". http://en.wikipedia.org/

In introducing the concepts of the business model, multiple current and near-future applications have been chosen. Each concept is defined briefly, followed by the Business Model Canvas for that application. The models developed include: (1) delivery of cargo in remote areas, (2) police operations, (3) power line and pipeline inspection, (4) agricultural use for management of crops and livestock, (5) augmented flight assistance for manned flight, and (6) communications media relay.

5.1.3 Cargo Delivery

Cargo delivery is the delivery of materials to the customer where efficiencies can be gained in terms of access, productivity, timeliness, and service quality. For this business model, the Kaman K-MAX single pilot helicopter is used. This helicopter has been used since 1991 for lifting and placing up to 6,000 pounds of payload. The K-MAX has been modified to operate as a UAS for the U.S. Marine Corps.

The remote controlled version, known as the K-MAX Unmanned Multi-Mission Helicopter, is used operationally in Afghanistan to resupply outposts. The K-MAX Unmanned version requires a pilot to startup and shutdown the helicopter that can operate remotely for pickup and delivery of slinged cargo pallets. Operating under contract to Lockheed Martin as of July 2012, the K-MAX had flown 485 missions, with 525 hours of flight time, and delivered more than 1.6 million pounds of cargo since arriving in Afghanistan.[89] Table 1 shows the business model for civilian applications. It should be noted that the manned K-MAX is used commercially for a wide variety of lifting operations today, mainly in the logging industry and for remote construction.

5.1.4 Police Operations

The U.S. Department of Justice's Bureau of Justice Statistics conducted a law enforcement census of aviation use.[90] One in five large law enforcement agencies[91] had an aviation unit. Collectively they employed 3,400 officers and operated 900 aircraft in 46 states and the District of Columbia. Units operated more than twice the number of helicopters (604) than planes (295). $300 million was spent on aircraft purchases, leasing and financing, maintenance, and fuel. The median cost for operations per aviation unit was $347,300, maintenance $167,200 and fuel $80,600. Each of 201 aviation units responding logged a median of 1,100 hours of flight time, with state police units logging an average of 2,000 hours.

The most common missions were vehicle pursuits, counter narcotics missions, and counterterrorism. Nearly 70 percent of the units also used their aircraft in association with firefighting. In conducting these missions, the most common tool on the aircraft is a searchlight (90 percent of units) and forward-looking infrared (FLIR) systems (80 percent) to increase night observation and for search and rescue. Half of the aviation units had night vision capabilities.

While some of these manned missions do not lend themselves well for UAS, the proven record for use of UAS for surveillance has created a market opportunity. The downsizing of the flight platform from a

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89 "Unmanned Helos: The USMC's Unmanned Cargo Helicopters". *Defense Industry Daily*, October 2012. http://www.defenseindustrydaily.com/usmc-looks-for-an-unmanned-cargo-helicopter-06672/

90 "Aviation Units in Large Law Enforcement Agencies, 2007". U.S. Department of Justice, Office of Justice Programs, Bureau of Justice Statistics, July 2009, NCJ226672. http://bjs.gov/index.cfm?ty=pbdetail&iid=1709

91 Large law enforcement agencies are defined as having 100 or more sworn officers.

helicopter to a hand-held UAS has significantly shifted the cost structure. Table 2 presents the business model for using UAS for police operations in surveillance, using small, patrol officer operated surveillance applications. Table 3 presents a broader application for traffic, emergency response and special events.

5.1.5 Power Line and Pipeline Inspection

Routine power line and pipeline patrols are a cost effective way to visually inspect structures, conductors, and changes in vegetation, and to identify both natural and man-made encroachments along the right of way. The benefit of these inspections is sustaining the reliability of the system. Most inspections for power lines are based on visual inspection using a pilot and an observer. For power lines, helicopters are preferred because of their slow forward speed and maneuverability close to the ground and the structures. Speeds of 20 to 70 knots are typically used.

For pipelines, visual inspection of natural gas, oil, and fuel pipelines identify leakage as well as encroachment. A typical operation is flight offset from the right-of-way between 100 and 500 feet above the ground and at speeds of 60 knots or higher. A typical inspection involves a pilot and observer. Sensors are beginning to supplement visual observation to detect unobserved leakages and may require a sensor equipment operator.

Flight operations are evolving from routine to detailed patrols, where the aircraft will fly to a location carry additional sensors that go beyond visual inspection and which require slower flight and hovering. Detailed power line patrols require extensive hovering time at the site. These detailed patrols are looking for damaged insulators, structural issues with towers, arcing, and cable conditions.

The business model for inspection is provided in Table 4. Construction and repair using aircraft assets are not covered in this business case.

5.1.6 Agriculture

When one considers aviation in agriculture, one might imagine crop dusting or herding livestock on the open plains. But with the introduction of Small UAS, the technical opportunities are expanding, thanks to GPS, GIS, and remote sensors, especially video and IR. A UAS fitted with visual and IR sensors can fly over farm fields and locate pests, weeds, and diseases, significantly improving the application of pesticides at reduced loading to the crops and soil. The use of IR can differentiate between the green of the crop and the green of the weed.

Since the overhead image of the field can be tied to the GIS, the sensors can determine the size of individual plants, the crop stage of maturity, measure grain head densities, and estimate yields. Beyond the individual farmer, the UAS can be used to do crop analyses for diseases and plant development. The impact of drought can be readily assessed for large areas.

Livestock producers can cover large areas with UAS surveillance, tracking and herding cattle, assessing pasture land for grazing, looking for broken fencing and open gates, located stray livestock with grid searches, and using the technology to spot, track and neutralize predators to reduce livestock losses.

Recent research uses of Small UAS have included air quality sampling over sprayed fields, sampling of air for microbes to detect and map diseased areas, and flights to measure fertilizer needs and dispersal patterns. A sample business model for agricultural use of UAS is provided in Table 5.

5.1.7 Augmented Flight Assistance

The business opportunities in this category range from transfer of technology from UAS experience to the cockpit to provide the pilot with a pilot's assistant, to Optionally Piloted Aircraft (OPA) where the aircraft is capable of human piloted and autonomous flight. Using an automatic flight control system, UAS technology can be integrated into existing manned aircraft. Servos manage the throttle, control flight surfaces, raise and lower gear, apply braking, and tie all of these functions into a navigation system and autopilot. The transformation will likely start as a modification to general aviation aircraft, converting them to ISR aircraft to gain improved payload and leverage manned ferry flight capabilities.

The addition of a UAS operating package capable of autonomous landing will create a significant safety capability change, not unlike adding a parachute to the Sirius Aircraft line. With a UAS safety package, the pilot and passengers can enjoy the confidence of assistance in the case where the pilot is incapacitated. Likewise, if the pilot can shift from manned operations to UAS, the workload can be significantly reduced and the pilot becomes the safety observer. An OPA is certified to fly today.[92]

This business model in Table 6 starts with the concept of technology transfer for a pilot assistant to general aviation, where the safety benefits of auto-landing and navigation are provided as low-cost flight management and flight control functions. As experience and confidence grow, more functions can be added to ultimately transition to an OPA general aviation aircraft operation.

Taken one step further, two-person flight crews could be reduced to single pilot operations, significantly altering the economics of commercial flight operations. In this concept, the automatic flight control system augmentation provides the necessary redundancy and can assume greater workload than the second manned pilot. As many commercial cockpits are configured as a two-person crew, modifications would be needed for full access of all controls, switches, etc. by the single crewmember.

For cargo flight operations, the transition will likely be from OPA capabilities leading to replacement of the first officer on commercial cargo aircraft. This transition will be driven by reduction in flight crew cost.

5.1.8 Communications Media Relay

Communications Media Relay is dependent on the transmission to an airborne UAS that then rebroadcasts the information to a broader customer base on the ground. This may take the form of a temporary trunk network repeater for area communications supporting first responders to routine cellular phone communications. In essence, a UAS stays on station and provides the ability to connect users with a ground station for distribution of information to a larger customer base.

[92] Aurora Flight Sciences Centaur OPA.

In the sample business model the concept of a high-altitude long-endurance UAS is used to provide telecommunications for a wide choice of media, from telephone to television, for distribution of video to educational services. Only the number of transponders carried aloft limits options for communications.

The business case is built around a lower cost option than today's use of satellites.

[93]A typical geosynchronous telecommunications satellite has the following cost profile:

- Manufacture - $150 million
- Launch - $120 million (typically $10,000 to $25,000 per kilogram of weight)
- Launch Insurance - $20 million
- Orbit Insurance - $20 million
- Operations - $1 million per year

A lighter-than-air non-rigid airship that has a skin capable of photovoltaic electric generation with battery for night operations is launched and climbs into the stratosphere above the Jet Stream. Operating at altitudes between Flight Level (FL) 500 and FL 650, the UAS airship can remain aloft for months at a time and five airships can cover the United States, coast-to-coast. Costs are a fraction of that required to achieve similar satellite coverage. In this airspace, the winds are light, making it possible to station keep without significant need for propulsion. The communications package is downscaled in cost and the weight penalty is not as great for a stratospheric UAS station and is better than on-orbit, low-earth orbiting, or geostationary satellites. Launch costs are a fraction of that of a satellite launch on a rocket.

The non-rigid airship may integrate the communications capabilities into the airship design or carry a separate package that hangs under a balloon. For example, the U.S. Naval Air War Center has recently awarded a contract to a Colorado firm[94] to investigate the application of balloons to lift sensor packages.

Once on station, the package operates much the same as a satellite and the commercial market provides a revenue stream not unlike satellite communications, but at a fraction of the cost. The "satellite equivalent" packages are carried aloft, returned to Earth after replacement by a new on-station payload, repaired, and re-launched. Unlike satellites, the transponders can be swapped out on a shorter cycle, tailoring the transponders to the market. High altitude platforms can support Internet access, operating similar to WiMAX[95] to deliver broadband connectivity with a relatively small ground antenna.

5.1.9 Specific Business Model Canvasses

In developing the business models, the companies are fictitious; however, the partnerships contain a mix of real companies, associations, and fictitious partners for illustration purposes only.

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[93] "SF Wireless ISP MonkeyBrains Tries to Crowdfund $325 Million for a Satellite". *TechDirt*, December 2012. http://www.techdirt.com/blog/wireless/articles/20121228/01025121504/sf-wireless-isp-monkeybrains-tries-to-crowdfund-325-million-satellite.shtml

[94] "Paris 2011: Commercial Markets Will Drive Stratospheric UAV Demand". *AIN Online*, June 2011. http://www.ainonline.com/aviation-news/paris-air-show/2011-06-19/paris-2011-commercial-markets-will-drive-stratospheric-uav-demand/

[95] Worldwide Interoperability for Microwave Access.

- Table 1 – Cargo Delivery
- Table 2 – Police Operations, Patrol Surveillance
- Table 3 – Police Operations, Traffic, Emergency Response and Special Events
- Table 4 – Power Line and Pipeline Inspection
- Table 5 – Agriculture
- Table 6 – Pilot Assistant
- Table 7 – Stratospheric Communications Media Relay

Cargo Delivery

Precision Carriers is a cargo delivery company that uses UAS technologies for delivery of specialty cargo to remote locations, construction sites, offshore rigs, towers, etc., and can handle any job below 6,000 pounds in capacity. Shape and packaging of the cargo is of no concern, since Precision Carriers uses a sling method of delivery. If it can be hooked, it can be lifted and hauled. They use the combat-proven K-MAX optionally piloted aircraft with a ground crew of two, a system operator and a ground rigger. This crew can operate up to four different K-MAX flight operations at a time. In supply chain operations, Precision Carriers takes delivery of the supplies, nets and slings the package, and sets flight operations in motion. Precision Carriers operators use a special positioning beacon with video and infrared at the receiving site to remotely observe the drop zone as well as use the video and infrared feed aboard the K-MAX. This positioning beacon is air delivered and positioned on the first delivery and then used to aid in delivery of the customer's repeat loads. K-MAX operates with both a satellite link and line-of-sight communications.

Precision Carriers provides value-added services for challenging deliveries to help companies be successful in delivering cargo that meets the construction schedule and can be staged for either just-in-time delivery (as in tower construction) or stockpiling of materials at a remote site. Since the sling approach is used for carry, when over the job site, the system operator can either hover to allow workers to attach cargo and then remotely release, or employees can release the load when safely positioned on the ground. On larger jobs, Precision Carriers will provide a system operator and ground rigger at both ends of the supply chain.

Some of the many services offered are logging, where logs are removed from remote areas, lifting of air conditioning units to building rooftops, resupply of remote locations, delivery of construction equipment in rugged terrain, lifting unusually shaped objects, construction of towers, lifting of wind turbine blades, positioning of buoys at sea, resupply of ships at sea, repositioning of equipment, stringing of cables across rivers and gorges, lift and positioning of sculptures, and delivery of housing components to remote areas.

Table 1 - Cargo Delivery Business Model Canvas

<table>
<tr><th>Key Partners</th><th>Key Activities</th><th>Value Propositions</th><th>Customer Relationships</th><th>Customer Segments</th></tr>
<tr><td rowspan="3">Aircraft Manufacturers</td><td>Expansion to the mountainous west with a base in Montana. Develop end of supply chain ground sensors to aid in the remote delivery.</td><td rowspan="3">• Precision lifting and hauling.
• “Last mile” supply chain delivery to remote or challenging locations.
• Lower labor costs than traditional manned helicopter operations.
• Competitive lift capabilities to conventional tall cranes.
• Precision placement of structures.
• Lift and removal of materials and structures.
• Logging in areas where roads are not possible.
• Offshore resupply.
• Construction supply and lift into position.</td><td>Possible customers: Telecommunications companies, logging companies, remote constructors, offshore companies. Expand customer base using co-creation of lift and haul activities with specialized construction and remote operations companies.</td><td rowspan="3">Niche markets in construction, remotely located industries like logging, mining, solar and wind energy, offshore platform services, and energy infrastructure lifting.</td></tr>
<tr><th>Key Resources</th><th>Channels</th></tr>
<tr><td>UAS and ground vehicles for transporting them.</td><td>Web presence for description and ordering of services, technical articles on previous lifts in trade publications, construction trade shows, and direct sales, especially in the West</td></tr>
</table>

Cost Structure	Revenue Streams
Kaman K-MAX $5.1 M per unit (6 units operational) OPA package $0.5 M per unit Operating cost $1,100 per hour Gulf Coast and Montana Bases $3.2 M Personnel $1.7 M	Individual lift and hall contracts – Sales of $18 M in 2011. Retainer contracts with repeat customers to assure availability

Police Operations, Patrol Surveillance

Top Cover, Inc. is an emergency services quad-copter UAS supplier and applications developer providing highly mobile, hand-held UAS that fits a cruiser trunk or fire truck. Top Cover is an integrated electric stealth UAS with a computer interface for the operator with unprecedented autonomous or manually operated flight profiles. While not in use, the quad-copter and computer are charged by the cruiser or fire truck's electrical system or with an optional solar capability for more remote operations. The Top Cover quad supports video, infrared (IR) and acoustical sensors. Flight endurance time is 3 hours on a charge, with spare battery packs that can be swapped out. The computer interface records sensor information and provides the ability to link directly to trunked communications to share live and playback information with other officers or firefighters or with a central command post. Other officers within line-of-sight of the quad-copter can take advantage of its encrypted link to view images and hear acoustical signals through a smart phone application. An optional package can replace the acoustical listening device with a trunked relay function, allowing officers or firefighters to converse through their smart phone app using encryption. All authorized personnel within line-of-sight can participate in a party line while receiving live video and IR imaging in real time.

Top Cover's autonomous navigation capability uses a geographical information system linked to GPS coordinates. The operator calls up the area of interest, drops a position, drags a route, defines the size of the orbit, and a flight plan is created to upload the autonomous flight director through a USB port. Once loaded, the quad-copter is ready to go. The aircraft will lift off vertically, to the assigned altitude, identify the nearest point to join the defined track, and establish operations on that track. The operator can shift from autonomous to manual mode at any time. Encrypted video, IR, and acoustical feeds stream back to the control station or to any equipped smart device. All information is recorded automatically for later review for compliance with privacy policies and for use as evidence in the event of a crime.

The electrical stealth features provide the Top Cover UAS with the ability to operate at lower altitudes without detection. Manual flying can be done along streets. The UAS can set down on rooftops and still provide sensor feeds. The UAS uses Edge Technology, ™ where attitude sensors can tell the operator if the UAS is well balanced on the building edge before shutting down the shrouded rotors. If wind gusts are in the area, the quad-copter will remain running and adjust to compensate for turbulence, in essence using a hover with contact to the surface.

Top Cover provides full support and training in the use of UAS for police and fire operations, including 12 hours of flight time with every purchase that includes mission planning, flight, positioning for different incidents, patrol functions, surveillance, data recording and replay, and maintenance of the quad-copter. An additional training session is provided to cover the array of possible sensors that can be mounted and supported by the applications. For police and fire departments with aviation programs, an overview of integration of manned and unmanned operations is provided, especially for pursuit support and search and rescue operations.

