Small Unmanned Aircraft System Integration into the Mode C Veil Using an Enterprise Architecting Framework

by

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ABSTRACT

Integrating small unmanned aerial systems (sUAS) into the national airspace system (NAS) represents a challenging problem set that requires consideration through multiple lenses. Like most complex problems, considering one class of constraints is inadequate to developing a solution that satisfies all interested stakeholders. Rather than focusing solely on the technological limitations of sUAS operation, this work employs the Architecting Innovative Enterprise Strategy (ARIES) Framework to understand the current and future landscapes for the NAS. This work considers the ecosystem that influences the NAS and the key stakeholders with decision-making authority. The author uses the ARIES elements (strategy, information, infrastructure, products, services, processes, organizations, and knowledge) to holistically describe the current architecture that allows for very limited sUAS operations in the Mode C Veil. After considering the ongoing efforts to integrate sUAS into the NAS, the envisioned future describes how the enterprise may transform under ideal conditions.

This thesis incorporates aspects of the current architecture for sUAS operations and provides a recommended future architecture that expands sUAS use. By identifying current limitations and incorporating emerging mitigation techniques, the author is able to develop and evaluate different alternatives. These alternatives seek to address externalities that emerge from the increased use of sUAS in close proximity to the general public. Such externalities include safety, security, privacy, and transparency concerns. The recommended future architecture relies on airborne systems to detect and avoid manned aircraft and utilizes an unmanned traffic management system for information sharing and flight coordination. This architecture requires significant investment in developing a shared database to manage unmanned vehicle operations, but provides the structure and functions required to make sUAS operations feasible when considering constraints, externalities, and public acceptance.

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As I am an active duty Army officer I must acknowledge that the views expressed in this thesis are mine and do not reflect the official policy or position of the United States Army, the Department of Defense, or the United States Government.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AC	Advisory Circular
ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance Broadcast
AFR	Autonomous Flight Rules
AGL	Above Ground Level
AIAA	American Institute of Aeronautics and Astronautics
ALPA	Air Line Pilots Association
AMA	Academy of Model Aeronautics
ANSP	Air Navigation Service Provider
AOPA	Aircraft Owners and Pilots Association
APU	Auxiliary Power Unit
ARC	Aviation Rulemaking Committee
ARIES	Architecting Innovative Enterprise Strategy
ARMD	Aeronautic Research Mission Directorate
ATC	Air Traffic Control
ATM	Air Traffic Management
ATO	Air Traffic Organization (FAA)
ATS	Air Traffic Services
AUVSI	Association for Unmanned Vehicle Systems International
BCG	The Boston Consulting Group
BVLOS	Beyond Visual Line of Sight
CA	Controlled Airspace
CAS	Calibrated Airspeed
C3	Communications, Command, and Control
CA	Collision Avoidance
CDL	Common Data Link
CFR	Code of Federal Regulations
COA	Certificate of Authorization
ConOps	Concept of Operations
CONUS	Continental United States
COUHES	Committee on the Use of Humans as Experimental Subjects
DAA	Detect and Avoid
DAC	Drone Advisory Committee
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOI	Department of Interior
DOJ	Department of Justice
ECU	Engine Control Unit
EPA	Environmental Protection Agency
eVTOL	Electric Vertical Takeoff and Landing Vehicle
EXCOM	Executive Committee
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FEMA	Federal Emergency Management Agency

FL	Flight Level
FOIA	Freedom of Information Request
FPM	Feet per Minute
FTI	Federal Aviation Administration Telecommunication Infrastructure
GBSAA	Ground-Based Sense and Avoid
GIS	Geographic Information System
GE	General Electric
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IPP	Integration Pilot Program
IRB	Institutional Review Board
ISR	Intelligence, Surveillance, and Reconnaissance
IT	Information Technology
HALE	High Altitude Long Endurance
kg	kilogram
KIAS	Knots Indicated Air Speed
km	kilometer
LAANC	Low Altitude Authorization and Notification
lb	pound
LIDAR	Light Detection and Ranging
LOS	Line of Sight
LOV	Low Observability Vehicle
MALE	Medium Altitude Long Endurance
MassDOT	Massachusetts Department of Transportation
MAV	Micro Air Vehicle
MIT LL	Massachusetts Institute of Technology Lincoln Laboratory
MOPS	Minimum Operational Performance Standards
MPH	Miles Per Hour
MSL	Mean Sea Level
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controllers Association
NIST	National Institute for Standards and Technology
NM	Nautical Mile
NPR	NASA Procedural Requirement
NUAIR	Northeast UAS Airspace Integration Research Alliance
NVS	NAS Voice System
PIC	Pilot-In-Command
PwC	PricewaterhouseCoopers
R and D	Research and Development
RC	Radio Controlled
RF	Radio Frequency
RFID	Radio Frequency Identification Device
RPA	Remotely Piloted Aircraft
RTCA	Radio Technical Commission for Aeronautics
SATCOM	Satellite Communications