Table 2 - Police Operations, Patrol Surveillance Business Model Canvas

<table>
<tr><th>Key Partners</th><th>Key Activities</th><th>Value Propositions</th><th>Customer Relationships</th><th>Customer Segments</th></tr>
<tr><td rowspan="3">Quad-copter supplier

Battery and power charger supplier</td><td>Demonstration opportunities with documented results.
Potential customer use of demonstrators.
Grant development for customers.</td><td rowspan="3">• Ruggedized construction
• Ease of Operation
• 3-hour flight time on single charge
• Stealth
• Auto recording of sensor information for privacy audits and use as evidence
• Video, IR, and Acoustical sensing
• Optional Communications links for officers in the field
• Privacy protocols
• Training and support for out-of-the-box operations
• Lower cost aerial surveillance than manned flight</td><td>Current customers: 36 major police forces, 2 state police, 16 small police/sheriff
Expand customer base using new applications and regional training.</td><td rowspan="3">Diversified market based on size of police and fire force, urban and rural, with and without flight departments, topography differences, and differing privacy concerns by citizens</td></tr>
<tr><th>Key Resources</th><th>Channels</th></tr>
<tr><td>Quad-copter vehicles.
Sales force, training and applications developers with law enforcement backgrounds.</td><td>Direct marketing for local demonstrations and training, participation in regional, national law enforcement conferences, assistance in securing Federal grants, active in privacy forums, statistical center for use of UAS</td></tr>
<tr><th colspan="2">Cost Structure</th><th colspan="3">Revenue Streams</th></tr>
<tr><td colspan="2">$3,600 per unit quad-copter cost
$3,200 ruggedized control station
$187 per unit charger and spare battery
$1.8 M applications development
$3.0 M Sales and Marketing
$4.5 M Personnel, $1.3 M Facilities
$1.7 M Customer Training</td><td colspan="3">$13,700 per unit, including control station, additional power pack with a 20% volume discount quantities 10 and greater

Market size - approximately 1,000 large police units (100 or more officers) and 18,000 law enforcement units overall and 27,000 fire departments at the state and local levels.</td></tr>
</table>

Police Operations, Traffic, Emergency Response and Special Events

Top Cover Inc. also provides a larger fixed-wing UAS specifically designed as an eye-in-the-sky and secure communications relay system for covering emergencies, special events, and supporting major traffic events. Police and/or fire are linked together for video, IR, and voice. The system can be adapted to support trunked communications. As a fixed-wing UAS, it is intended to orbit the area at any altitude up to 10,000 feet, based on the area of coverage needed. Multiple units can be programmed to overlap and extend the coverage. The UAS performance is 20 hours continuous flight with sufficient power to provide the sensor services. Like its smaller quad-copter version, it has both autonomous and manual operations provided from a ground station computer that is identical in its interface with the operator. Anyone trained in the smaller quad-copter can fly this unit. The unit is launched along a mobile rail and recovered by capture in a net. The UAS is powered by a pusher powerplant and weighs less than 43 pounds.

Top Cover Inc. knows that an obstacle to use of UAS in law enforcement is the issue of personal privacy. As such, Top Cover is an active participant in privacy forums, demonstrates how privacy audits can be conducted by citizen panels, and has created and supports a Law Enforcement UAS Statistical Center tied to a university, where data is collected on the efficacy of ISR in police operations using UAS.

Table 3 - Police Operations, Traffic, Emergency Response and Special Events Business Model Canvas

<table>
<tr><th>Key Partners</th><th>Key Activities</th><th>Value Propositions</th><th>Customer Relationships</th><th>Customer Segments</th></tr>
<tr><td rowspan="3">UAS providers

Communications relay companies</td><td>Demonstration opportunities with documented results.
Potential customer use of demonstrators.
Grant development for customers.</td><td rowspan="3">• Ruggedized construction
• Ease of Operation
• 20-hour flight time
• Auto recording of sensor information for privacy audits and use as evidence
• Video, IR, and Optional Communications links for officers in the field
• Privacy protocols
• Training and support
• Lower cost aerial surveillance than manned flight</td><td>Current customers: 4 major police forces, 2 state police, 4 small police/sheriff
Expand customer base using new applications and regional training.</td><td rowspan="3">Diversified market based on size of police and fire force, urban and rural, with and without flight departments, topography differences, and differing privacy concerns by citizens</td></tr>
<tr><th>Key Resources</th><th>Channels</th></tr>
<tr><td>UAVs

Sales force, training and applications developers with law enforcement backgrounds.</td><td>Direct marketing for local demonstrations and training, participation in regional, national law enforcement conferences, assistance in securing federal grants, active in privacy forums, statistical center for use of UAS</td></tr>
</table>

<table>
<tr><th>Cost Structure</th><th>Revenue Streams</th></tr>
<tr><td>$96,000 per UAS unit cost
$28,000 Communications relay capability for NightEagle™</td><td>$170,000 per unit, including control station, rail launch system and supply support for one year
Application licensing
Market size - approximately 1,000 large police units with additional 960 federal units</td></tr>
</table>

Power Line and Pipeline Inspection

Line Inspection Vertical Environment (LIVE) Inc. is a provider of both utility company owner-operated and service provision in the use of UAS for inspection of power lines and pipelines. LIVE uses a variety of UAS capable of autonomous and ground controller operated observation and recording capabilities. For high tension power lines, LIVE uses a unique navigation system that senses the corona of the power lines themselves as a means of navigating along the length of the line. Encroachment inspections can be pre-programmed, while manual operation may be needed to go vertical, hover, observe, and document needed repairs on lines, tower structures, wire, and insulators. For the pipeline industry, LIVE offers an assortment of sensors that can detect hydrocarbons or other chemicals in the air, map vegetation for changes in growth as an indicator or leakage, and perform grid searches to document extent of leakage. The sensor packages are designed to be interchangeable between multiple UAS, from fixed to rotary wing. LIVE currently uses six different flight platforms to serve the industry, provides initial mapping into a geographical information system that provides the basis for applications that overlay inspection results. LIVE provides routine inspections and detailed, site-specific inspections that avoid the need to climb the structure or operate from a manned helicopter platform to identify the work needed. LIVE's detailed inspection post-flight data reductions include the translation of aerial video to digital photos for use with cities, counties, and state agencies on encroachment issues, including the visual mapping and definition of the offender's registered boundary lines.

LIVE's natural resources department uses UAS to define tree and brush removal needs to the customer's specification and provides the customer with detailed location, access, and cut line drawings to support right-of-way maintenance.

LIVE's unique leasing arrangement can put top quality Small UAS vehicles and control computers in the hands of their customer, complete with training on flight operations, safety, and data collection and reduction using LIVE's licensed applications. As a full service company, LIVE can also conduct the necessary operations and deliver the results to the customer.

Table 4 - Power Line and Pipeline Inspection Business Model Canvas

<table>
<tr><th>Key Partners</th><th>Key Activities</th><th>Value Propositions</th><th>Customer Relationships</th><th>Customer Segments</th></tr>
<tr><td rowspan="3">Multiple quad-copter manufacturers
Electric Power Research Institute (EPRI)

Sensor development partner</td><td>Demonstration opportunities through EPRI</td><td rowspan="3">• External inspection at a fraction of the cost of manned flight
• Ease of operation
• Tailored use of UAS to meet individual inspection and monitoring needs
• Video, IR, chemical detection, electrical flux sensors
• Training and support
• Rapid response capabilities to detected problems
• Unprecedented documentation with job orders, GIS mapping, encroachment documentation tied to property boundaries
• Broader use by employees or use a services contract
• Continuing development of applications</td><td>Communities of interest approach to customers, where the communities are built around encroachment, power line and structure maintenance, and pipeline condition sensing.</td><td rowspan="3">Niche market tailored to electric power maintenance and pipeline inspection tied to remote sensing of leaks.</td></tr>
<tr><th>Key Resources</th><th>Channels</th></tr>
<tr><td>Quad-copter UAS.

Sales force, training and applications developers with power and pipeline experience

Technical support facility with structural mockups.</td><td>Direct marketing for local demonstrations and training, participation in power and pipeline trade shows and conferences, technical journal articles, Web presence with video demos, research, and support center</td></tr>
</table>

<table>
<tr><th>Cost Structure</th><th>Revenue Streams</th></tr>
<tr><td>$7,800 per unit Quad-copter cost
$3,200 ruggedized control station
$2.8 M applications development
$1.0 M Sales and Marketing
$4.5 M Personnel, $1.3 M research and support center
$1.1 M Customer Training</td><td>$25,700 per Quad-copter unit, including control station, GIS overlay mapping, job order production application, encroachment reports, training
Services contract option for inspection
Application licensing
Market size - approximately 325 electric utility companies, 195 regulated pipeline companies, 148,622 miles of pipeline</td></tr>
</table>

Agriculture

FlightAg, Inc. offers Flight Farm Hand, a small UAS tailored for use in agriculture and linked to a larger GIS that maps and then monitors crops providing data on locations for fertilizer and pesticide use, physical weeding, watering, and other tools to enhance crop yield. The great advantage of Flight Farm Hand is the savings realized in managing crops through timing and application of costly materials in a way that saves the farmer money and allows for higher crop yields. Due to the flight sensing applications, labor is saved over traditional crop inspections. A companion capability Flight Ranch Hand helps the livestock rancher better manage rangeland, control herds, locate missing animals, check gates and fence lines, and watch for and scare off predators. Flight Farm Hand and Flight Ranch Hand can operate on an autonomous flight track set by the farmer or rancher through a GIS application, or can be flown by the farmer or rancher manually. Both methods rely on an interface specifically designed to define the flight, collect and store the data, reduce the data, and map this information as a layer on the farmer's or rancher's GIS. The UAS and its powerful applications provide aerial survey and mapping capabilities to save hours in the field or riding the range, provides pinpoint accuracy in locating weeds or lost animals, and collects infrared images that can be used to measure crop growth, the need for water, fertilizer, and/or pesticides tailored to the condition of the crop.

Since rangeland may cover a significant area well out of the line-of-sight of the operator, the autonomous mode can be used, where the flight is planned and flown autonomously, with the UAS returning to a location within range where it would enter an orbit and wait for manual control to land the vehicle. Whether out of range or within line-of-sight, the UAS records information from sensors and broadcasts at the same time. This way, the farmer or rancher can choose to "ride" with the UAS or download the information for later review.

Flight Farm Hand and Flight Ranch Hand come with video and infrared sensors as standard. Both forward and side-views are provided. The IR sensor also has the ability to look straight down for mapping. Optional sensors include air sampling, temperature and moisture sensors, and a special module that can discharge shell crackers for scaring predators.

Flight Farm Hand and Flight Ranch Hand are marketed through cooperatives and farm and ranch implement companies with maintenance support being provided with return to FlightAg through the dealer. Dealers carry spare units for loan. FlightAg trains the dealer in use of Flight Farm Hand and Flight Range Hand and offers on-line training for farmers and ranchers, including flight simulations through the flight control station. Dealer or FlightAg representatives train farmers and ranchers throughout FlightAg's support network.

Table 5 - Agriculture Business Model Canvas

<table>
<tr><th>Key Partners</th><th>Key Activities</th><th>Value Propositions</th><th>Customer Relationships</th><th>Customer Segments</th></tr>
<tr>
<td rowspan="3">Tractor Companies

Marketing via agricultural supply companies

National Council of Farm Cooperatives Membership
Farm Bureau for financing and state-level assistance and networking

UAS manufacturers</td>
<td>Introductory demonstrations, co-op and implement dealer incentives and training</td>
<td rowspan="3">• Improved yield at lower cost through tailored application of water, fertilizer, pesticides
• Ease of Operation
• Video, IR, chemical detection, electrical flux sensors
• Training and support
• Tractor and agricultural supply stores.
• Unprecedented ag analysis capabilities with GIS mapping
• Farmer/rancher use or a services contract
• Continuing development of applications tied to university research</td>
<td>Direct wholesale sales to dealers and co-ops</td>
<td rowspan="3">Niche market tailored to use of general sensors for mapping and agricultural applications.</td>
</tr>
<tr><th>Key Resources</th><th>Channels</th></tr>
<tr>
<td>Fixed-wing UAS.

Sales force, training and applications developers with agricultural experience.

Dealer financing for farmers and ranchers.</td>
<td>Direct marketing for local demonstrations and training, participation in agricultural and range shows and conferences, technical journal articles, Web presence with video demos, research and support content</td>
</tr>
</table>

<table>
<tr><th>Cost Structure</th><th>Revenue Streams</th></tr>
<tr>
<td>$3,100 per unit quad-copter cost
$2,200 control station
$1.3 M GIS Mapping integration applications development
$1.0 M Sales and Marketing
$1.6 M Personnel, $1.3 M facility
$1.1 M Customer Training</td>
<td>$14,000 per UAS unit suggested retail, including control station, GIS overlay mapping, training
Services contract option available for large agribusiness
Application licensing
Numerous agricultural equipment distributors</td>
</tr>
</table>

Pilot Assistant

The Autonomous UAS Technologies Organization (AUTO) is a consortium of manufactures founded to support technology transfer from UAS flight control technologies to manned aircraft, starting with the Optionally Piloted Aircraft (OPA) for the military market. The technology transfer has grown to include a safety package called the Pilot Assistant.

Pilot Assistant supports controlled aircraft flight (AUTO Control) and safe aircraft recovery and landing (AUTO Safe), to fully autonomous flight operations (AUTO Flight). The Pilot Assistant can include any or all of these applications. The basic Pilot Assistant functions provide for navigation and flight control that support en route flight, flight management, and engine management. Pilot Assistant can fly the aircraft while the pilot plays the role of safety observer, or the pilot can fly and use the AUTO suite of applications as they are needed to manage workload. At any time, the pilot can select the AUTO Safe application that comes standard with the AUTO family of products and the Pilot Assistant will find the nearest appropriate runway and approach, proceed to that airport, and execute an approach and landing, including breaking to a full stop on the runway. The pilot may also select a destination. In the event of single pilot incapacitation, the Pilot Assistant will also alert ATC of an emergency, set the aircraft's transponder, and provide the necessary information as to destination, estimated time of arrival, and flight profile.

AUTO also offers flight control for large transport aircraft as a replacement to the first officer, fitted for most existing air cargo and air carrier aircraft. AUTO connects to the flight management system to manage navigation and through the fly-by-wire interface for the flight control surfaces. This expansion of the pilot assistant has demonstrated full flight functions from takeoff, route navigation, approach, and landing and is currently being certified for commercial flight operations. Marketed as a pilot replacement, its first application will likely be for cargo operations converting existing smaller aircraft to OPAs with a pilot safety observer along for the flight. As experience is gained, the need for continued use of the safety observer can be assessed for smaller commercial aircraft.

Table 6 - Pilot Assistant Business Model Canvas

<table>
<tr><th>Key Partners</th><th>Key Activities</th><th>Value Propositions</th><th>Customer Relationships</th><th>Customer Segments</th></tr>
<tr>
<td rowspan="3">Consortium members

Cargo carrier launch partner for commercial

Aircraft manufacturers (general aviation and sport aviation)

Department of Defense for Optionally Piloted Aircraft applications</td>
<td>Introductory Demonstrations, Engineering trials leading to certified operations in sport aviation, general aviation instrument flight, and commercial</td>
<td rowspan="3">• Significant safety and peace of mind with lower insurance costs with AUTO Safe – recovery and landing
• Pilot Assistant with AUTO Control provides flight control that reduces pilot workload and compensates for proficiency
• AUTO Flight makes the aircraft an Optionally Piloted Aircraft
• For commercial operations, aircraft can be flown with one less pilot, cutting flight labor in half while improving safety performance through the Pilot Assistant functions</td>
<td>Applicant with federal government for certification, co-creator with aircraft manufacturers, leverage consortium member teams for engineering and standards</td>
<td rowspan="3">Segmented market to include sport aviation (AUTO Safe), new general aviation aircraft (AUTO Control and AUTO Safe), Small Cargo Carrier conversions (AUTO Flight), and replacement of the first officer with the combination of all three applications.</td>
</tr>
<tr><th>Key Resources</th><th>Channels</th></tr>
<tr>
<td>Fixed-wing demonstration aircraft. Engineering force drawn from consortium partners.

Investment of consortium members.</td>
<td>Flight demonstrations and direct marketing with aircraft manufacturers, commercial aircraft operators, and Government regulators. Web presence with video demos, research and support content.</td>
</tr>
<tr><th colspan="2">Cost Structure</th><th colspan="3">Revenue Streams</th></tr>
<tr>
<td colspan="2">$3.6 M engineering for small general aviation aircraft
$6.5 M flight testing and demonstration
$8.0 M for certification for use in sport, general aviation and small cargo aircraft
$3.0 M marketing and sales</td>
<td colspan="3">Four tiered pricing with a multiplier of 10 for each tier from (1) sport aviation (20,000 units), (2) general aviation (50,000 units), (3) small cargo (8,000 units) and (4) large cargo and commercial aviation (9,000 units). Retrofit is twice the cost of new installed, following general industry trends. Military sales for OPA 200 units</td>
</tr>
</table>

Stratospheric Communications Media Relay

IONSAT, Inc. began its business as a research company exploring the use of non-rigid unmanned airships for ionosphere, earth sciences, and communications research. With a proof of concept and development contract from NASA, IONSAT successfully built four lighter-than-air ships that carried science packages aloft. One such package was a series of commercial low-earth orbiting satellite transponders. Designed to fly at the boundary between the ionosphere and the mesosphere, these airships could stay aloft for two to three months and then were recovered using solar powered propulsion. While tested for flights to 90 kilometers (FL 295), time-on-station was limited by gas leakage. Satellite transponder testing demonstrated the feasibility of a satellite stationed at the lower end of the ionosphere. With an additional contract from Homeland Security to provide communications, IONSAT, Inc. began to develop a stratospheric version using synthetic fiber skin and photovoltaic surfaces as a layer on that skin. IONSAT approached the Department of Homeland Security (DHS) with a public-private partnership whereby Homeland Security would be the launch partner for a new age in satellite operations at a fraction of the cost of traditional satellites. IONSAT would carry aloft a package for Homeland Security communications and would also wholesale satellite time to other media providers on the remainder of the transponders.

Because the satellite package could be carried without the ruggedized requirements of space, and because this package could be replaced yearly as opposed to an 8- to 10-year cycle typical for satellite constellations, IONSAT has positioned itself to offer a wide range of products. The next stage is a demonstrator that would cover the entire Northeast, with two unmanned ships delivering redundancy. In flight trials, these ships have an estimated on-station time of 10 to 12 months and take one day to get into position. IONSAT has a ready ground spare. The entire U.S. could be covered with five ships single thread and eight ships with redundancy. For coast-to-coast coverage, the cost of the eight ships plus their satellite package is estimated at $436 million, with an annual refurbishment cost on the order of $8 million per airship. Change-out costs for the satellite transponders are dependent on the customer's needs. Annual operations for control, uplink, and associated ground station costs are $7 million.

IONSAT was able to increase the payload and power distribution by decreasing the propulsion requirements for the airship. Designed to operate between FL 500 and FL 650, station keeping was not going to require significant thrust so smaller engines could be used to maintain position. The tradeoff was that there would be insufficient power to get the airship into position. IONSAT solved this problem by using a docking system. Before release from the ground, another UAS is docked to the end of the airship and it pushes the airship through the climb using conventional fueled flight, then releases from the airship at FL 450. On return, the airship descends to FL 450 and the pusher UAS docks with the airship to guide it back to Earth. This approach allows for the ferry of the IONSAT airship anywhere in the world within 5 days using multiple docking maneuvers.

IONSAT warrants its satellite service for 24/7, high bandwidth digital services using spectrum and bandwidth tailored to the customer's needs.

As a means to accommodate the broadest possible market, IONSAT has teamed with a provider of cable television control boxes to produce the STRATBOX™. IONSAT designed the STRATBOX and its small antenna to provide signal processing, encryption, billing, and a unique interface that provides Wi-Fi connection to all the consumer's electronic devices. The user can route media from IONSAT through the

STRATBOX to televisions, computers, handheld devices, and even use the STRATBOX to order products and view them on the customer's own schedule. Built into the STRATBOX is a digital recorder for playback. A commercial version, STRATBOX Exchange™ operates as a two-way interface with an uplink unit capable of supporting telepresence for meetings, remote medical operations, and similar high-bandwidth requirements.

Unlike many UAS manufacturers, IONSAT is a full-service media operation with partnerships in various media endeavors that provide both wholesale connectivity and end consumer products.

Table 7 - Stratospheric Communications Media Relay Business Model Canvas

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
Homeland Security as launch partner for the capability Communications relay companies Server providers Transponder providers	Launch of Northeast primary and backup **Key Resources** Airships Pusher UAS Engineering and integration across key partners System operations	• Low-cost alternative to satellite use time • Adaptable transponder configurations • Low nonrecurring costs to get your capability airborne • Unprecedented fully encrypted bandwidth • Media user tailoring through the STRATBOX • High reliability with dual redundant coverage and one-day standby spare • Services can be ordered for events requiring special coverage.	Co-creator with media partners, automated services for media users (STRATBOX) **Channels** STRATBOX or STRATBOX Exchange offers direct connection with the media user, units are leased for security control and servicing, on-line diagnostics and on-line digital resets for servicing.	Government as service provider Media providers as wholesale satellite time provider Media end-users as retail provider

Cost Structure	Revenue Streams
$436 M for 8 ship configuration $8 M per ship annual refurbishment $7 M annual ground station operations $11 M annual facility costs $18 M annual personnel costs	Direct Services contract with Homeland Security ($500 M) Direct Services contract with NASA ($200 M) Wholesale sale of transponder time with media providers ($300 M) Retail leasing with media users ($800 M to $1.2 B)

5.2 Technology Transfer

The U.S. Government, especially through the DoD, has made a significant investment to produce unmanned aircraft. While less reliable than civilian certified manned aircraft, these flying platforms are primarily used to replace manned missions where risks are high or to provide an "eye-in-the-sky" extending the reconnaissance capabilities of the soldier on the ground. Long loiter times for sensors have proven their worth in battle areas. Patrol capabilities to seek and detect threats have significantly improved both the vehicles and the sensors they carry.

However, the market value is in the applications, not the aerial platform. The technology transfer that is needed is the adaptation of military technology for civilian applications, the freeing up of flight restrictions to stimulate application development, and the generation of revenue in the private sector through delivery of new ways of gathering information and converting that information for commercial use, whether to reduce cost of existing activities or create new opportunities.

Technology transfer can be divided into two major categories: the transfer of aviation technology to manned flight, and the transfer of sensor technologies for adaptation in the civil market.

5.2.1 Aviation Technology

Much of the aviation technology deployed is in the form of avionics, systems that control flight, provide navigation, and support systems monitoring of the UAS. Some examples of short-term technology transfer opportunities include:

- Small autopilots that can be adapted for use in general aviation aircraft to improve performance and offer value added features at lower cost. The technology transfer is geared toward adapting autonomous flight opportunities from UAS to general aviation aircraft.
- Sense and avoid technologies could aid general aviation safety, since most general aviation aircraft do not carry collision avoidance systems.
- Fuel and engine management systems used for optimizing loiter can be added to a Pilot Assistant for manned aircraft.

Autonomous operations are at infancy. The ability to operate with a safety observer in a manned vehicle significantly shifts the labor costs of commercial use of aviation. This capability would allow a basic pilot to operate in more demanding conditions, setting the flight profile and observing the operation. Additionally, it would enable conformance to pre-defined trajectories and times to increase capacity in the airspace. It is of interest to note that the U.S. Air Force's Chief Scientist identified reduction in labor costs through autonomous operations as a key challenge between now and 2030.[96]

Autonomous operations have as a transitional capability, the augmentation of pilot performance; the concept of a Pilot Assistant to manage the flow of information, monitor aircraft systems, and aid in the management of flight. Much of the control technology based in the UAS ground station can be transferred for use in the aircraft to assist the crew. Humans are becoming increasingly burdened with cockpit

[96] Technology Horizons, A Vision for Air Force Science and Technology During 2010-2030, Volume 1, AF/ST-TR-10-01, 15 May 2010.

systems as capabilities expand. There is a need to find ways to augment humans in the management and use of information.

Autonomy must pass a major hurdle, that of attaining what the Air Force calls "certifiable trust in autonomy." The processes for certification are an area of joint collaboration between the military and civil sectors. New methods of Verification and Validation (V&V) will be needed, and this V&V must be certifiably reliable, meaning there are scientific and engineering processes to prove performance.

5.2.2 Sensor Technology

Electro-optical video and IR, synthetic aperture radars, ground penetrating radars, laser targeting systems, and the like make up the suite of current sensors. Two trends are to produce the same or better performance with less system weight and to use signal and information processing to improve the product sensing for the operator. Approximately 80 percent of the commercial market will be realized in Small UAS, where weight is a key factor. The vast majority of the users of the information the sensors capture will not be for a warfighter mission. Therefore, information presentation in usable forms will be key to commercial success. Information processing and presentation is an area of technology transfer that can take a military application and convert it to a civil application.

As a simple example, IR is used in military operations to detect hot spots (the enemy and their vehicles). In land use, the gradation of IR returns tells the story of the types of vegetation, extent of coverage, and location, relative to other mapping databases. Technology transfer from current military operations to land use will require additional signal processing from the sensors.

New sensors will be needed for civilian applications. Most of these sensors will be a technology transfer from systems carried on aircraft (e.g., power line inspection tools) that will need to be miniaturized for carriage on UAS. The technology of miniaturization is an area of technology transfer.

Mapping technologies will need to be adapted to accept UAS-derived information. The fight track, the sensor data, and the underlying mapping must merge in order to realize the benefits of sensor payloads on UAS. The technology transfer is a combination of information registry and visualization coupled with greater virtual reality applications, where information is presented with the fundamental concept that the viewer is there, seeing what the UAS platform is enabling the sensor to detect.

A related sensor opportunity is in pattern recognition and differentiation. This includes improved terrain matching for navigation, recognition and identification of topographical features, ability to differentiate vegetation, moisture, water quantity and quality, differentiation of soil and mineral types, pattern recognition of tree cover, animals, and even people. A significant element of visual and IR surveillance with cameras on the ground is to recognize threats, differentiate acquired targets, and provide the necessary processing to present this information to the operator. All of this electro-optical signal processing advances can be transferred to a mobile platform.

As identified in the Pilot Assistant business model examples, consortia will need to be formed with the expressed purpose of technology transfer. This brings together the user industries, sensor, and aviation communities to develop and market new UAS capabilities, leveraging the investment by the DoD and other federal agencies.

5.3 Commercialization Benefits

The transition from military and Government use to commercial use of UAS represents a new aviation industry. While the initial market will be in producing the flying platform and its sensors, the longer-term market is in the information the sensors produce. When coupled with detailed mapping information through a (GIS), new opportunities are created, from the farmer or rancher, to the large timber company, to water management authorities, to any case where a business involves land use.

Better ways of providing communications – from disaster relief to everyday internet access – is an untapped market for delivery of bandwidth, just as satellite communications was in 1962 with Telstar. Much lower-cost stratospheric satellites and even lower communication relays can blanket the Earth with access.

The cost of air transport can be reduced, whether through UAS cargo operations, power line inspections, or even replacement of one of the two pilots on commercial flights. The labor savings make for a more competitive environment. The commercial market will leverage DoD experience to move from a pilot and systems operator for each UAS to being able to manage multiple UAS with a single system operator. The intensity of a combat environment and its higher manpower needs is replaced with the routine nature of commercial UAS operations – delivering cargo and stores, gathering information for better management of natural resources and agriculture, providing platforms for communication, and flying more autonomous applications.

Most market surveys performed for UAS have focused on military growth and uses in law enforcement and the civilian market will emerge over the next 10 years. Teal Group[97] estimates that over the next 10 years, the U.S. research and development market is approximately $17.6B, procurement of UAS is on the order of $33B. On the civil side, Teal estimates around 1,000 UAS with a value of $587M.

[98]Lucintel, a global research firm, estimates a $7B market over the next 10 years worldwide, with 60 to 70 percent of that market in North America. This is a forecast for the UAS hardware and sensors only, not the information it derives.

Leading universities are operating with UAS in conducting research in civilian applications. A significant part of these experiments is to study the use of the UAS in land use, from agriculture to forestry. Research is also being conducted on sensor development for power line and pipeline remote inspection.

While most of the UAS industry is focused on a derivative of current military uses for security and police operations, the civil industry is looking to use the UAS as a platform to produce revenue from the data derived through the sensors.

Taking a longer view, the benefits are clear:

- Lower labor costs to accomplish tasks that are now performed by manned flight
- Lower labor costs through a faster way to autonomously gather information needed

[97] 2012 Market Profile and Forecast, World Unmanned Aerial Vehicle Systems, Teal Group, 2012 Edition.
[98] Growth Opportunity in Global UAV Market, Lucintel, March 2011.

- Lower labor costs in land use field surveys and management
- Greater use of information derived from UAS to manage application of water, fertilizers, pesticides, timing of crop harvests and management to produce greater yields (from corn to timber)
- Improvements in water management and allocation through use of GIS technologies paired with UAS sensor information
- Reduced cost of environmental oversight and enforcement
- Improved public safety through surveillance
- Improved flight safety through technology transfer from UAS to manned flight operations
- Recognition of UAS flights as a data collection tool, with the market driven by the information gained
- Ease of operation to attain the data through information processing and presentation.

The commercialization of UAS technology and the commercialization of flying sensors, with emphasis on the information derived, is limited by constraints imposed by the federal regulatory actions and by general citizen concern over law enforcement applications of surveillance and the right to privacy. Both of these challenges will be overcome, but not without an impact on the economics of UAS. This delay will defer commercialization benefits and present obstacles to market entry.

6. Market Challenges

6.1 Legal and Regulatory Policies and Procedures

Historically, UAS use has been primarily by the military in war zones, and in restricted airspace within the U.S. A primary UAS mission of an aerial target anticipates destruction of the vehicle, so their designs did not typically consider longevity or robustness important. New domestic missions and vehicles present a totally different picture. The anticipated expansion of UAS into a myriad of public, private, and commercial missions routinely using the national airspace alongside other air traffic has highlighted both the UAS operational needs and the public concerns associated with those operations. The FAA's current operational requirements for UAS operators provide a safe environment for other aircraft as well as persons and property on the ground.

[99]FAA's *"Interim Operational Approval Guidance 08-01"* gives the rules for gaining approval to operate UAS in the NAS and the operating limitations that are imposed on those flights. In general, the rules for manned aircraft governing vehicle airworthiness, pilots, maintenance, and use of the airspace have been directly applied to UAS operations with the caveat that relaxation of some of these rules may be granted if FAA accepts an operator-proposed safety case using "Alternate Methods of Compliance." Without that, the UAS must meet equivalent certification standards (usually experimental category), and be flown by a licensed pilot. Except in Class A airspace, UAS must be flown in VMC in sight of the pilot or, if a chase plane is used, in sight of the observer. UAS are to be maintained like a manned aircraft. All UAS flights in the NAS require a Certificate of Waiver or Authorization (COA), typically valid for up to a year, obtained by submitting an application and receiving specific approval by the FAA.

[100]Many stakeholders recognize the time and costs these policies and procedures place in the way of achieving UAS benefits. Efforts are underway at FAA and through the RTCA Special Committee 203 to create standards specifically for UAS of varying size and sophistication and for realistic operating procedures that would permit using their unique capabilities while still safeguarding the public. Once in place, these new standards should eliminate the time-consuming COA process. One of the most difficult operating limitations to overcome is the see-and-be-seen requirement of FAR 91.113 to visually avoid other aircraft whenever operating in VMC. Work is taking place on systems to "detect, sense, and avoid," the automated equivalent of pilot-based see and avoid. Creating such a system that is light enough and inexpensive enough to be used on any but the largest UASs is very difficult. Other operating requirements to be met include systems to ensure safety under a "lost link" condition and a means to safely terminate the flight in the event of any catastrophic loss of control.

[99] "Interim Operational Approval Guidance 08-01: Unmanned Aircraft Systems Operations in the U.S. National Airspace System". Aviation Safety Unmanned Aircraft Program Office AIR-160, March 2008. http://uas.usgs.gov/pdf/uas_guidance08-01.pdf
[100] John Walker. "RTCA-SC 203". RTCA 2010-2011 UAS Yearbook – UAS: The Global Perspective. 8th edition, June 2010. http://uas.usgs.gov/UAS-Yearbook2010/pdf/P071-072_RTCA-SC203_John-Walker.pdf

6.2 Social Issues

Even when these technical and safety concerns are overcome, there is still a growing challenge to widespread use of UAS in the NAS brought on by the public's privacy concerns. The most widely used mission for UAS is ISR, or more simply, surveillance. As many missions provide low altitude, high-resolution surveillance, the privacy rights of citizens caught collaterally in the surveillance, should be protected.

6.3 Environmental Impacts

Many proposed UAS missions identified in Section 4 would place the vehicles in close proximity to persons who are not directly involved in the UAS operation. Civilian stores delivery, for example, could require a drop off right next to people. The noise produced by the UAS could mean the difference between the success and failure of this type of mission. Helicopters are notoriously loud noise producers. Additionally, their blades are hazardous to be around. The wind produced by their hovering lift can also be strong enough to damage articles that are not heavy or tied down. The fumes and gaseous emissions produced by the powerplants will be subject to the same scrutiny of all other transportation appliances and vehicles.

[101]A company called D-Star Engineering has recently received a contract from IARPA, the Intelligence Advanced Research Projects Agency, to develop a new class of quiet, small, unmanned aircraft. Electric power to a ducted fan is the proposed solution but this normally restricts both the payload available and the endurance of the vehicle. D-Star Engineering’s proposed solution is a hybrid turbine-electric propulsion system that would run on either gasoline or diesel fuel. A gas turbine engine would generate electricity that would directly power the fan, eliminating noisy gearboxes. A quiet flight segment would result from running on battery power for about 30 minutes while in the area where silence is essential. The battery would be re-charged by the turbine engine before and after the quiet segment. The goal is to stay under 60 phon, a perceived loudness based on the frequency of the sound emitted. Similar technologies will be needed to keep the noise and emission signatures of UAS very low when operating close to the public.

Larger payloads and long endurance can also be achieved quietly using lighter than air (LTA) or hybrid LTA vehicles with similar multi-mode propulsion capabilities. The lift required to keep large payloads aloft is not obtained aerodynamically, but through buoyancy, which is completely silent. This lift also produces no emissions, so if the thrust can be hybrid electric, most environmental concerns can be overcome.

6.4 Other

There are other, more subtle, potential challenges to acceptance of widespread use of UAS in the NAS. Cost is still a big factor for all but recreational radio controlled models. The costs of even experimental

[101] Graham Warwick. “Hovering Near You – IARPA’s Quiet UAV”. *Aviation Week: Ares Defense Technology Blog*, July 2012. http://www.aviationweek.com/Blogs.aspx?plckBlogId=Blog:27ec4a53-dcc8-42d0-bd3a-01329aef79a7&plckPostId=Blog%3A27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post%3A27bcb5c2-5216-4ed5-b53d-1e6f0fc2c0a5

certification, pilot and mechanic training, salaries for pilots, mechanics, and other mission specialists needed to carry out a UAS mission, and the relatively poor accident record for UAS which can result in total loss of the expensive vehicles, are all substantial.

Insurance costs for UAS operations over cities and towns are still being determined as actuarial data is slowly accumulated. No matter how quiet or clean it is, the sight of a large vehicle passing overhead where none had been before will draw complaints and political pressure to restrict or ban their operations.

This is not to suggest that these challenges cannot be overcome to the benefit of many domestic civil and military UAS missions. The concerns need to be understood and addressed so that their potential to stop the use of UAS is neutralized. The technical challenges are much simpler to overcome than the political and social ones, so continuous public education about the benefits of UAS use and the measures taken to ensure the safety and privacy of the general public is essential.