SME	Subject Matter Expert
sUAS	Small Unmanned Aircraft System
SWaP-C	Size, Weight, and Power – Cost
SWIM	System Wide Information Management
TCAS	Traffic Alert and Collision Avoidance System
TCLs	Technical Capability Levels
TIS-B	Traffic Information System Broadcast
TOLAs	Take-off and Landing Areas
TRACON	Terminal Radar Approach Control Facility
TSA	Transportation Security Administration
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UASCA	Unmanned Aircraft System in Controlled Airspace
UASFM	UAS Facility Maps
UAV	Unmanned Aircraft Vehicle
UCAV	Unmanned Combat Air Vehicle
UHF	Ultra-High Frequency
U.S.	United States
USS	UAS Service Supplier
UTM	UAS Traffic Management System
V&V	Verification and Validation
VHF	Very High Frequency
VFR	Visual Flight Rules
VLOS	Visual Line of Sight
VTOL	Vertical Takeoff and Landing

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1. CHAPTER 1: INTRODUCTION

This thesis seeks to explore the current environment that has limited the proliferation of small Unmanned Aircraft Systems into low altitude urban airspace. By considering the holistic environment, major stakeholders, and the current landscape, the author is able to develop an envisioned future and make recommendations to resolve the barriers that limit small Unmanned Aircraft System operations. This chapter establishes the objective, motivation, and scope of this research. It also introduces specific research questions the author seeks to address, as well as the methodology he employs to answer these questions.

1.1. Objective

The objective of this thesis is to understand the barriers to small unmanned aircraft systems being integrated into the national airspace system and propose an architecture that permits operations within the Mode C Veil. This chapter lays out the motivation, scope, research questions, and approach that the author employs for this thesis.

1.2. Motivation

When an emerging technology is introduced to an existing environment, it impacts many factors. For the airspace surrounding major airports (Class B) throughout the United States, current FAA regulations limit the operation of small Unmanned Aircraft Systems (sUAS). Specifically, there are requirements to maintain line of sight with a sUAS and have adequate detect and avoid capability (among others). These requirements exist for the safety of other aircraft and passengers, as well as ground personnel and property that could be impacted by a sUAS [1]. However, increasing demand for the use of sUAS, both commercial and public, around major urban areas requires changes to existing regulations. Additional constraints exist, from technological limitations to public acceptance of the widespread sUAS use. All of these constraints deserve consideration.

The addition of sUAS to the National Airspace System (NAS) introduces many externalities, both positive and negative. Externalities include (among others) safety, privacy, security, and economic benefits and costs. By identifying these emergent characteristics and attempting to understand the implications and interactions, the overall impacts of sUAS operations can be better understood.

Many organizations are working to develop realistic concepts of operations for sUAS within the NAS; however, some of these entities focus on only one aspect (e.g. technical feasibility, regulatory compliance, safety impacts). This thesis broadly considers the NAS as an enterprise and uses multiple lenses to understand the current environment and to capture the as-is and future conditions. With this systems mindset, the author develops and proposes a future architecture for sUAS operation within the Mode C Veil that serves as a possible step to reaching a long-term state of fully integrated sUAS operation within the NAS.