7. UAS Future Forecasts

The development, deployment, and acceptance of many modern technologies are tied to human generational perspectives, knowledge, and skills. The computer, the smart phone, and other contemporary technologies, including multiple iterations of similar disruptive technologies, are keyed to societal dynamics. As previously discussed, this drives many of the 20 to 25-year market life timelines. Although UAS technologies have been around for more than 50 years, it is only in the last few years that emerging technologies have converged with economic opportunities and growing mission needs to place UAS in a notable and measurable growth mode. In a suitably large or statistically significant market, unconstrained growth rates would increase until the inflection point on the S-curve is reached and market growth begins to decline. This would typically be about a third of the forecast market saturation. In the case of the total UAS market (i.e., DoD, federal, state, and local public agencies, and commercial interests) this is expected to occur in the 2026 to 2028 period.

7.1 Overview

Over the past decade, UAS have become an integral part of the United States military and government operations. Currently, over a dozen different types and over 8,000 unmanned aircraft are operational within the military services other federal government agencies.
[102]UAS are beginning to take an active role in homeland defense, homeland security, and defense support to civilian authorities and other domestic operations. The Department of Homeland Security (DHS) requires NAS access at several locations around the country as well as in the Gulf of Mexico. Currently, DHS operates and is expanding operations of Predator UAS along the southwest border with Mexico and the northern border with Canada. Additionally, DHS supports humanitarian missions such as Federal Emergency Management Agency (FEMA) flood support to the 2009 flooding disaster in North Dakota and Minnesota. Further, DHS recently developed a Maritime Predator-B variant, based in Florida and jointly operated by Customs and Border Protection and the Coast Guard, to monitor illegal immigration and drug trafficking in the Gulf of Mexico.

Many U.S. public agencies have a need for safe and routine access to U.S. airspace in order to execute a wide range of missions including surveillance and tracking operations, training, test and evaluation, and scientific data collection. UAS are already a significant part of DoD and will eventually require U.S. NAS access similar to manned aircraft whether segregated from manned aircraft or sharing the airspace side-by-side with manned aircraft.

In addition to the DoD and other federal agencies, state and local government are anxious to take advantage of the benefits of UAS for a variety of governmental functions and missions. This includes some 18,000 metropolitan police departments, fire departments, and other first responders.
In addition to governmental agencies there are significant pressures and opportunities to advantage commercial UAS. This market no doubt has the largest potential for a wide range of UAS applications.

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[102] "Department of Defense Final Report to Congress on Access to National Airspace for Unmanned Aircraft Systems". Undersecretary of Defense (Acquisition, Technology, and Logistics), October 2010. http://www.emptywheel.net/wp-content/uploads/2012/01/101001-Report-to-Congress-on-UAS.pdf

Lastly, there currently exists a significant recreational market known as Radio Controlled Models. This market demonstrates the viability of UAS since there is little differentiation between a Micro, Nano, or Small UAS and an RC Model except for its commercial use.

One fundamental requirement for operation in the NAS is to preserve the safety of the general public. Therefore, the implications for different classes of UAS operation should be examined based upon the requirement to operate at an equivalent level of safety. The purpose of this section is to identify potential design requirements and approaches for integrating different classes of UAVs into the NAS that meet FAA system safety requirements.

Currently, classification of UAVs has been closely associated with airframes needed for a specific operational mission without regard for a requirement to operate in the NAS. In considering potential UAS operations in the NAS, it is important to recognize that the label "Unmanned Aircraft System" can be applied to a broad range of vehicle types, configurations, and sizes.

[103]The modern DoD concept is to have the various aircraft systems work together in support of personnel on the ground. The integration scheme is described in terms of a "tier" system, and is used by military planners to designate the various individual aircraft elements in an overall usage plan for integrated operations. The tiers do not refer to specific models of aircraft, but rather roles the aircraft must fill. Periodically, the models that fill each role become outdated. The Air Force, Army and Marine Corps each have its own tier system which is not integrated. Additionally the Army has designated UAS based on the nature of support from tactical, to theater to strategic extending from small units, to companies, to battalions, to brigades known as Future Combat Systems (FCS). If this possible confusion were not enough, additional UAS categories are also referenced based upon a UAS grouping from 1 to 4 delineated by maximum gross takeoff weight, normal operating altitude and speed.

While there is not currently a consensus on classifications for flight in civil airspace, the current definitions are consistent with nomenclature used by both research and military communities (i.e., Micro, Mini, Tactical, Medium Altitude, and High Altitude/ UCAV (Unmanned Combat Air Vehicle). These classifications are based upon UAV mission requirements. As the architecture and requirements change for better performance, increased endurance, and stealth operation, this study recommends using a more comprehensive breakdown of UAV classification associated with a kinetic energy envelope which will make it easier to determine safety metrics for catastrophic events or accidents so that an educated assessment can be made for integration of UAS operation into the NAS. The proposed notional breakdown of UAS classification is explained below with additional emphasis placed upon the promising future development of nano and micro vehicles.

AeroVironment UAS Nano Hummingbird

Image credit: Wikipedia

[103] "U.S. Military UAV Tier System". http://en.wikipedia.org/wiki/U.S._Military_UAV_tier_system

NANO (Less than 1 lb) [104]**:** In 1997, DARPA began a multi-year, $35 million development program to develop a tiny drone whose largest dimension was no more than 6 inches; would carry a day-night imager, have an endurance of about two hours, and be very low cost. These devices are typically bigger and heavier than a real hummingbird, but are smaller and lighter than the largest hummingbird varieties. These Nano Air Vehicles (NAVs) could be deployed to perform reconnaissance and surveillance in urban environments or on battlefields, and might perch on windowsills or power lines, or enter buildings to observe its surroundings, relaying camera views back to its operator. According to DARPA, the NAV's configuration will "provide the warfighter with unprecedented capability for urban mission operations." This NAV is also called the "Hummingbird**.**"

Nano vehicles support ISR, research and development and recreational applications. The DoD does not currently operationally field Nano vehicles, although there is currently notable research underway for use in biomimicry.

MICRO (More than 1 lb to 4.5 lbs)[105]**:** The term, Micro Air Vehicle (MAV), may be somewhat misleading if interpreted too literally. We tend to think of flying model aircraft as "miniature," so the term "micro" now alludes to a class of significantly smaller vehicles. But MAVs are not small versions of larger aircraft. They are affordable, fully functional, militarily capable, small flight vehicles in a class of their own. These vehicles include the Raven, Wasp, TacMac, Skate, and Inceptor, among others. The definition employed in DARPA's program limits these craft to a size less than 15 cm (about 6 inches) in length, width, or height, (though they can be larger if required). This physical size puts this class of vehicle at least an order of magnitude smaller than any missionized UAV developed to date.

Micro UAS
AeroVironment Raven A/B
Image Credit: Aerovironment

In general the micro vehicle mission is limited sensor ISR that combines tactical portability into a small LOV package. In terms of the DoD this is a sub-Tier I System for the Army and Marines, but does fulfill the role of a Class I System in the Future Combat System (FCS) parlance for small military tactical unites.

Small UAS
Honeywell RQ-16A T-Hawk
Image credit: Wikipedia

SMALL UAS (More than 4.5 lbs to 55 lbs)[106]**:** The flight control, mission control, and communications gear aboard Small UAVs—like the T-Hawk, Raven,

[104] "Miniature UAV". http://en.wikipedia.org/wiki/Miniature_UAV
[105] James M. McMichael and Col. Michael S. Francis. "Micro Air Vehicles – Toward a New Dimension in Flight". August 1997. http://www.fas.org/irp/program/collect/docs/mav_auvsi.htm
[106] Jeff Child. "Small UAVs Upgrade for New Capabilities." *COTS Journal*, December 2010. http://www.cotsjournalonline.com/articles/view/101654

Dragon Eye, Shadow, Scan Eagle, Silver Fox, Manta, Coyote and Super Bat—face some of the most challenging design restrictions. Selecting the right embedded electronics and embedded computers in those systems becomes a make or break decision. Investment in UAV development and procurement continues across all branches of the DoD. In volume, the Small UAV segment of this market exceeds that of medium and large UAVs due to costs when considering mission needs. This class of UAVs faces the most difficult challenges with reducing size, weight and power (SWaP) while at the same time cramming more functionality and autonomy into Small UAV payload systems.

Small UAS support broader multi-sensor ISR missions than Micro UAS. They are less sensitive to meteorological conditions than Micros as well as have greater range, endurance and payload capabilities. These vehicles also possess the ability to carry stores for delivery, including target marking and ordinance delivery. In terms of the DoD this can be a Tier I or Tier II System for the Army and Marines and does fulfill the role of a Class I and Class II System in the Future Combat System parlance for small military tactical unites.

Ultralight Size UAS
Boeing RQ-21A Integrator
Image credit: UAV Global

ULTRALIGHT (FAA defined as 55 lbs to 254 lbs)[107]: FAA Rule Part 103 weighs less than 254 pounds empty weight, excluding floats and safety devices which are intended for deployment in a potentially catastrophic situation. A large number of various aircraft reside in this weight category. They can be fixed-wing as well as rotary. Ultralight size UAS include the Inceptor, Mako, Cobra, Bat 4 and Golden Eye.

The majority of these vehicles are in the 100 pounds to150 pound range. Popular missions include ISR; some can be fitted with stores delivery as well. This is an Army Tier III System that performs the role of an Army Class III UAS for battalion-size forces.

LIGHT SPORT AIRCRAFT (FAA Defined 255 lbs to 1,320 lbs): FAA LSA Rule Maximum gross takeoff weight—1,320 lbs, or 1,430 lbs for seaplanes. Examples of these types of aircraft are the Shadow and Pioneer series that have been built for military operations and are time-tested platforms for providing reconnaissance, surveillance, targeting, and assessment.

Light Sport Aircraft Size UAS
AAI RQ7B Shadow 200
Image credit: SUAS News

There are a limited number of UAVs in this size and weight range. Their major missions include ISR and some vehicles can be fitted with stores delivery. In addition to the Ultralight this is an Army Tier III System that performs the role of an Army Class III UAS for battalion-size forces.

[107] "FAR Part 103 – Ultralight Vehicles Operating Requirements". October 1982. http://www.usua.org/Rules/faa103.htm

SMALL AIRCRAFT (FAA defined 1,320 lbs to 12,500 lbs): These are systems over 1,320 lbs, operating below Class A airspace. Examples of these types of aircraft are the "Hunter and Predator" series UAVs that have been built for military operations and are time-tested platforms for providing Reconnaissance, Surveillance and Target Acquisition (RSTA).

This class of UAS also provides a fast, powerful combat attack vehicle that is relatively small when compared to a manned fighter. The Reaper is a better-known variation of these vehicles.

Small Aircraft Size UAS General Atomics MQ-9 Reaper

Image credit: Weapons Blog

These vehicles can be considered an Army Tier III vehicle fulfilling a Future Combat System Class III and IV roles for battalion and brigade size forces. While these vehicles can provide ISR, they are more versatile in delivering stores as well as being employed for cargo and search and rescue. They also slot into a possible class of optionally manned aircraft.

MEDIUM AIRCRAFT (FAA defined 12,500 lbs to 41,000 lbs): An example of this aircraft is the Global Hawk that is configured to carry a large payload of munitions. These vehicles move into the strategic range of long distance ISR missions. There are no comparable vehicles planned for the Army or Marines. The Air Force defines its tier levels uniquely and vehicles in this weight range Tier II+ and Tier III. Coincidentally, the Navy has adopted at least one vehicle called the MQ-4C Triton Broad Are Maritime Surveillance (BAMS UAS) to fulfill and ISR role.

LARGE AIRCRAFT (FAA defined 41,000 lbs to 300,000 lbs): Other than the X-47B Pegasus (AV-1), there are no UAS in this weight range. However, it is expected a new class of DoD aircraft will emerge as optionally pilot aircraft. These aircraft, some of which will be flown unmanned depending on mission, will begin to replace current manned aircraft with the same of similar missions as bombers and transport aircraft.

Large Aircraft Size UAS Northrop Grumman X-47B Pegasus

Image credit: ProBoards

OTHER (Various Weights and Sizes): There are a variety of vehicles that are currently unclassified, represented by paragliders such as the Long Endurance Autonomous Powered Paraglider (LEAPP), airborne wind turbines (),[108] and blimps (Spector)[109]. Generally, cargo movement and possibly communications relay can define the missions of these non-aircraft aerial vehicles.

A number of classification systems developed by the DoD and others attempt to organize the types and characteristics of over 200 different UAS vehicles in Groups, Tier Levels or Combat Support. Table 1 provides a different set of descriptors that uses some FAA classifications, such as Ultralight and Light Sport, to further define the growing variety of smaller UAS. Given trends toward micro-miniaturization

[108] Makani Power. http://www.makanipower.com/
[109] American Blimp Corporation. https://en.wikipedia.org/wiki/American_Blimp_Corporation

associated with greater operational capabilities, especially to support ISR missions, a further expansion of the smaller end of the UAS spectrum is warranted. These classifications are easily cross referenced with the representative UAS vehicles.

Table 8 - Notional UAS Vehicle Classification and Categorization

UAS Description	Weight (Pounds)	Overall Size (Feet)	Mission Altitude (Feet Above the Surface)	Mission Speed (Miles per Hour)	Mission Radius (Miles)	Mission Endurance (Hours)
Nano	< 1	<1	<400	<25	<1	<1
Micro	1 to 4.5	<3	<3,000	10 to 25	1 to 5	1
Small UAS	4.5 to 55	<10	<10,000	50 to 75	5 to 25	1 to 4
Ultralight Aircraft*	55 to 255	<30	<15,000	75 to 150	25 to 75	4 to 6
Light Sport Aircraft*	255 to 1320	<45	<18,000	75 to 150	50 to 100	6 to 12
Small Aircraft*	1,320 to 12,500	<60	<25,000	100 to 200	100 to 200	24 to 36
Medium Aircraft*	12,500 to 41,000	TBD	<100,000	TBD	TBD	TBD

***FAA-defined Manned Aircraft Weight Categories**

7.2 Department of Defense[110]

Since 1917, United States military services have researched and employed UAVs.[111] Over that time, they have been called drones, robot planes, pilotless aircraft, RPVs (remotely piloted vehicles), RPAs (remotely piloted aircraft) and other terms describing aircraft that fly under control with no person aboard.[112] They are most often called UAVs, and when combined with ground control stations and data links, form UAS, or unmanned aircraft systems.

The DoD defines UAVs as powered, aerial vehicles that do not carry a human operator, use aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, and artillery projectiles are not considered UAVs by the DoD definition.[113] UAVs are either described as a single air vehicle (with associated sensors), or a UAV system (UAS), which usually consists of three to six air vehicles, a ground control station, and support equipment.

A major new category of vehicles is emerging known as optionally piloted aircraft, also referred to as pilot augmented vehicles. This represents technology transfer from UAS to manned aircraft to allow for more aircraft pilot automation – to the degree that the aircraft may be flown with a reduced flight crew or even without a pilot onboard. Developments in aircraft automation systems have been ongoing for decades with efforts to offload pilot workload or at least organize workload into manageable sequences that humans can master. The concept of “pilot agents” and “decision support” are popular nomenclature for these continuing efforts. UAS technologies are expected to be blended with continuing aircraft flight-deck automation to create this new class of optionally piloted aircraft.

UAS use has increased because of a convergence of technology, mission needs, and economic factors. Advanced navigation and communications technologies were not available just a few years ago, and increases in military communications satellite bandwidth have made remote operation of UAS more practical. The nature of the Iraq and Afghanistan wars has also increased the demand for UAS, as identification of and strikes against targets hiding among civilian populations required persistent surveillance and prompt strike capability, to minimize collateral damage. Further, UAS provide an asymmetrical—and comparatively invulnerable—technical advantage in these conflicts.

Reflecting a growing awareness and support for UAS, Congress has increased investment in unmanned aircraft vehicles annually. The FY2001 investment in UAS was approximately $667 million. For FY2012, DoD asked for $3.9 billion in procurement and development funding with much more planned for the out-years.[114] The DoD inventory of unmanned aircraft increased from 167 to nearly 7,500 from 2002 to 2010.[115]

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[110] Excerpts from “Policy Options for Unmanned Aircraft Systems”, United States Congressional Budget Office, June 2011, and Jeremiah Gertler, January 2012, are widely used and quoted in this section.

[111] National Museum of the U.S. Air Force. “Kettering Aerial Torpedo ‘Bug’”. http://www.nationalmuseum.af.mil/factsheets/factsheet.asp?id=320.

[112] Drones differ from RPVs in that they are designed to fly autonomously.

[113] “Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Terms.” Department of Defense, November 2010 as amended through March 2013.

[114] “Program Acquisition Costs by Weapon System”. Office of the Under Secretary of Defense, February 2011, p. 1-1.

DoD UAS research and development (R&D) funding has also grown for a variety of reasons: UAS are considered a growth industry; many UAS are relatively inexpensive to produce; and new technology in miniaturization has helped accelerate the development of many UAS types. Congress has approached UAS development with strong encouragement tempered with concern. Notably, in 2000, Congress set the goal of making "one-third of the aircraft in the operational deep strike force aircraft fleet" unmanned. Currently DoD is investing in communications, command, and control infrastructures with particular emphasis upon human interface. Research is investigating and prototyping operator command stations that can permit a single operator to manage and control multiple UAS vehicles.

7.2.1 Quantity and Types of UAS

The quantity and type of UAS procured and deployed by the DoD will result in a convergence of affordability and technologies with mission needs. Technological innovation is well on its way in a number of major UAS subsystem areas including: airframes; power plants; sensors; communications; command and control; and information processing. In many regards these enabling technologies will not only satisfy long-term mission needs, but will create new mission needs as well.

It is expected there will be a robust development and deployment of UAS because they satisfy the basic tenets of a newly emerging disruptive technology. First, they alter time. In the case of DoD, UAS can provide persistent and actionable activity over a target of interest for extended periods. Second, they alter space. Command and control of UAS can be exercised from thousands of miles away. Third, they change the relationships of individuals and organizations. UAS remain the first and last end of a chain of networked-enabled operations.

While the contemporary development and deployment of UAS has mostly supported ISR missions, it is the ordinance or stores delivery that has taken a high profile in the press. In addition to stores delivery, including cargo, a number of other missions are met by UAS. These include but are not limited to: communications relay; search and recovery; electronic jamming; aerial refueling; mapping; bomb detection and destruction; firefighting; reconnaissance for nuclear, chemical, or biological weapons of mass destruction; support of special operations; marine interdiction; emplacement of obstacles, such as mines; and psychological warfare.

In addition to obvious benefits, UAS can perform dirty, dull, and dangerous missions previously requiring manned aircraft. This reduces the risk to human life as well as extends the range of human physiological capabilities and endurance. The fact that aircraft no longer need to be burden by design considerations that support humans, aircraft can be lighter, smaller, more maneuverable, and less costly. In other words, UAS provides a faster, cheaper, and a better means of accomplishing needed tasks reflected in a projection of accelerating market growth in all aviation segments.

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[115] Ed Wolski, "Unmanned Aircraft Systems, OUSD (AT&L) Unmanned Warfare", briefing, January 2009, p. 6; and Dyke Weatherington, "Current and Future Potential for Unmanned Aircraft Systems, OUSD (AT&L) Unmanned Warfare", briefing, December 2010. (Hereinafter "Weatherington brief.")

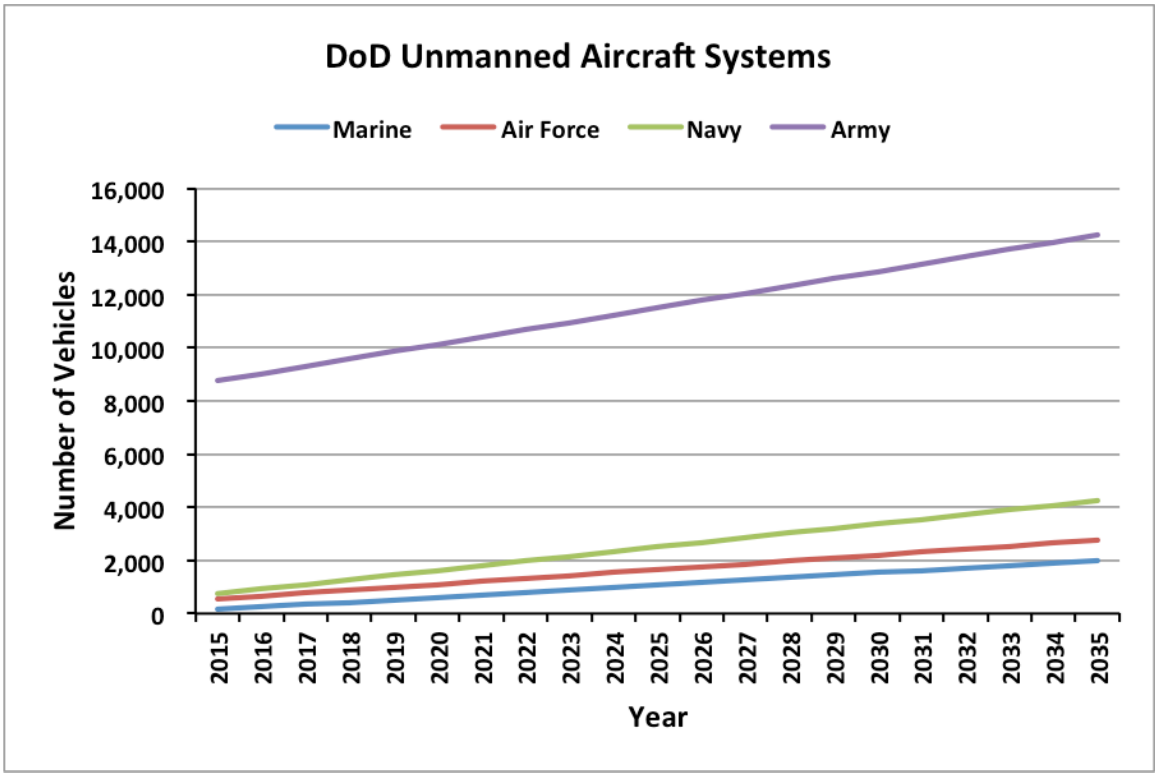

Figure 7-1 - DoD Unmanned Aircraft Systems by Service

[116]As of 2010, the DoD had 146 UAS units based at 63 continental United States (CONUS) locations. By 2015, the Joint UAS Center of Excellence (JUAS COE) estimates the DoD will have 197 units at 105 locations - a 35 percent increase in units and 67 percent increase in number of locations.

[117]Over the next 10 years, DoD plans to purchase about 730 new medium-sized and large unmanned aircraft systems based on designs currently in operation, while also improving the unmanned aircraft already in service. By the Congressional Budget Office's (CBO's) estimates, completing the investments in systems for which there are detailed plans will require about $36.9 billion through 2020.
DoD currently operates 7,500 unmanned aircraft plus an additional estimated 11,250 manned aircraft. The majority of those unmanned aircraft are short-range reconnaissance systems that have a wingspan of a few feet and have handheld controls used by small military units in combat to look "around corners" or "over hills." Spending for those systems represents a relatively small proportion of the total investment planned for unmanned aircraft systems. The bulk of DoD planned spending is for the more costly medium-sized and large unmanned aircraft systems that are designed to conduct reconnaissance missions or attack ground targets. The development and deployment of HALE and MALE is planned to be the core competency of the USAF.

The armed services have developed detailed procurement plans, including estimated quantities and costs, for the unmanned aircraft systems that are in or nearing production. Those plans would increase the inventory of the aircraft by 35 percent over the next 10 years. DoD also is investing in research and

[116] "Unmanned Aircraft System Airspace Integration Plan". Department of Defense UAS Task Force Airspace Integration Integrated Product Team, March 2011, Version 2.0, p. 6.
[117] Congressional Budget Office, p. 1-2.

development for the next generation of more technologically advanced unmanned aircraft, which will provide improved reconnaissance and attack capabilities and will broaden the types of missions that can be accomplished.

As the funding required for near-term manned systems are forecast to begin to decline after 2015, funding for the next generation of unmanned aircraft will probably increase. Accurately analyzing the longer-term plans will not be possible until they are defined in more detail.

It should be noted that projected DoD growth is more managed due to fiscal constraints and mission needs than an unfettered emerging market. This means that to a large degree typical "S-curve" profiles will not likely be seen in DoD procurements of UAS.

It is expected that the total number of DoD aircraft, both conventionally manned as well as unmanned, will grow to 27,000 vehicles by 2035 including 8,000 traditional aircraft, 14,000 UAS of all sizes and types and 5,000 new aircraft with UAS technologies for pilot augmentation or optional pilot replacement. This growth is paced by the introduction of new and more capable unmanned or optionally manned aircraft accomplishing broader DoD missions. The percentage of DoD unmanned vehicles is expected to grow from 25 percent in total today to 70 percent of the DoD fleet by 2035, including new, optionally manned or pilot augmented aircraft.

The Air Force currently operates about 5,400 aircraft. Less than 5 percent of this total is unmanned and none are optionally manned. The Air Force projects that its fleet could grow to some 5,800 aircraft by 2035 with almost 60 percent optionally manned or unmanned. For example, replacement of the traditional long-range manned bomber fleet is under discussion to be replaced by an initial new fleet of 80 optionally manned aircraft at a cost of some $100 billion. The Air Force also expects that its large unmanned aircraft fleet will grow to about 750 vehicles leaving the bulk of the Air Force fleet modernization focused on optionally piloted vehicles assuming broad mission roles from attack to transport.

It is expected the shift in Navy and Marine assets toward optionally manned and unmanned aircraft will parallel that of the Air Force, although the Navy will employ smaller shipboard tactical vehicles for surveillance as well as weapons ordinance delivery. In addition, the Marines will increase the use of tactical UAS for both ISR and weapons ordinance delivery. This should increase the naval and marine aircraft inventory from 3,700 vehicles today to some 4,800 by 2035, including as many as 2,500 UAS vehicles. A much more significant change is expected in the Army in terms of the development and deployment of UAS.

Currently 55 percent of the Army's aircraft are represented by some 6,200 predominantly Small UAS. This number is expected grow to some 10,000 UAS representing more than 75 percent of the Army's aviation assets. As optionally manned aircraft will drive Air Force UAS development and investments, tactical UAS platforms that can effectively deliver ordinance will be a notable driver in the future for the Army. This is not unlike the introduction of aircraft in WWI when the initial reconnaissance mission developed into combat roles, both attacking ground targets and air-to-air combat. In addition, the Army is advancing its requirements for larger UAS vehicles, such as the Grey Eagle, for "regional theater" activities and in some cases may overlap with Air Force missions and vehicles.

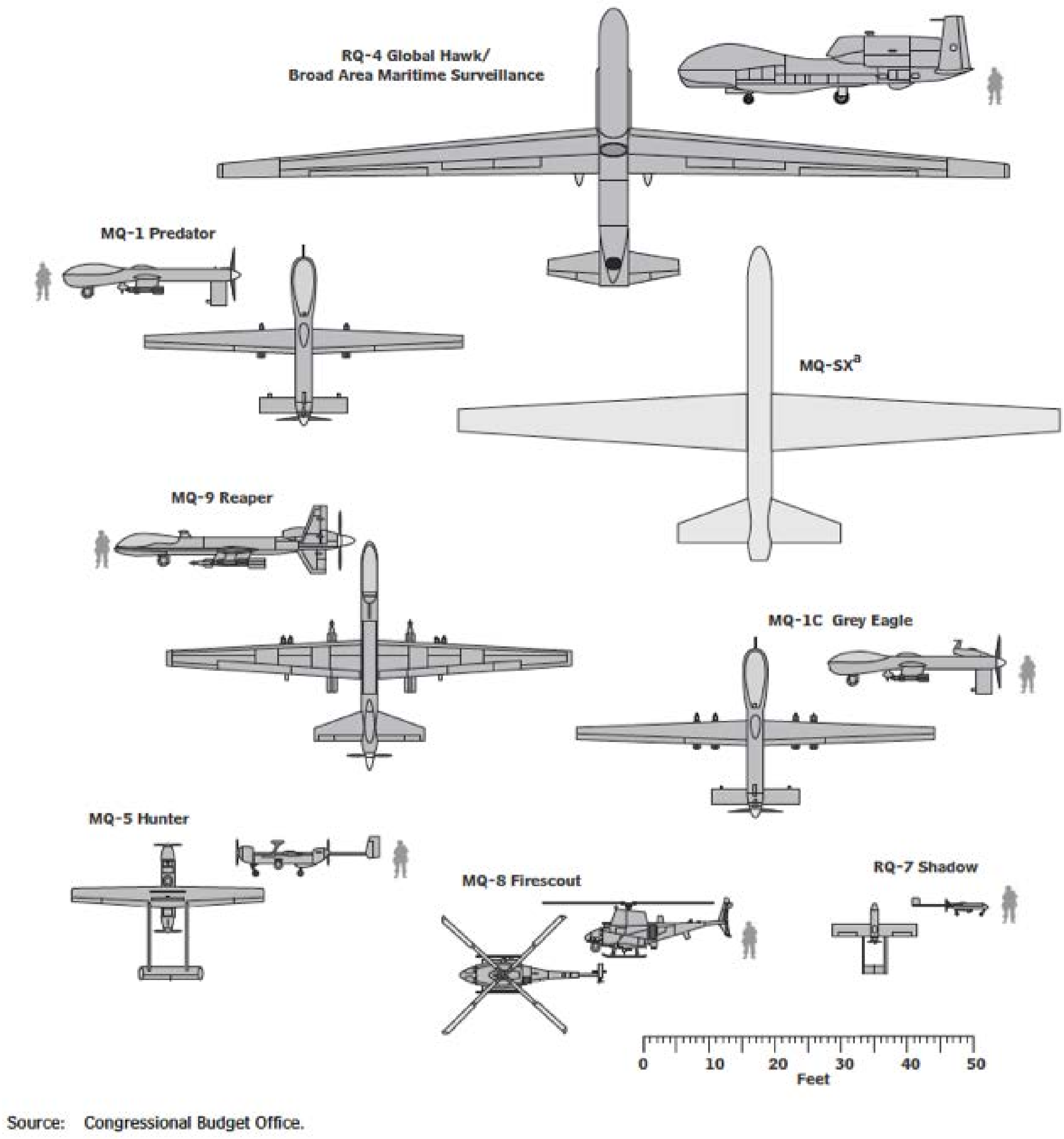

Figure 7-2 - DoD UAS Aircraft Larger than Small UAS

7.2.1.1 Air Force

[118]The Air Force, in early 2011, operated at least four medium-sized or large unmanned aircraft: Global Hawks, Predators, Reapers, and Sentinels. The largest aircraft is the jet-powered RQ-4 Global Hawk, and the Air Force has 14 of them, according to CBO information. The most numerous, at approximately 175 aircraft, is the MQ-1 Predator, a piston-engine propeller aircraft that can take still or video imagery and

[118] CBO Policy Options, p. 1-3

shoot Hellfire missiles. A larger version of the Predator, the turboprop-powered MQ-9 Reaper, is beginning to enter the force, and about 40 have been delivered as of 2011. (The "MQ-" designation for the Predator and Reaper identify them as multi-mission aircraft capable of reconnaissance and attack missions.)

The RQ-170 Sentinel is a stealthy reconnaissance aircraft whose existence has only recently been acknowledged by the Air Force. Most performance characteristics of the Sentinel remain classified. The Air Force's near-term goals are to increase the number of Global Hawk and Reaper aircraft that can be continuously and simultaneously operated. To meet that goal, the Air Force plans to purchase 288 Reapers (48 per year from 2011 through 2016) and 28 Global Hawks from 2011 through 2018. Documents provided to Congress by DoD indicate plans to continue purchasing multi-mission unmanned aircraft after 2016, although the type of aircraft is not specified.

On the basis of the information available, CBO assumed that the Air Force's purchases after 2016 would continue at 48 aircraft per year and would comprise either additional Reapers or a follow-on aircraft with range, payload, and cost similar to the Reaper. The Air Force is also exploring the characteristics that would be desired in a larger aircraft a generation beyond the Global Hawk. About $20.4 billion will be needed for the aircraft the Air Force plans to purchase through 2020, CBO estimates: $7.3 billion for Global Hawks and $13.1 billion for Reapers and their follow-on. Costs would average about $2.0 billion per year through 2020.

7.2.1.2 Army

According to the CBO in 2011 the Army operated three medium-sized unmanned aircraft systems: Hunters, Shadows, and Predators. Overall, the Army's inventory included about 20 MQ-5B Hunters (older aircraft scheduled for retirement by 2013), about 450 RQ-7 Shadows, and about 40 MQ-1 Predators in two versions (specifically, MQ-1 Warrior Alphas and MQ-1C Grey Eagles). From 2011 to 2016 the Army planned to purchase 20 Shadows to replace losses, upgrade the existing Shadows with tactical data links and a laser targeting system, and purchase 107 more of the medium-altitude Grey Eagles. CBO estimates that Army plans will cost about $5.9 billion ($1.9 billion for the Shadows and $4.0 billion for the additional Grey Eagles). In the longer term, the Army is exploring concepts for an aircraft that has greater endurance. The Army may also decide to resume efforts to increase the capabilities of unmanned aircraft used by combat brigades; those plans were shelved when the Army's Future Combat System was canceled in 2009.

7.2.1.3 Navy and Marine Corps

[119]In 2011 the Navy tested two new types of aircraft that it hopes to field in the near future: the long-endurance Broad Area Maritime Surveillance (BAMS) aircraft, which is a Global Hawk variant optimized for naval operations, and the MQ-8B Firescout unmanned helicopter. The Navy plans to purchase 36 BAMS aircraft at a cost of about $9.4 billion by 2020 and operate them from a few bases worldwide to provide surveillance of activities on the oceans. The Navy also plans to purchase 61 Firescouts by 2020 at a cost of $1.0 billion; those helicopters will be based on selected surface ships and will provide local

[119] CBO Policy Options, p. 3

reconnaissance and the capability to attack hostile surface targets. The Navy plans call for purchasing a total of 65 BAMS through 2026 and 168 Firescouts through 2028.

The Marine Corps is in the process of fielding the Shadow to support ongoing operations in Southwest Asia. Thirteen systems (with four aircraft per system) were delivered by the end of calendar year 2009. The Marine Corps does not plan to purchase additional Shadow systems but instead will spend about $120 million to upgrade some Shadows already in its inventory. In the longer term, the Navy is exploring concepts for a carrier-based unmanned aircraft, called the Unmanned, Carrier-Launched Airborne Surveillance and Strike (UCLASS) aircraft, and is currently flying a demonstrator aircraft to help develop the technologies and procedures needed to operate such an aircraft. The Marine Corps is exploring concepts for a medium-sized system that would be designed to perform various missions in support of amphibious operations. Both systems might enter service by 2020. In addition, the Navy procured the RQ-21A a Small Tactical UAS (STUAS) from Boeing Insitu in a fee for services contract arrangement also referred to as “buy by the pixel”

7.2.2 Effects on NAS Airspace

From an FAA perspective, DoD users should present the most manageable UAS challenge in terms of operations and airspace. USAF operations will focus on HALE and MALE missions that are conducted in Class A airspace[120]. This means these aircraft will be operating at mission altitudes in an airspace environment where all aircraft are known and under control of air traffic controllers. These vehicles will be launched and recovered within designated Restricted or Warning airspace areas, thus minimizing their near-term impact to FAA air traffic controllers and the National Airspace Systems
Similar to manned aircraft, HALE and MALE UAS aircraft will be operated by pilots. These pilots, however, will be located on the ground and could be thousands of miles away from the vehicles they are flying. This will provide a number of major challenges. While a reference to an autonomous UAS is often used, all current unmanned aircraft systems have a human in the command and control loop.