1.3. Scope

The intent of this thesis is to use the Architecting Innovative Enterprise Strategy (ARIES) Framework to understand the as-is and future landscapes for the NAS. The author develops a reasonable operational concept for sUAS integration within the Mode C Veil considering the ARIES view elements. This architecture serves as a potential intermediate step between the as-is and long-term future landscape. However, the author acknowledges the breadth of this topic area and specific limitations that must be defined. The ConOps developed focuses on only Mode C Veil operations, not the entire NAS. The focus is on operations *in the air* and does not put significant emphasis on take-off or landing areas (TOLAs), which can be an entirely different problem set involving land regulation, ownership, and usage. During the architecture development, the use cases discount commercial delivery of goods, as there is substantial uncertainty about what regulatory requirements are applicable to commercial delivery missions [2, p. 2] [3, p. 5]. Currently, sUAS have strict limitations on delivering goods for compensation. There is ongoing discussion as to whether sUAS delivering goods should be regulated under Title 14 Code of Federal Regulations (CFR) Part 107 (Small Unmanned Aircraft Regulation) or Part 135 (Air Carrier and Operator Regulation). As such, this work focuses on the numerous other meaningful commercial and public use cases for sUAS. Recreational use of UAS are not considered, as such usage falls under Part 101 Subpart E (Special Rule for Model Aircraft).

Additionally, it is beyond the scope of this thesis to analyze hostile/malicious actors, sUAS propulsion systems, international operations, and cybersecurity issues. While some of these areas are briefly addressed, counter UAS, sUAS aeronautics, supranational institutions, and cybersecurity are extensive fields and worthy of separate analysis.

1.4. Research questions

Based on motivation and scope for this thesis, specific research questions to address the major areas of interest emerged. These questions help to frame the approach and define the scope.

OVERALL RESEARCH QUESTION: How can sUAS safely operate within the Mode C Veil considering constraints and externalities while employing mitigation techniques and existing/emerging operational concepts?

CONSTRAINTS: What are the critical technological, regulatory, and operational factors that may limit sUAS in Mode C Veil implementation in the United States?

EXTERNATILITES: What externalities may emerge from the increased use of sUAS in the Mode C Veil and how may they in turn influence sUAS operations?

MITIGATIONS: What technology or policy options may be considered in both the near and far-term to mitigate or resolve the constraints and negative externalities of sUAS in the Mode C Veil implementation?

1.5. Approach

This thesis applies the ARIES Framework to analyze the as-is and future architectures for the NAS focusing on sUAS operations. With the future architecture in mind, the author develops an example use case for the integration of sUAS into the NAS within the Mode C Veil. Content relies heavily on existing literature and the author analyzes and integrates multiple perspectives to form reasonable conclusions. Each chapter will address a step (or combined steps) of the ARIES Framework. The author addresses the necessary background information relating to sUAS, the NAS, and the ARIES Framework. Next, stakeholder analysis identifies the key entities that deliver value and impact the current enterprise. With stakeholders identified, the author assesses the as-is state through the ARIES view elements. Considering stated goals from the FAA and other organizations, the author then sets the expectations for the future architecture, both near-term and long-term. He develops an architecture that could serve as an intermediate step between ongoing efforts and the long-term future that allow sUAS to operate in major urban airspace (Mode C Veil). Finally, subject matter experts provide review and evaluates the work. Evaluation was conducted using a protocol approved by MIT's Committee on the Use of Humans as Experimental Subjects (COUHES) (MIT's Institutional Review Board (IRB)) This feedback stimulates future work and further analysis. This research approach is shown visually in Figure 1-2.

1.6. ARIES Framework

The ARIES Framework is an approach that focuses on transforming an enterprise from its current state to a desired future state. Developed by Drs. Deborah Nightingale and Donna Rhodes, the ARIES Framework seeks to develop a thorough understanding of the current enterprise environment based on its defined elements (see Section 1.6.1) [4]. After conducting this analysis, the architect(s) can establish an envisioned future and select an architecture and implementation plan that moves the enterprise toward that envisioned goal. An enterprise "consists of people who generate value for others…is a whole system that has a purpose… [and] benefits from being part of a larger ecosystem" [4, p. 1]. Under this definition, it is appropriate to consider the NAS, and the encompassed Mode C Veil, to be an enterprise.

1.6.1. ARIES Elements

Using multiple lenses is critically important when considering an enterprise transformation. Many modern enterprises have failed during a transformation initiative because they focused solely on a new technology and its implementation [4, p. 5]. Figure 1-1 shows the ARIES element models. The first two elements include entities that may be either internal or external to the enterprise, while the remaining eight elements focus internally on the enterprise. The *ecosystem* is represented as the outermost element, since it includes the external factors that impact the enterprise, specifically the regulatory, political, economic, and societal factors. *Stakeholders* are the next ARIES element, and include the people and organizations that contribute to or are affected by the enterprise [4, p. 16].

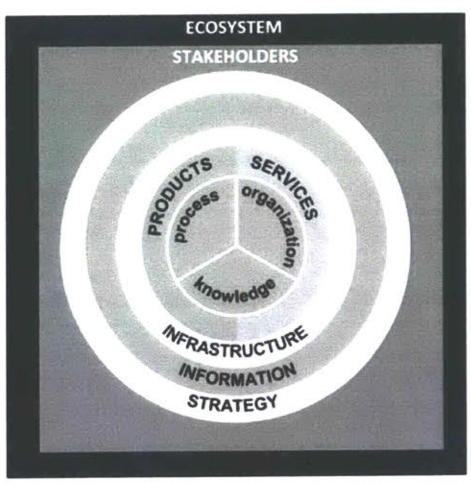

Figure 1-1: ARIES Elements [4, p. 16]

The internal ARIES elements provide different lenses to consider the enterprise. *Strategy* is the element that includes the enterprise core values, overall objectives and sets the direction for the organization. The *information* element entails what information is shared throughout the enterprise and how that material is transmitted. *Infrastructure* is the element relating to the supporting structures (physical facilities, information technology, and communication systems) that allow for continued operations. The *product* element is/are a physical device(s) or tool(s) related to an enterprise that affect a stakeholder. Similarly, *services* deliver value to stakeholders from enterprise knowledge, skills, and attributes. *Processes* are the established actions and procedures that support the enterprise goals. The *organization* element includes the hierarchical structure and organizational culture for the enterprise and its key stakeholders. The *knowledge* element contains the expertise and intellectual property residing within the enterprise [4, pp. 16-17].

While the ten ARIES elements are distinct, an enterprise is a complex system and there are interactions between elements. Viewing an enterprise through ARIES elements cannot be done in isolation, as emergent properties from the "entanglement" of elements may develop [4, p. 20]. Thus, after using the elements to decompose and analyze an enterprise, additional consideration must be given to the emergence of unforeseen conditions and externalities.

1.6.2. ARIES Process

The ARIES process (see Figure 1-2) consists of seven activities, beginning with understanding the enterprise landscape and progressing through to developing an implementation plan. To *understand the enterprise landscape,* one must consider the effects of external factors (regulatory, political, economic, and societal) that impact the enterprise. *Performing stakeholder analysis* examines the value exchanges and impacts different entities have on the enterprise. During the *capture the as-is architecture* activity, the current enterprise architecture is described using the ARIES elements (Figure 1-1). Considering the ecosystem and stakeholder values, a *holistic future vision* establishes the goal of the enterprise transformation. *Generating alternative architectures* involves ideation and creativity to construct feasible architectures and *deciding on the future architecture* requires scoring and selecting one architecture. Finally, an *implementation plan* establishes the necessary next steps for the enterprise to successfully transform [4, pp. 22-26].