7.2.2.1 Communications, Command, and Control

The first challenge is the availability, reliability, integrity, and latency of one or more communication links between the remote pilot and the air traffic controller. Current FAA policy requires the UAS vehicle to have air-to-ground communications through the vehicle and relayed to the pilot. While the current FAA communications air-to-ground infrastructure supports a robust and frequency-protected short range VHF and UHF radio frequency link, it does not address the requisite link from the UAS vehicle to the remote pilot or operator.

If the UAS aircraft’s mission is within a hundred mile radius or so, air traffic control communications can be relayed from the vehicle to and from the remote operator through a non-air traffic control terrestrial communications network. Coincidentally the 2012 World Radio Communication Conference (WRC) approved a shared international allocation within two aeronautical bands, 960–1164 MHz and 5091–5150 MHz, for terrestrial communications, command, and control UAS activities. Although approved, little if

[120] Generally, airspace from 18,000 feet mean sea level (MSL) up to and including flight level (FL) 600, including the airspace overlying the waters within 12 nautical miles (NM) of the coast of the 48 contiguous states and Alaska. Unless otherwise authorized, all pilots must operate their aircraft under instrument flight rules (IFR).

any work is underway to define the functional use and protocols or the designated frequencies for this spectrum of UAS activities.

In the case of long-range HALE and MALE missions, this is a satellite communications (SATCOM) link outside of any FAA approved or controlled spectrum. Until this SATCOM link is addressed specifically for civil communications, expansion of non-DoD HALE and MALE UAS will be problematic. Another predominantly domestic communication alternative that does not require a radio frequency solution is the use of (VOIP) integrated into ground-based communication systems that could exist between an air traffic controller and a UAS pilot or operator in a fixed location. Some major manufacturers of air traffic control voice switching systems have already experimented with this approach. The concept is the ground communications between pilot and controller would be concurrently broadcast to airborne aircraft to provide situational awareness.

Although the major emphasis has been on voice, data communications alternatives are emerging that may provide viable improvements in reducing pilot and controller workload as well as reducing errors inherent in human voice communications, such as misspeak – mishear. Currently DoD UAS operators and pilots are extensively using instant text messaging (IM) as a means of communicating one-on-one as well as conferencing. This provides an accurate and detailed record of all communications that can easily be reviewed without being forgotten or confused. Adding text messaging between an air traffic controller or air traffic control data systems specialist or traffic flow management specialist and a UAS pilot or operator would be another communication alternative that should be considered. No doubt an even more important development would be the capability to encode and decode speech to create instant text messages that can be routed by voice command throughout the command and control infrastructure.

7.2.2.2 Vehicle Performance

In addition to communications, another major concern is the performance of a UAS vehicle when operating in the NAS. Safety in NAS is dependent upon air traffic controllers understanding the performance parameters for an aircraft. This is because separation is planned based upon what an experienced controller expects a pilot and aircraft will do in terms of rates of climb, descents, and turns, not to mention speeds. Introducing aircraft into the NAS that may operate outside of a traditional manned aircraft norm, introduces workload and risks, especially if this performance difference is not expected or realized. For example, a communications delay resulting in an unmanned aircraft reacting slowly to an air traffic control instruction could challenge an air traffic controller to establish or maintain safe separation between aircraft. Additionally, an unexpectedly aggressive rate of turn could have an effect on safety. Lastly, speed differentials of UAS (Mach 0.4) and manned aircraft (Mach 0.8) would provide a challenging control environment. These speed challenges require preforming necessary altimetry research to allow slower moving UAS to operate at Flight Levels plus 500 feet.

7.2.2.3 Airspace Transition

A major challenge in integrating UAS into the NAS is in a mixed rules and airspace environment from the surface to 18,000 feet Mean Sea Level (MSL). The FAA has created a number of designated airspace environments, such as Class B[121] and C[122], which require two-way radio communications between pilots and controllers as well as an altitude encoding transponder, and Class D[123] Airspace that only requires two-way radio communications between pilots and controllers. Other designated airspace environments, such as Class E[124] or Class G[125] (uncontrolled airspace), provide only for see-and-be-seen as a primary method of separation for manned VFR aircraft, whether with IFR aircraft or other VFR aircraft.

Obviously a UAS with no pilot eyes onboard poses significant challenges to the efficacy of the FAA Regulation Part 91.1139(b)[126] for see-and-be-seen. In an effort to address this issue, the FAA has conceptualized "sense-and-avoid" which involves aircraft and/or ground surveillance systems to detect other aircraft and automated or manual flight control systems to engage a "fly away" maneuver. Unfortunately, the human pilot is not always predictable. This is one reason the FAA has developed the fully automated Traffic Alert and Collision Avoidance System (TCAS) in use on commercial transport aircraft today. Solving this collision risk challenge for aircraft, both manned and unmanned, flying in reference to visual flight conditions remains a major impediment to NAS integration of UAS notwithstanding a NextGen focus to develop collision avoidance mechanisms under a new FAA NextGen program called Airborne Collision Avoidance Systems (ACAS-X).

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[121] Class B. Generally, airspace from the surface to 10,000 feet MSL surrounding the nation's busiest airports in terms of airport operations or passenger enplanements. The configuration of each Class B airspace area is individually tailored, consists of a surface area and two or more layers (some Class B airspace areas resemble upside-down wedding cakes), and is designed to contain all published instrument procedures once an aircraft enters the airspace. An air traffic control (ATC) clearance is required for all aircraft to operate in the area, and all aircraft that are so cleared receive separation services within the airspace. Mode C altitude encoding altimeter is required.

[122] Class C. Generally, airspace from the surface to 4,000 feet above the airport elevation (charted in MSL) surrounding those airports that have an operational control tower, are serviced by a radar approach control, and have a certain number of IFR operations or passenger enplanements. Although the configuration of each Class C area is individually tailored, the airspace usually consists of a surface area with a 5 NM radius, an outer circle with a 10 NM radius that extends from 1,200 feet to 4,000 feet above the airport elevation and an outer area. Each aircraft must establish two-way radio communications with the ATC facility providing air traffic services prior to entering the airspace and thereafter maintain those communications while within the airspace. Mode C altitude encoding altimeter is required.

[123] Class D. Generally, that airspace from the surface to 2,500 feet above the airport elevation (charted in MSL) surrounding those airports that have an operational control tower. The configuration of each Class D airspace area is individually tailored and when instrument procedures are published, the airspace will normally be designed to contain the procedures. Arrival extensions for instrument approach procedures (IAPs) may be Class D or Class E airspace. Unless otherwise authorized, each aircraft must establish two-way radio communications with the ATC facility providing air traffic services prior to entering the airspace and thereafter maintain those communications while in the airspace.

[124] Class E. Generally, if the airspace is not Class A, B, C, or D, and is controlled airspace, then it is Class E airspace. Class E airspace extends upward from either the surface or a designated altitude to the overlying or adjacent controlled airspace. When designated as a surface area, the airspace will be configured to contain all instrument procedures. Also in this class are federal airways, airspace beginning at either 700 or 1,200 feet above ground level (AGL) used to transition to and from the terminal or en route environment, and en route domestic and offshore airspace areas designated below 18,000 feet MSL. Unless designated at a lower altitude, Class E airspace begins at 14,500 MSL over the United States, including that airspace overlying the waters within 12 NM of the coast of the 48 contiguous states and Alaska, up to but not including 18,000 feet MSL, and the airspace above FL 600.

[125] Class G. Airspace not designated as Class A, B, C, D, or E. Class G airspace is essentially uncontrolled by ATC except when associated with a temporary control tower.

[126] (b) *General.* When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.

The challenge for all UAS aircraft is negotiating or navigating within this mixed aircraft environment airspace. For HALE and MALE UAS this is the transition from and to the airport surface to Class A airspace where 100 percent of the aircraft are IFR and under positive air traffic control.

Coincidentally, there are currently two acceptable alternatives for DoD or public agency UAS aircraft to transition to or from Class A airspace or operate in Class E or Class G airspace. First is to be contained within Special Use Airspace, Restricted, or Warning Areas, and second to operate within FAA designated and approved COA airspace. While there are no operational constraints in operating within a Restricted or Warning Area with the approval of the using agency, there are numerous operational restrictions imposed by the FAA on UAS operating within a COA. Commercial UAS operations by any operator are not currently permitted by FAA policy, although FAA has implied commercial operations will be possible with COA-type operational restrictions for UAS that receive FAA airworthiness certification.

Although Small UAS aircraft and Radio Controlled (RC) model aircraft are virtually indistinguishable in size, performance, and payload, RC models may be operated with few FAA operational constraints[127] while similar vehicles used for commercial purposes are barred from operations by FAA policy.
Until the FAA can adequately address the UAS issues associated with (1) communications, command, and control, (2) vehicle performance, and (3) airspace transitions, UAS operations will be constrained in the NAS by the current air traffic control systems, including its policies, procedures, and technologies. The UAS community is not alone in facing this challenge. Recent airline user efforts championed by RTCA Task Force 5 have recommended the FAA to develop ground-based automation capabilities that complement the automation developments over the last three decades in the cockpit. As yet FAA has not implemented an agenda to automate air traffic controller functions.

7.2.3 Deployment Timelines

With some 8,000 UAS aircraft of all types and sizes deployed, DoD development and deployment timelines are relatively mature. Vehicles committed to ISR and weapon ordinance delivery missions will continue to grow incrementally as new vehicles are developed and deployed to address new UAS mission needs. Cargo and stores delivery is expected to be a new growth area within the next 10 years as well as growth of small tactical weapons delivery systems.

The most notable growth in UAS is expected in about 2020 to 2025, with the development and deployment of optionally piloted aircraft, or in other terms, pilot-augmented aircraft. These aircraft will be able to operate with a reduced crew when carrying humans or highly valuable cargo, but when operating on more routine cargo or stores delivery missions they may be unmanned depending upon points of origin or destination.

By 2035, a more accurate analysis of UAS aircraft and missions will be reasonably refined in terms of cost effective definitions for matching aircraft characteristics with mission needs.

[127] "FAA Advisory Circular AC-91-157: Model Aircraft Operating Standards". Federal Aviation Administration, June 1981.

7.2.4 NAS Changes Needed

Given the nature of the operational, technical, and procedural complexities surrounding the routine use of UAS in the NAS, it is very likely that rather than simple rule and procedural changes accommodating a growing UAS presence; the growing usage of UAS will likely entail transformational changes in the basic concepts and paradigms for aircraft certification, operation, and air traffic control. This in turn means new investments in new means and methods to employ an enabled infrastructure that can accommodate the demands and benefits of UAS.

The UAS challenge for the DoD will be the operation of HALE and MALE aircraft within the NAS. In many cases, this will be driven by the need to transition these aircraft from military bases to and from Class A, or positive control, airspace. This means transiting aircraft outside of Restricted or Warning Areas with a mix of both VFR and IFR aircraft and entails communicating and coordinating command and control of these HALE and MALE vehicles with ATC. Unfortunately, addressing these issues requires investments in technology as well as changes in ATC paradigms, policy, and procedures.

Establishing and sustaining timely, clear, and concise communications between aircraft pilot/operators and air traffic controllers is a basic requirement for aviation safety. Current FAA policy requires that UAS establish and maintain terrestrial radio communications with ATC. This requires that other than small, locally operated vehicles, UAVs operating outside of the operator's line-of-sight carry VHF or UHF ATC band radios. Communication links to the pilot/operator are not defined by FAA and may or may not be within protected spectrum.

Below is the first set of considerations for FAA research needs (and DoD and industry, where appropriate) attendant to facilitating UAS operations in the NAS:

(1) FAA and DoD consider both satellite and terrestrial spectrum frequencies to be designated for UAS activities within protected spectrum bands as a communication link from the UAS to the pilot/operator.

(2) Take regulatory authority to establish and maintain the spectrum identified in (1), including providing standards for radio equipment on the aircraft as well as on the ground, to ensure acceptable communication availability and performance.

(3) Develop a VOIP communications infrastructure to provide ground-to-ground communications links from an air traffic controller to a pilot/operator.

(4) Support both voice and data to enable "Instant Messaging" between multiple parties.

(5) Determine performance and functional standards for portable and fixed communication data links.

(6) Research speech recognition and encoding and decoding for both controller and pilot/operator, which should be enabled over any communications channel capable of carrying data.

(7) FAA and DoD consider that surveillance of HALE and MALE UAS should rely upon ADS-B. Any class, size, or type of UAS above a given size and weight should be required to carry a dual

link 1090 Extended Squitter (1090ES) and a Universal Access Transceiver (UAT) ADS-B transceiver for ATC identification and surveillance. Given the one-megabit-per-second bandwidth of UAT at 978 MHz, it should be used to satisfy the need for protected spectrum as well as available and needed data bandwidth.

(8) Modify UAT to provide two-way data link for both piloted and remotely piloted aircraft. Currently, only a modest portion of the UAS bandwidth is used for ADS-B, TIS-B, and FIS-B. This UAT link could easily serve potential communication, command, and control functions related to ATC.

(9) Research, develop, and integrate a coordinated mission planning and related ATC conformance monitoring mechanism for UAS. The objective is to build a detailed, low-risk four-dimensional flight profile, including lost link and other contingencies, avoiding areas of high population density, critical infrastructure, and heavily used airspace. This UAS mission profile (a.k.a. flight plan) could be filed 24 hours in advance with an FAA radar control facility and reviewed at a position that specializes in UAS operations. Appropriate changes could be made by the FAA and retransmitted to the operator for further negotiations or acceptance. This mission flight plan could be activated and executed within an approved 15-minute window. In essence this creates a “file and fly” approval in lieu of a COA.

(10) Research the feasibility of introducing a UAS position into an FAA facility, manned by a qualified FAA controller or DoD controller or pilot, while being either “worked” or “watched” by an air traffic controller with cognizant control area responsibility. This would enable workload-intensive communications and coordination to be handled primarily by the “monitor” position relieving potential workload for the primary controller. This is similar to the longstanding en-route controller teams (i.e., tracker, radar controller, manual controller) that share workload responsibilities.

(11) FAA, DoD, and industry stakeholders jointly research, develop, and apply new remotely piloted aircraft design and build standards for categories of UAS aircraft certification larger than 4.5 pounds. This will be an important consideration in improving safety of UAS vehicles to a level acceptable to the FAA and the public as criterion to access the NAS. According to a 2012 Bloomberg Report, UAS accident rates of DoD UAS have been in continuing decline and are now approaching that of DoD manned fighter aircraft. For example, in 2011 Predator accident rates were 4.86 per 100,000 flight hours compared to F-16 accident rates of 3.89 per 100,000 flight hours. In many cases marginally higher UAS accident rates are associated with human factor issues as well as software, hardware, and equipment failures attributable to system design or build factors that may not meet established minimum FAA aircraft certification standards.

(12) Leverage DoD-operated domestic air traffic control facilities to research communication, command and control concepts, functions and systems between UAS pilots/operators and air traffic control personnel. This would also allow the DoD to develop procedures and validate standards and requirements for timely recommendations to the FAA supporting civil UAS integration into the NAS.

Given the notable performance differential between many unmanned and manned aircraft, segregation of aircraft with divergent operating characteristics should be a first consideration to facilitate access to the NAS. Providing spacing, sequencing, and separation to a diversity of aircraft with differing operating characteristics imposes a notable workload on an air traffic controllers and can decrease capacity and erode safety margins. Establishing rules and procedures for segregating and integrating slow moving VFR aircraft from high-speed commercial jet transports had been a basic policy and design paradigm since the inception of air traffic control.

(13) Perform research to reduce vertical separation between manned and unmanned aircraft above 18,000 feet to 500 feet, especially when speed differentials are considered. As with Reduced Vertical Separation Minima (RVSM), this research should focus on improved aircraft altimetry and flight control systems.

7.2.5 Value of UAS Products and Services

Reflecting a growing awareness and support for UAS, Congress has increased investment in unmanned aircraft vehicles annually. The FY2001 investment in UAS was approximately $667 million. For FY2012, DoD has asked for $3.9 billion in procurement and development funding with much more planned for the out-years.[128] DoD inventory of unmanned aircraft increased from 167 to nearly 7,500 from 2002 to 2010.[129]

DoD UAS research and development (R&D) funding has also grown, for a variety of reasons: UAS are considered a growth industry, many UAS are relatively inexpensive to produce, and new technology in miniaturization has helped accelerate the development of many UAS types. Congress has approached UAS development with strong encouragement tempered with concern. Notably, in 2000, Congress set the goal of making “one-third of the aircraft in the operational deep strike force aircraft fleet” unmanned.

The dynamic changes associated with new and emerging UAS technologies should serve to shorten UAS lifespan in comparison to manned aircraft. However, it is expected these UAS lifespans will increase as technologies mature and mission requirements stabilize over time thus diminishing lifecycle costs.
It is expected that DoD expenditures will average approximately $4 billion annually for UAS systems through 2020 with marginal growth thereafter to $6 billion and eventually to $10 billion by 2035 as UAS mission roles continue to expand. Reconnaissance and sentry manned aircraft should be rapidly transitioned to UAS while optionally manned aircraft will garner growth for the next 25 years, eventually supplanting much of the DoD manned aircraft fleet.

A critical aspect of cost will be development of non-DoD markets. While initially technology transfers from the DoD salted nascent public and commercial UAS investments, market maturity outside of the DoD will provide innovation and economies of scale that will ultimately benefit the DoD with lower costs for its long-term UAS investments.

The technological maturity of optionally manned aircraft will drive those costs upward an additional $15 billion annually as DoD begins a migration from manned to optionally manned aircraft starting with transport, sentry, tanker, and bomber missions The DoD expects that attack and fighter aircraft missions will be similarly transitioned; furthermore, they envision that any aircraft carrying humans will have a

[128] “Program Acquisition Costs by Weapon System”. Office of the Under Secretary of Defense, February 2011, p. 1-1.
[129] Weatherington brief.

qualified pilot in the cockpit and that only the carriage of non-precious cargo or stores will warrant an unmanned optionally piloted aircraft.