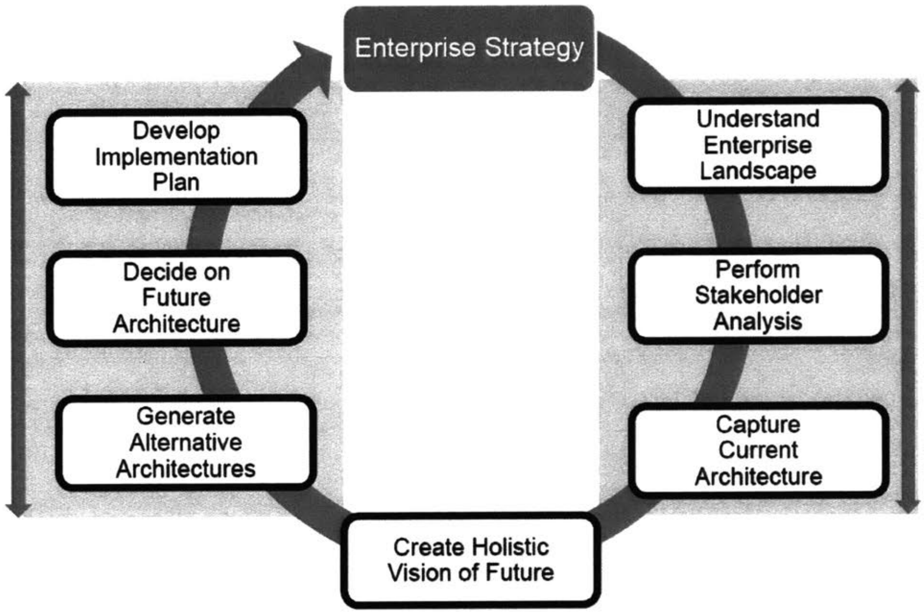

Figure 1-2: ARIES Process [4, p. 15]

1.7. Thesis Structure

The structure for this thesis generally follows the ARIES Process (Figure 1-2), starting with understanding the enterprise landscape and concluding with a potential future architecture. Chapter 2 focuses on establishing the necessary definitions and environmental factors impacting sUAS integration. In Chapter 3, the author considers the people and organizations that contribute value to and from the enterprise. In Chapter 4 the author discusses the current practices and ecosystem for sUAS operations in the Mode C Veil and NAS. Chapter 5 considers the future vision for the NAS architecture relating to sUAS integration using the ARIES elements. Chapter 6 consists of alternative architectures and a recommended architecture and example use case for sUAS use within the Mode C Veil, as well as expert evaluation and feedback to provide feedback and initial validation of the concept.

2. CHAPTER 2: sUAS & NAS BACKGROUND and ENTERPRISE LANDSCAPE

Commercial sUAS use has rapidly increased within the United States in recent years, especially with the establishment of 14 CFR Part 107 in June 2016. The FAA's latest forecast indicates sustained commercial sUAS growth for the foreseeable future, with a forecasted average annual increase of at least 33% through 2022 for the United States [5, p. 43]. This chapter examines the history and characteristics of sUAS, the characteristics of the NAS and Mode C Veil, and the current ecosystem that affects the NAS. The intent is to provide background for the progress of UAS, the existing the NAS environment, and the ecosystem factors that are influencing NAS operations.

2.1 sUAS Background

2.1.1. Historical Context and Development of UAS

UAS development began in 1917 when the U.S. Navy awarded a contract to develop a bomb-carrying drone to employ against German U-boats. Two inventors, Elmer Sperry and Peter Hewitt, competed for and were awarded the contract. On March 6, 1918 their *Speed Scout* successfully completed the first flight by a powered, unmanned aircraft. This endeavor required overcoming major obstacles in the areas of automatic stabilization, remote control, and autonomous navigation, and failures continued to arise after that first successful flight. The *Speed Scout* relied on gyroscopes for stabilization and had a range of 50 miles, top speed of 90 mph, and could carry a payload of 1000 lb. All told, six *Speed Scouts* were produced, with 12 total flights before all had crashed beyond repair [6, pp. 15-21]. Despite the challenges, Sperry and Hewitt established the unmanned branch of aviation.

During World War II UAS did not have major impacts on war efforts, and mainly were used as target aircraft for anti-aircraft ground-based gunners. In 1941 the Navy launched "Project Fox" and installed RCA television cameras and transmitters on unmanned aircraft with the goal of using the video feed to ensure accuracy when using the unmanned aircraft (dubbed Unmanned Combat Air Vehicle or "UCAV") to strike targets. The UCAV controller operated from a manned aircraft that remained within close proximity [6, p. 66]. By the time this innovative concept had proved reliable, Naval leadership was succeeding in the Pacific theater using conventional aviation and UCAV implementation was limited [6, pp. 69-70]. Even so, the capability of viewing from the unmanned aircraft's perspective as well as delivering munitions were significant advancements during this period.