7.3 Public Agencies Other Than DoD

While the Department of Defense has pioneered Unmanned Aircraft Systems for operational deployment, public governmental agencies at the federal, state, and local levels are rapidly beginning to recognize their benefits. In many cases, current aviation investments, such as helicopters costing $1 million or more per year, can be replaced by unmanned aircraft systems at one-tenth the cost. In addition, not only can current governmental missions be more cost effectively accomplished by the use of UAS, but also new capabilities available with UAS can extend an agency's effectiveness bringing greater value to the American public.

For example, securing the nation's land and maritime borders are two challenging and important roles of government. DHS, through Customs and Border Protection (CBP) and the Coast Guard, needs to operate UAS in the NAS to effectively accomplish persistent border and maritime surveillance to detect, interdict, and prevent acts of terrorism and the unlawful movement of people, illegal drugs, and other contraband toward or across the borders of the United States. U.S. maritime and land borders present attractive avenues for entering illegally, conducting terrorist attacks, trafficking contraband, or committing other criminal activities. As the United States improves control over its land borders through a variety of CBP programs and initiatives, the nation's expansive maritime borders, with relatively open ports and coastlines, could become a less risky alternative for bringing people and materials into the country illegally. Key to an effective, layered system of border controls, then, is balance and coverage across the land and maritime domains, including the integrated and aggressive use of UAS. Other UAS applications for DHS involve disaster relief, training of crews, and testing of systems and payloads.

7.3.1 Quantity and Types of UAS

The number and type of UAS vehicles wanted, needed, or desired by the non-DoD Public Agencies very closely reflect those of the DoD with one notable exception. It is unlikely, although not improbable, that public agencies would routinely operate long distance, long persistence vehicles such as the transcontinental Global Hawk. If nothing else, their high costs and demanding support requirements would make their use challenging for non-DoD organizations, although an exception has already been noted for the use of one Global Hawk operated by NASA for atmospheric research for a five-year period.

7.3.1.1 Federal Non-DoD Public Agencies

The government markets for UAS, including the DoD, are comprised of federal, state and local governments known as public agencies. Public agencies include any institutions organized and controlled by government authority or charter. Currently a number of public sector federal agencies, including the CIA, Homeland Security, Department of Justice, Department of the Interior, Department of the Treasury, and NASA operate some 125 UAS for a variety of missions.

Assuming the current and complex underlying UAS issues are resolved thereby allowing the FAA to establish regulatory pathways to operate UAVs by 2015, federal agencies will begin to acquire UAS to cost-effectively meet their mission needs. In addition to the agencies currently using UAS, it is expected UAS will play notable support roles for the Department of Agriculture, Department of Commerce, and the Department of Energy. Between 2015 and 2035 it is expected that federal agency UAS fleets will grow from a few hundred to 10,000 with over 90 percent of these vehicles categorized as Nano, Micro, or Small UAS. Ultralight, Light Sport, and Medium, as defined by Table 8, will find a role with a number of agencies, such as Bureau of Land Management or Coast Guard, that need to survey large tracts of land or water for a variety of missions. In all cases, the UAS is the transport for the payload, be it sensors or cargo. The number and type of UAS developed, acquired, and deployed will be driven by mission needs and costs.

7.3.1.2 State and Local Public Agencies

In addition to the non-DoD federal public sector, there are 50 states and other U.S. territories and possessions that will find great potential benefits in adopting and using UAS technologies. The pace of acquisition and use is expected to parallel the federal public sector since many states have programs aligned with very similar federal interests. From the modest acquisition of a few hundred UAS in 2015, state UAS inventories should grow to 10,000 vehicles by 2035. These will include modest UAS inventories at colleges and universities.

All told, the federal and state sectors are forecast to be collectively operating some 36,000 UAS vehicles by 2035. This number is comparable to the Nano, Micro, and Small UAS forecasts for local governments; especially including some 18,000 metropolitan police departments and other first responders. The number of UAS vehicles forecast for first responders jumps from a few hundred in 2015 to a number almost equal to all others except the commercial sector - some 34,000 UAS vehicles by 2035. This means an expected population of 70,000 state and local public UAS by 2035.

7.3.2 Effects on NAS

While the effects on NAS airspace will be similar to those discussed in Section 7.2.2 for vehicles operating above 18,000 feet, there is increased complexity and concern for those UAS vehicles operating below 18,000 feet in a mixed VFR and IFR environment with a significant diversity of UAS types and equipage.

The critical concern is the collision risk between UAS and VFR aircraft. To some degree this risk is mitigated within terminal airspace that has a two-way communication requirement between an air traffic controller and a pilot. Risks are further mitigated in these terminal airspace environments where radar or ADS-B surveillance is available and the air traffic controller has responsibility for aircraft separation. For the past 100 years, aviation has adopted the historical “rules of the road” for providing right of way to aircraft in a see-and-be-seen environment. This is referred to as “see and avoid”, and means pilots must be vigilant to watch out for other aircraft and avoid them following the rules of the road that are signified in the color of the navigation lights on the wingtips of powered aircraft. For example, the right wingtip on an aircraft is green, signaling that an aircraft converging from the right has the right of way. This of course assumes both aircraft see one another in a timely manner and have the ability to avoid each other. [130]Unfortunately, a number of GA accidents, at least thirty-four during the period from 2007 to 2009, have occurred as a result of the pilot's failure to see and avoid one another. In response to this concern, the FAA has encouraged many organizations to work on UAS sense and avoid.

Given operating altitudes, speeds, sizes, and weight differences, strategies may be explored to enable UAS operations in mixed environment below 18,000. Large vehicles, also easier to see in visual meteorological conditions (VMC), may have a sense-and-avoid system similar to today's Traffic Alert and Collision Avoidance System (TCAS). Perhaps this system will be incorporated into the newly planned Airborne Collision Avoidance Systems X (ACAS X), as the next-generation of TCAS. This system may eventually require all aircraft to have some form of automated collision alerting such as ADS-B UAT TIS-B if they are not equipped with ADS-B 1090ES or Mode S with some form of TCAS. For smaller and slower vehicles, such as a Small UAS between 4.5 pounds and 55 pounds, operating at 10,000 feet and below, within a radius of 25 miles, ground-based surveillance in lieu of airborne surveillance makes sense to detect all manned aircraft and provide automated or pilot-controlled maneuvers to the UAS for collision avoidance.

The other major concern is the risk to persons or property on the ground. The ultimate requirement for UAS vehicle safety will be determined by future, as yet unknown, certification requirements. Since these vehicles do not have a human onboard, their safety requirement does not need to be as stringent as those of transport category aircraft, since the loss of a UAS vehicle would not cause either passenger or operator loss of life. Again depending on characteristics of the vehicle, the mission, and the flight location and path, the associated risk to persons and property on the ground may be minimal. This means that FAA could require minimal regulatory restrictions that encourage UAS market development and growth and sustain an acceptable level of risk and safety. Efforts to allow arctic operations of UAS at altitudes below 400 feet above ground level are an example of absolute minimum safety risk to persons or property.

No doubt the optimal approach to minimizing ground-based risk is to provide mission planning that can optimize flight profiles to minimize flight over populated areas, critical infrastructures, and into high-density airspace environments. This operator plan can be automatically filed and pre-coordinated with FAA 24 hours in advance to create UAS "file and fly," eliminating the need for COAs (FAA Certificate of Authorization). The FAA can review the proposed four-dimensional flight profiles and make amendments as required to minimize impact on the NAS. This modified and approved flight "mission" is sent back to the operator with the proviso that the mission must be launched and conducted within a 15-minute window based on the approved time of departure.

Merging (GBSAA) with mission planning would establish a viable means and method for integration of Small UAS into the NAS. The remaining key is to provide additionally trained personnel at FAA En Route Centers and TRACONS who can serve as UAS flight data mission specialists and/or UAS mission controllers. They would ensure that the integration of UAS into the NAS did not unduly burden the

[130] "Review of U.S. Civil Aviation Accidents: Review of Aircraft Accident Data, 2007-2009". National Transportation Safety Board report No. NTSB/ARA-11/01, p. 47, Figure 41. Washington, D.C., March 2011. http://www.ntsb.gov/doclib/reports/2011/ara1101.pdf.

current air traffic control workforce, both in terms of the number of aircraft and in the complexity of the operations for aircraft spacing, sequencing, and separation services.

7.3.3 Deployment Timelines

The Federal Aviation Administration Modernization and Reform Act of 2012 requires the FAA to develop and implement operational and certification requirements no later than December 31, 2015 for the operation of public unmanned aircraft systems in the NAS.

Chart 2 represents the effects if the current underlying UAS issues are resolved allowing the FAA to establish regulatory pathways to operate UAVs by 2015.The chart illustrates the resultant forecast for UAS market growth in the public agency sector—provided there are no significant regulatory challenges or market development delays that emerge after this time.

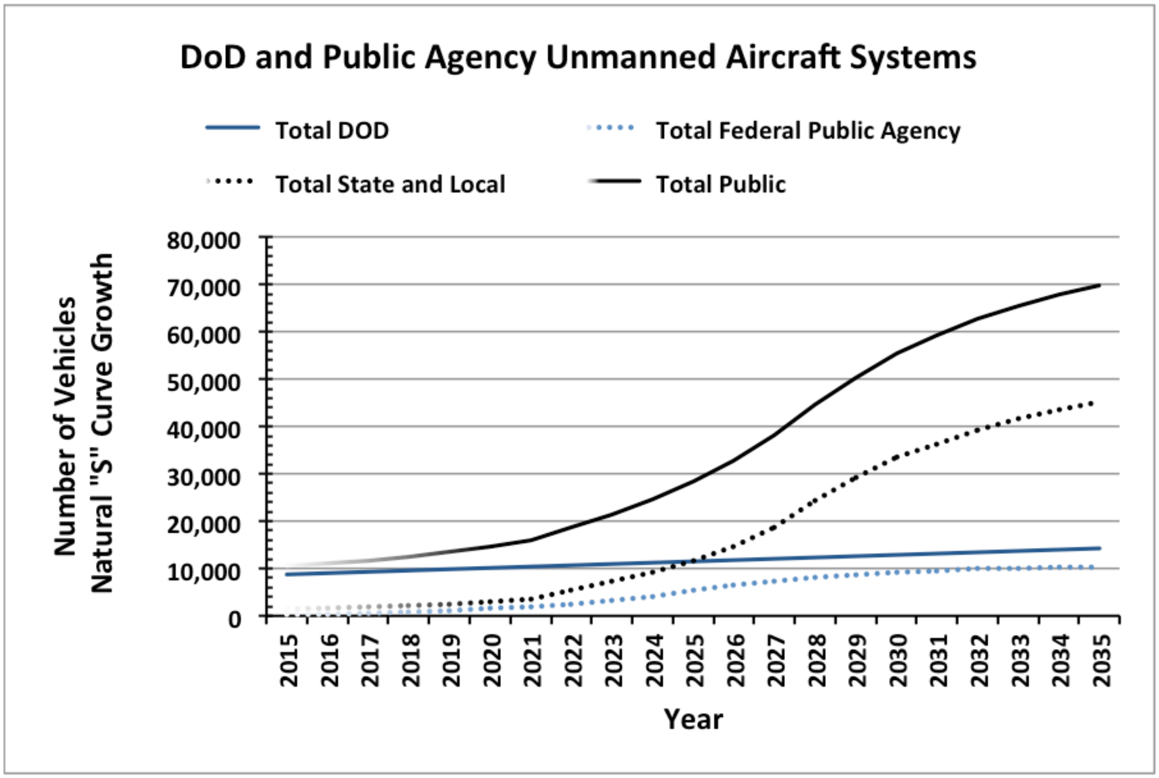

Figure 7-2: Projection of All DoD and Public Agency UAS, 2015 to 2035

7.3.4 NAS Changes Needed

Below is second set of considerations for FAA research needs (and DoD, where appropriate) attendant to facilitating UAS operations in the NAS.

(1) Consider and adopt appropriate categorical exclusions with operational constraints only for small, Micro, and Nano vehicles under 4.5 pounds. These operational constraints would follow the lines of the current Advisory Circular for Model Radio Controlled Aircraft AC-91-57 to stay at or below 400 feet above ground level and more than 3 miles from a public airport, unless approved by air traffic control. Given the continuing developments in UAS integrated micro-miniaturization and the growing endurance and range of Nano and Micro UAS vehicles, this FAA action would reduce unnecessary regulatory burdens on the FAA and the general public affecting tens of thousands of smaller UAS.

(2) Expedite the issuance of the Notice of Proposed Rulemaking for Small UAS. Accepting public comments is essential, and the FAA must publish an acceptable final rule that can lift policy burdens on the social and economic benefits of new technological applications.

(3) Research and establish standards for unique UAS colors and lighting to enhance visibility for pilots to see-and-avoid in addition to any other work pertaining to sense-and-avoid.

(4) Explore UAS nominal kinetic energies to determine ground hazard risks for persons and property to assess vehicle safety needs driving regulatory requirements. Frangibility should also be part of this consideration.

(5) Establish and adopt standards and procedures for GBSAA. This entails the use of three-dimensional primary radar that can detect non-cooperative aircraft targets and provide both emergency multicast broadcasts of UAS activities on aviation frequencies as well as provide collision avoidance maneuvers to a UAS pilot or automated commands directly to a UAS vehicle.

(6) Consider the benefits of better managing UAS controller workload and complexity afforded by increasing the workforce in En Route Centers and TRACONs to handle UAS mission planning and approval, as well as complex UAS coordination and communication tasks.

(7) Review aviation weather requirements as they may apply to various classes and types of UAS vehicles. Current aviation weather needs and requirements have been predicated on a pilot's ability to determine inflight weather conditions. This "left seat" perspective is no longer available for UAS. FAA should undertake an effort to determine if weather-related FAA procedures, rules and requirements can be met by remotely piloted or semi-autonomous or fully autonomous UAS vehicles and their operational constructs.

7.3.5 Value of UAS Products and Services

Over a twenty-year period from 2015 to 2035, the estimated value of public agency UAS products and services are estimated to grow to $30 billion annually and be directly responsible for 200,000 new jobs.

7.4 Commercial Markets

There is a significant uncertainty in the predictability of commercial markets. However, looking at the current radio controlled model market of hobbyists provides some insight that is helpful in extrapolating what the future might bring.

There are over 150,000 member of the U.S.-based Academy of Model Aeronautics (AMA) flying a conservatively estimated 150,000 radio controlled recreational aircraft that carry no payload devices (i.e., electronic devices, such as cameras). Also, there are some 60,000 members of Radio Controlled (RC) Model Clubs in the U.S. as well. Many of these RC Club Members are also members of the AMA.

In addition, there are an estimated 100,000 models, such as the A.R. Parrot Quadra Copter, carrying or capable of carrying one or more payload devices that have the potential for commercial UAS applications. This includes a number of manufacturer and model-specific Do-It-Yourself (DIY) members. All of these DIY models carry payloads capable of commercial applications. The largest member group is the Ardu Copter and Ardu Plane group with some 1,500 members. All told there are approximately 200 model manufacturers in the U.S., many producing RC models. Manufacturers produce approximately 50 RC models capable or enabled for payloads that can be used for commercial UAS missions.

Today, the total number recreational radio controlled or autonomous flying models may well exceed 500,000, many of which are capable of commercial UAS applications.

This very large base of modelers provides an excellent opportunity to jumpstart innovative commercial endeavors once FAA's Small UAS Rule is finalized and adopted. Of course this assumes the rule will not contain undue burdens or challenges that inhibit Nano, Micro or Small UAS market growth, such as requirements for all commercial UAS, regardless of size, to be certified as airworthy by the FAA. Given FAA's regulatory approach not to provide airworthiness certification for Light Sport Aircraft (LSA) and Ultralights, certification for Small UAS vehicles would not be expected as long as industry standards, such as those being developed by the American Society for Testing and Materials (ASTM) F-38 group, were met in Small UAS construction. Further, it is expected that Nano and Micro sized vehicles, as defined by Table 1, would be excluded from an FAA manufacturing requirements.

A crossover market from manufacturers of DoD and public aircraft is expected. However, many DoD and public agency suppliers will be slow to compete in any recognized or growing commercial markets as a result of pricing differentials. A $50,000 DoD Small UAS would not expected to be competitive with a commercial alternative constructed by an experienced DIY or RC modeler whose price point could be closer to $5,000.

There is no question that the development of commercial markets would force many DoD and related public agency suppliers to rethink their business models to create lower cost alternatives that also avoid ITAR (International Traffic in Arms Regulations) restrictions. Perhaps the greatest opportunities for these established DoD suppliers would be high-end UAS (Ultralight and Small as denoted in Table 1) for both domestic use as well as international export.

As previously referenced, the FAA has no timeline to accept or integrate commercial UAS into the NAS. The Congressional Mandate for NAS integration into the NAS only addressed "public" aircraft or vehicles.

7.4.1 Quantity and Type of UAS

It is expected that the overwhelming majority of commercial UAS will fall into the Micro and Small UAS categories as defined by Table 8. The majority of these vehicles will be low-cost and dedicated to specific new and emerging tactical market applications. The source of supply of these vehicles will come initially from the RC-type vehicle makers as opposed to the suppliers of DoD and public agency aircraft. After an initial surge or upswing in commercial sales, reduced growth is expected as needs for early adopters and innovators are met. As UAS usage becomes more mainstream, DoD suppliers are expected to seriously enter the commercial marketplace which will encourage changes in business models, especially emphasizing a service model where professional organizations offer routine ISR and other services wanted, needed, or desired by business and individuals. These changes should again accelerate market growth through 2035.