The next major development occurred in the 1960s and 1970s when UAS began flying reconnaissance missions. The U.S. employed UAS to fly surveillance over North Vietnam, China, and North Korea using the *Ryan AQM-34 Lightning Bug*. This UAS variant flew 3,435 sorties and collected imagery, electronic, and communication intelligence [6, p. 83], [7, p. 12]. In addition to delivering munitions and providing targetry for training, UAS were now able to collect intelligence. While the *Ryan AQM-34 Lightning Bug* flew the most reconnaissance missions, many other variants were developed and successfully employed during this period. Another milestone occurred on August 12, 1960 as the *Gyrodyne QH-50 DASH* completed its first flight. This airframe became the first rotary wing UAS and the first UAS to take off and land aboard a vessel at sea [6, pp. 87-88]. These new employments and technologies decreased the threat to pilots as fewer pilots had to fly reconnaissance missions as UAS prevalence increased.

Since 1990 the FAA has incrementally allowed for introduction of UAS into the NAS beyond military applications. A major challenge is continuing to maintain the world's safest aviation system while introducing UAS (and specifically sUAS) into the environment. Initial UAS use required FAA approval coupled with a specific public mission such as firefighting, disaster relief, search and rescue, law enforcement, or scientific research [8]. The FAA has gradually expanded UAS operations, to include passing 14 CFR Part 107 in June 2016. Part 107 permits sUAS to operate in defined areas of the NAS (see Chapter 4). The potential uses for sUAS are vast, but currently limited by the regulatory infrastructure currently in place. Before discussing constraints for sUAS, specific definitions, characteristics, and capabilities of sUAS, and the Mode C Veil region of the NAS are addressed.

2.1.2. sUAS Definitions and Characteristics

UAS represent a large array of vehicles that have varying characteristics. To standardize the definition of sUAS, the *FAA Modernization and Reform Act of 2012*, Public Law 112-95, approved by the 112th U.S. Congress on February 14, 2012, serves as an initial reference. Public Law 112-95 provides the following definitions:

"**Small unmanned aircraft** means an unmanned aircraft weighing less than 55 pounds."

"**Unmanned aircraft** means an aircraft that is operated without the possibility of direct human intervention from within or on the aircraft."

"**Unmanned aircraft system** means an unmanned aircraft and associated elements (including communication links and the components that control the unmanned aircraft) that are required for the pilot in command to operate safely and efficiently in the national airspace system" [9].

A system boundary clearly illustrates what composes the UAS, based on this definition:

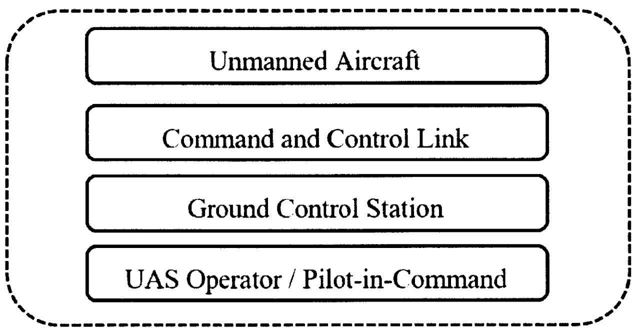

Figure 2-1: System Boundary for UAS

It is important to note that a UAS encompasses not only the aircraft but the supporting systems as well, to include the operator (also referred to as the Pilot-in-Command (PIC)) [10]. The FAA requires a "human in the loop" for UAS operation [1], as fully autonomous flight remains relatively unproven at this time. However, the term UAS, especially when relating to characteristics and performance, frequently is referencing the unmanned aircraft as opposed to the entire system.

The vast majority of government agencies, civil organizations, and industry participants accept the 55-pound limit as the threshold for classifying and separating small and large UAS. While the above definition provides some clarity differentiating a sUAS from other manned and unmanned aircraft systems, they are not sufficient. As of June 2016, the FAA added a characteristic to the *FAA Modernization and Reform Act of 2012* sUAS rule, limiting sUAS airspeed to a maximum groundspeed of 87 knots (100 mph) (more detail on FAA sUAS regulation in Section 4.2). This maximum groundspeed limitation aligns with the UAS classifications developed by National Aeronautics and Space Administration (NASA). NASA has further detailed UAS into three specific categories that also consider airspeed, airworthiness, configuration management, and safety. Category I applies to model and sUAS (Micro – Small), Category II applies to small to medium UAS, and Category III applies to medium to large UAS.

Per NASA Procedural Requirement (NPR) 7900.3D, if vehicle weight and airspeed fall into different categories, the most restrictive category applies [11]. Table 2-1, Table 2-2, and Table 2-3 describe the general characteristics that NASA uses to classify UAS.

Table 2-1: NASA Category I: Model to Small UAS [11]

Cat I	Model or sUAS (Micro-Small)
Weight	Takeoff gross weight does not exceed 55 lb.
Airspeed	Maximum airspeed in level flight does not exceed 87 KIAS.
Airworthiness	Aircraft are required to have an airworthiness statement provided by a designated NASA Flight Operation office.
Configuration Management	sUAS aircraft in this category typically operate on a fly to failure maintenance schedule. Flight-critical parts will be inspected at least once per day, prior to flight activities--normally accomplished during the first preflight of the day. An appropriate maintenance inspection schedule will be developed for critical components. Individual aircraft log books will be maintained for each aircraft.
Safety	Only requirements levied by the FRR/AFSRB will be required for this category of aircraft, except for cases in which the aircraft caused injury to people or property reaching NPR 8621.1 cost thresholds.

Table 2-2: NASA Category II: Small to Medium UAS [11]

Cat II	sUAS (Small-Medium)
Weight	Takeoff gross weight exceeds 55 lb but does not exceed 330 lb.
Airspeed	Maximum airspeed in level flight does not exceed 200 KIAS.
Airworthiness	Aircraft need to have an airworthiness statement provided by a designated NASA Flight Operation office.
Configuration Management	sUAS aircraft in this category typically operate under a program maintenance plan or planned maintenance schedule. Flight-critical parts will be inspected at least once per day, prior to flight activities--normally accomplished during the first preflight of the day. An appropriate maintenance inspection schedule will be developed for critical components. Individual aircraft log books will be maintained for each aircraft.
Safety	System safety analysis will be an integral part of system operation. A hazard analysis and accepted risk list will be developed. The Center flight safety office will review and approve the analyses. Mishap reporting in accordance with NPR 8621.1.

Table 2-3: NASA Category III: Medium to Large UAS [11]

Cat III	UAS (Medium-Large)
Weight	Takeoff gross weight exceeds 330 lb.
Airspeed	Maximum airspeed in level flight may exceed 200 KIAS.
Airworthiness	Aircraft need to have a Certificate of Airworthiness provided by a designated NASA Flight Operation office. NASA Center airworthiness and flight safety review and a flight readiness review are required. Any subsequent system modifications require technical review and FRR/AFSRB in accordance with Center requirements.
Configuration Management	Aircraft maintenance will be accomplished in accordance with this NPR and applicable NASA guidance and managed in NAMIS.
Safety	Accomplished in accordance with this NPR, NPR 8621.1, and applicable NASA and Center-developed reporting procedures.

Although the FAA's current regulations pertaining to sUAS do not include all of these specific requirements, the NASA UAS categories help emphasize a generally accepted threshold. Based on the characteristics outlined by the *FAA Modernization and Reform Act of 2012*, NASA, and the FAA, this work considers a sUAS to be an unmanned aircraft weighing between 0.55 lb (250 grams) and 55 lb, traveling up to 100 mph. While other constraints may be imposed on a sUAS, this serves as the baseline. Of particular note, there is no distinction in sUAS classification related to body style, body size, or fixed wing versus rotary wing.

2.1.3. sUAS Configurations and Performance Capabilities

Within the sUAS category there still exists a range of aircraft types with differing performance capabilities. The rapid pace of innovation makes it difficult to capture all types of sUAS, but some major subsets related to design and performance exist. A variety of categorization schemes exist by military, regulatory, industry, and public entities. These classifications have used gross weight, aircraft performance, operating altitude, airspeed, use cases, or some combination thereof. NASA commissioned a study attempting to group UAS based on characteristics and develop reliability and design assurance requirements. Despite these efforts, "there is no single widely accepted existing UAS categorization, nor is there a single existing categorization that serves all purposes" [12, p. 4]. Having defined sUAS as an unmanned aircraft weighing between 0.55 lb and 55 lb and traveling up to 100 mph, applying three distinct classifications is useful to demonstrate the breadth of vehicle configuration and performance capabilities that sUAS encompasses. These classifications are: aircraft configuration, speed, and vertical rate.

sUAS can have multiple configurations that can be clearly defined. While these configurations may imply performance capabilities or use cases, it is unfair to assign those characteristics to the specific configuration type. Table 2-4 represents the configuration classification that has been adapted from manned aircraft classifications from experts across government, industry, and academia. Any sUAS can be classified using this scheme.