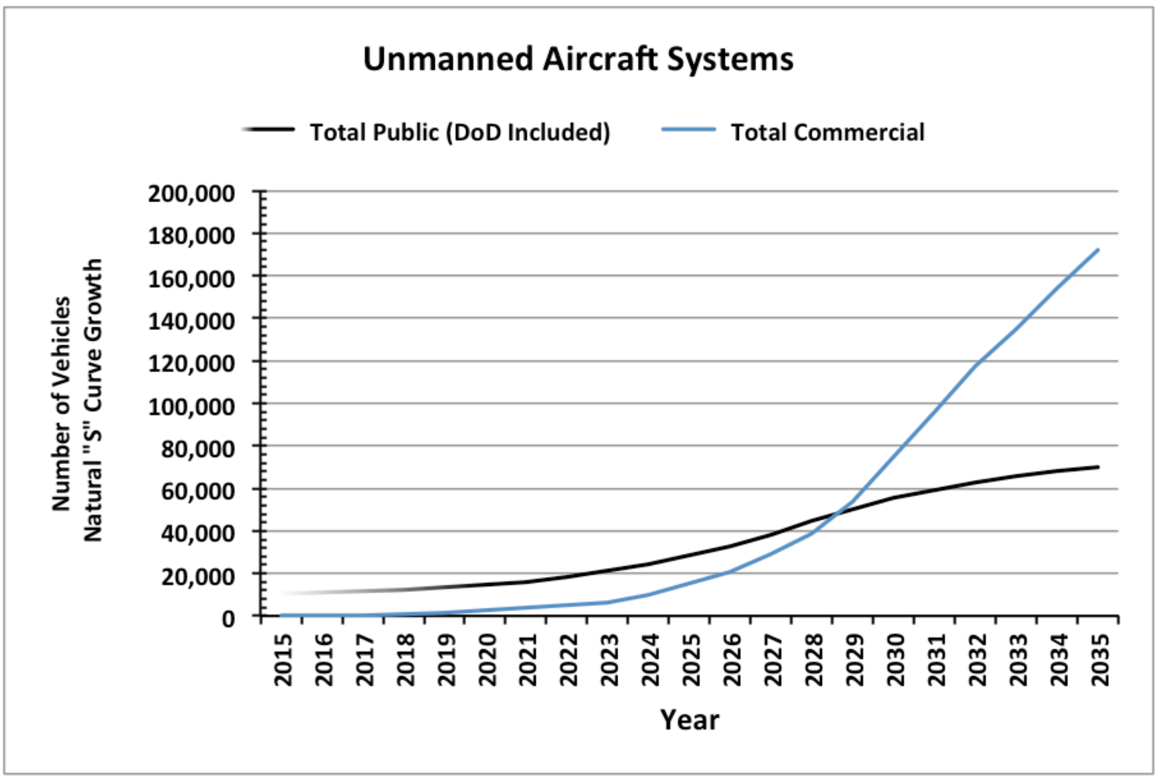

Figure 7-4: Total All U.S. UAS Systems in the NAS

As markets are defined and refined it is expected that beginning in the 2022 to 2023 period commercial sales of UAS vehicles, including products and services, will experience accelerated growth with total UAS vehicles approaching 250,000 by 2035, of which 175,000 will be in the commercial marketplace.

These commercial numbers may be conservative considering potential market sizes. For example, there are over 152,000 farms that have annual incomes of $250,000 or more. It is reasonable for a majority of these farms to employ a Small UAS vehicle with hyperspectral sensors to routinely inspect crops. Larger UAS vehicles could easily replace crop spraying manned aircraft[131] as well. To appreciate the size of the commercial market consider the 450,000 real estate brokers and agents who may want the advantage of a Small UAS to provide marketing perspective for their clients' properties.

There are a number of identified mission needs for UAS. Many of these missions have been previously covered in this report. Their variety and scope can stretch the imagination. The diversity of UAS applications will drive future vehicle and systems development throughout a multitude of UAS categories, classes, and types.

7.4.2 Effects on NAS Airspace

The impacts of commercial UAS vehicles to the NAS will be very similar to those of public agencies as previously discussed in 7.3.2. The major difference will be that Small UAS and larger UAS commercial vehicles will need to meet FAA airworthiness requirements, whether as a result of using and documenting to an accepted industry standard or as part of an FAA certification process resulting in the issuance of an FAA Certificate of Airworthiness under a current regulations (i.e., FAR Part 23) or new FAR regulations tailored to UAS vehicles.

It is expected that an overwhelming majority of commercial UAS vehicles will be split between Small UAS and Micro UAS for predominantly ISR missions. This means that methods and means must be developed to accommodate the thousands of vehicles that will be operating in the NAS. From an operational perspective Nanos and Micros should align with operational constraints currently imposed on RC models, requiring them to fly below 400 feet above the ground and away from airports. Small UAS that fly above 400 feet and below 18,000 feet must meet collision avoidance requirements for onboard or GBSAA, as well as an autonomous or remotely piloted command and control capability. Additionally, air traffic control must be aware of these vehicles and their planned flight profile with airborne or ground-based communication links established and maintained in some, but not all, circumstances.

It is expected that the number of Light Sport, Ultralight, and Small UAS will have a modest impact on the NAS with operational requirements paralleling those of similarly sized public agency UAS vehicles. However, it is believed the development vehicles for non-ISR missions, such as cargo movement, stores delivery, search and recovery, etc., will have unique NAS certification and operational requirements that will have to be developed as the markets begin to emerge and developed.

7.4.3 Deployment Timelines

Given the regulatory policies implemented by the FAA, it is expected that commercial market developments will be delayed as many of the certification and operational issues associated with commercialization of UAS are identified and addressed. Therefore, the ability to start commercial applications of UAS in the NAS is not expected to begin in earnest until 2015.

If FAA regulations are modified, it is expected that many of non-DoD UAS manufacturers, represented "hobbyist" with Micro vehicles, will quickly begin to supply initial ISR market demands to innovative users and early adopters. This will result in an early market interest and surge. There may likely be some

[131] According to the National Agricultural Aviation Association (NAAA) there are 508 companies in the U.S. engaged in crop dusting.

slowdown in rate of sale after an initial surge as more high-end, serious, mission-oriented manufacturers begin design and development of commercial UAS models. Eventually, DoD manufacturers are expected to enter the commercial market predominantly in the Small UAS and larger categories driven by service companies that can better amortize bigger, more sophisticated, and more costly vehicles that can accommodate both ISR and non-ISR missions.

The future of bio-mimicking Nano vehicles is exciting and promising. However, much of the technological development needed to be able to conduct ISR missions is well beyond the hobbyist.. Robust commercial markets are not expected to take hold until the 2020 to 2023 period. This is not unexpected given the generational nature of the adoption of new technology that brings new means and methods to developing wants, needs, and desires.

7.4.4 NAS Changes Needed

Below is the third and final set of considerations for FAA research needs (and DoD, where appropriate) attendant to facilitating UAS operations in the NAS.

> (1) Research and address public privacy concerns for UAS and consider adopting a policy, or create a proposed rule, enabling a process of web-based operator and/or vehicle registration with rapid approval for operating authorization for Small UAS and larger UAS vehicles. Not only might this allow tracking of UAS vehicles, operators, and markets, but it provides a method to withdraw operating approval from those who have been convicted of violating local, state, or federal law, including the illegal invasion of privacy.
>
> (2) Research and assess certifications (FAA AIR), standards (FAA AFS), and operational (FAA ATO) approaches to accommodate UAS. This may eventually mean new, separate, and distinct FAA Aviation Regulations, FAA airmen requirements, and FAA operational guidelines and rules to accommodate UAS.
>
> (3) Evaluate risks attendant to UAS use, given there are no humans onboard and many missions can be profiled to avoid persons and property. A prime factor of risk for airborne and ground collisions is the kinetic energy (i.e., velocity and mass) and the frangibility of a UAS vehicle. For example, a Micro vehicle of foam and balsa construction weighing less than 4.5 pounds traveling less than 20 miles per hour poses little if any collision risk to airborne aircraft or persons or property on the ground. Kinetic energy and frangibility should be considered, especially in addressed categorical exclusion of UAS vehicles operating below 400 feet above the ground.

7.4.5 Value of UAS Products and Services

While the projected value of DoD and other public agency markets will create 200,000 jobs and be valued at estimated at $30 billion annually by 2035, commercial markets will grow to a $5 billion annual market creating an additional 50,000 jobs. Coincidently, the nominal costs for a majority of ISR for commercial application will cost only one-fifth as much as a comparably capable DoD or public agency alternative. The total value of the UAS market in the U.S. looks to be in the neighborhood of $35 billion by 2035 supporting 250,000 workers.

8. Conclusions and Considerations

UAS operations have become a critical aspect of military operations. The volume of UAS operations is expected to surpass manned aircraft operations, for both military and commercial domains, in 2030. The technologies needed to support this transformation are developing rapidly and all the market enablers (with the exception of UAS-friendly policies and regulations) are in place to create innovations in the use of UAS to revolutionize airborne operations. There are considerable challenges to UAS market growth for operations within the NAS; these include regulatory, policy, and procedural considerations; social issues, such as privacy and nuisance concerns; environmental issues, such as noise and emissions; and safety.

In the next two decades, the civil and commercial UAS market is expected to grow larger than the military UAS market. To accomplish this effectively, UAS must prove to be more cost-effective than current manned systems and more effective in carrying out complex tasks. Furthermore, it must be proven that UAS are as safe as current manned operations both in terms of platform airworthiness certifications and operational training and certifications.

As referenced previously in the report, the following considerations for government and industry research needs and considerations are put forth in order to facilitate the safe and effective facilitation of routine UAS operations in the NAS.

The following set of proposed research needs and areas to facilitate UAS operations in the NAS is offered to the FAA for consideration:

(1) Develop a VOIP communications infrastructure to provide ground-to-ground communications links from an air traffic controller to a pilot/operator.

(2) Establish and maintain the spectrum identified in (1), including providing standards for radio equipment on the aircraft as well as on the ground, to ensure acceptable communication availability and performance.

(3) Support both voice and data to enable "Instant Messaging" between multiple parties.

(4) Determine performance and functional standards for portable and fixed communication data links.

(5) Research speech recognition and encoding and decoding for both controller and pilot/operator, which should be enabled over any communications channel capable of carrying data.

(6) Modify UAT to provide two-way data link for both piloted and remotely piloted aircraft. Currently only a modest portion of the UAS bandwidth is used for ADS-B, Traffic Information System Broadcast (TIS-B), and Flight Information System Broadcast (FIS-B). This UAT link could easily serve potential communication, command, and control functions related to ATC.

(7) Perform research to reduce vertical separation between manned and unmanned aircraft above 18,000 feet to 500 feet, especially when speed differentials are considered. As with Reduced Vertical Separation Minima (RVSM), this research should focus on improved aircraft altimetry and flight control systems.

(8) Consider and adopt appropriate categorical exclusions with only operational constraints for small Micro and Nano vehicles under 4.5 pounds. These operational constraints would follow the lines of the current Advisory Circular for Model Radio Controlled Aircraft AC-91-57 to stay at or below 400 feet above ground level and more than 3 miles from a public airport, unless approved by air traffic control. Given the continuing developments in UAS integrated micro-miniaturization and the growing endurance and range of Nano and Micro UAS vehicles, this FAA action would reduce unnecessary regulatory burdens on the FAA and the general public affecting tens of thousands of smaller UAS.

(9) Expedite the issuance of the Notice of Proposed Rulemaking for Small UAS. Accepting public comment is essential, and the FAA must publish an acceptable final rule that can lift policy burdens on the social and economic benefits of new technological applications.

(10) Research and establish standards for unique UAS colors and lighting to enhance visibility for pilots to see-and-avoid in addition to any other work pertaining to sense-and-avoid.

(11) Explore UAS nominal kinetic energies to determine ground hazard risks for persons and property to assess vehicle safety needs driving regulatory requirements. Frangibility should also be part of this consideration.

(12) Establish and adopt standards and procedures for ground-based sense-and-avoid (GBSAA). This entails the use of three-dimensional primary radar that can detect non-cooperative aircraft targets and provide both emergency multicast broadcasts of UAS activities on aviation frequencies as well as provide collision avoidance maneuvers to a UAS pilot or automated commands directly to a UAS vehicle.

(13) Consider the benefits of better managing UAS controller workload and complexity afforded by increasing the workforce in En Route Centers and Terminal Radar Approach Control Facilities (TRACONs) to handle UAS mission planning and approval, as well as complex UAS coordination and communication tasks.

(14) Review aviation weather requirements as they may apply to various classes and types of UAS vehicles. Current aviation weather needs and requirements have been predicated on a pilot’s ability to determine inflight weather conditions. This “left seat” perspective is no longer available for UAS. FAA should undertake an effort to determine if weather-related FAA procedures, rules and requirements can be met by remotely piloted or semi-autonomous or fully autonomous UAS vehicles and their operational constructs.

(15) Research and address public privacy concerns for UAS and consider adopting a policy, or create a proposed rule, enabling a process of web-based operator and/or vehicle registration with rapid approval for operating authorization for Small UAS and larger UAS vehicles. Not only might this allow tracking of UAS vehicles, operators, and markets, but it provides a method to withdraw operating approval from those who have been convicted of violating local, state, or federal law, including the illegal invasion of privacy.

(16) Research and assess certifications (FAA Aircraft Certification Service (AIR)), standards (FAA Flight Standards Service (AFS)), and operational (FAA Air Traffic Organization (ATO)) approaches to accommodate UAS. This may eventually mean new, separate, and distinct FAA

Aviation Regulations, FAA airmen requirements, and FAA operational guidelines and rules to accommodate UAS.

(17) Evaluate risks attendant to UAS use, given there are no humans onboard and many missions can be profiled to avoid persons and property. A prime factor of risk for airborne and ground collisions is the kinetic energy (i.e., velocity and mass) and the frangibility of a UAS vehicle. For example, a Micro vehicle of foam and balsa construction weighing less than 4.5 pounds traveling less than 20 miles per hour poses little if any collision risk to airborne aircraft or persons or property on the ground. The FAA should consider these factors of kinetic energy and frangibility, especially in addressed categorical exclusion of UAS vehicles operating below 400 feet above the ground.

The following proposed research need and area to facilitate UAS operations in the NAS is offered to the DoD for consideration:

(1) Leverage DoD-operated domestic air traffic control facilities to research communication, command and control concepts, functions and systems between UAS pilots/operators and air traffic control personnel. This would also allow DoD to develop procedures and validate standards and requirements for timely recommendations to the FAA supporting civil UAS integration into the NAS.

Given the notable performance differential between many unmanned and manned aircraft, segregation of aircraft with divergent operating characteristics should be a first consideration to facilitate access to the NAS. Providing spacing, sequencing, and separation to a diversity of aircraft with differing operating characteristics imposes a notable workload on an air traffic controller and can decrease capacity and erode safety margins. Establishing rules and procedures for segregating and integrating slow moving VFR aircraft from high-speed commercial jet transports had been a basic policy and design paradigm since the inception of air traffic control.

The following set of proposed research needs and areas to facilitate UAS operations in the NAS is offered jointly to the FAA and DoD (and industry stakeholders, where appropriate) for consideration:

(1) Consider both satellite and terrestrial spectrum frequencies to be designated for UAS activities within protected spectrum bands as a communication link from the UAS to the pilot/operator.

(2) Consider that surveillance of High-Altitude, Long-Endurance (HALE) and Medium-Altitude, Long-Endurance (MALE) UAS should rely upon Automatic Dependent Surveillance Broadcast (ADS-B). Any class, size, or type of UAS above a given size and weight should be required to carry a dual link 1090 Extended Squitter (1090ES) and a Universal Access Transceiver (UAT) ADS-B transceiver for Air Traffic Control (ATC) identification and surveillance. Given the one-megabit-per-second bandwidth of UAT at 978 MHz, it should be used to satisfy the need for protected spectrum as well as available and needed data bandwidth.

(3) Research, develop, and integrate a coordinated mission planning and related ATC conformance monitoring mechanism for UAS. The objective is to build a detailed, low-risk, four-dimensional flight profile, including lost link and other contingencies, avoiding areas of high population density, critical infrastructure, and heavily used airspace. This UAS mission profile (a.k.a. flight plan) could be filed 24 hours in advance with an FAA radar control facility and reviewed at a position enabling fast time simulation. Appropriate changes could be made by the

FAA and retransmitted to the operator for further negotiations or acceptance. This mission flight plan could be activated and executed within an approved 15-minute window. In essence this creates a 24-hour "file and fly" approval in lieu of a Certificate of Authorization (COA).

(4) Research the feasibility of introducing a UAS position into an FAA facility, manned by a qualified FAA controller or DoD controller or pilot, while being either "worked" or "watched" by an air traffic controller with cognizant control area responsibility. This would enable workload-intensive communications and coordination to be handled primarily by the "monitor" position relieving potential workload for the primary controller. This is similar to the longstanding en-route controller teams (i.e., tracker, radar controller, manual controller) that share workload responsibilities.

(5) FAA, DoD, and industry stakeholders research, develop, and apply new remotely piloted aircraft design and build standards for categories of UAS aircraft certification larger than 4.5 pounds. This will be an important consideration in improving safety of UAS vehicles to a level acceptable to the FAA and the public as criteria to access the NAS. According to a 2012 Bloomberg Report, UAS accident rates of DoD UAS have been in continuing decline and are now approaching that of DoD manned fighter aircraft. For example, in 2011 Predator accident rates were 4.86 per 100,000 flight hours compared to F-16 accident rates of 3.89 per 100,000 flight hours. In many cases marginally higher UAS accident rates are associated with human factor issues as well as software, hardware, and equipment failures attributable to system design or build factors that may not meet established minimum FAA aircraft certification standards.

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