Table 2-4: sUAS Aircraft Configuration Classification [12, p. 5]

Classification			Definition
Lighter than Air	**Airship**		Engine-driven lighter-than-air aircraft that can be steered.
Heavier than Air	**Fixed Wing**	**Glider**	Lift generated by wing, but not depending principally on an engine for sustained flight, including powered gliders.
		Airplane	Lift generated by wing, engine-driven propulsion, including weight-shift control and powered parachute aircraft, regardless of launch and recovery methods.
	Rotorcraft	**Helicopter**	Lift and propulsion generated by engine-driven rotor(s), principally depending on cyclic pitch and roll control, including compound helicopters with forward flight thrusters.
		Multirotor	Lift and propulsion generated by engine-driven rotors, principally depending on differential lift from multiple rotors (normally fixed pitch) for pitch and roll control.
	Powered-lift		Capable of vertical takeoff, vertical landing, and low speed flight that depends principally on engine-driven lift devices or engine thrust for lift; and cruise flight that depends principally on wing for lift. May include gyrodynes.
	Other		Any other heavier than air aircraft configurations that may not fit or may not be derived from defined classes, for example ornithopters, or gyroplanes.

With changing technology, a specific sUAS configuration may have performance characteristics that rapidly evolve beyond the established bounds. While the 14 CFR Part 107 limits airspeed to 100 mph (87 kts) as a risk mitigation, sUAS can achieve a range of calibrated airspeeds (CAS) during flight. Airspeed and vertical rate capture the maneuverability of sUAS, which is important to consider for avoiding obstacles or other manned/unmanned aircraft. Table

2-5 categorizes sUAS based on CAS and Table 2-6 categorizes sUAS based on maximum vertical rate.

Table 2-5: sUAS Speed Categorization [12, p. 9]

Category	Maximum CAS	Explanation
A1	< 22 kt (25 mph)	Intended to cover the slow flying sUAS fleet. Speed criterion to be determined by the ability to maintain safe flight in nominal wind and gust conditions.
A2	≥ 22 kt (25 mph), < 43 kt (50 mph)	Intended to cover the intermediate performance sUAS fleet, which are expected to comprise the largest portion of the entire sUAS fleet.
A3	≥ 43 kt (50 mph), < 65 kt (75 mph)	Intended to cover the more advanced performance sUAS fleet, which are expected to comprise a substantial portion of the BVLOS operations sUAS fleet and of the entire sUAS fleet as well.
A4	≥ 65 kt (75 mph)	Intended to cover the high performance sUAS fleet. Speed criterion to be determined by the requirement to conduct normal flight operations without exceeding the 87 kt (100 mph) groundspeed limit under normal tail wind conditions.

Table 2-6: sUAS Vertical Rate Categorization [12, p. 9]

Category	Maximum Vertical Rate	Note
N	±3 m/s (600 fpm)	**Normal**, nominal vertical maneuverability.
U	±7 m/s (1,400 fpm)	**Utility**, intermediate vertical maneuverability.
H	±10 m/s (2,000 fpm)	**High performance**, agile vertical maneuverability.

These three classifications underscore that sUAS have a broad variety of configurations and performance capabilities. A lightweight airship with a massive wingspan as well as a multirotor aircraft capable of vertical takeoff and landing (VTOL) operating at different airspeeds and capable of different vertical rates both fall within the sUAS arena. When considering the integration of sUAS into the NAS, this is significant. The FAA's definition of sUAS is intentionally broad to allow for innovation; however, integration and operation of sUAS must then accommodate for the wide array of sUAS models that may emerge.

2.2. NAS and Mode C Veil Background

The NAS is a complex system with the overall purpose of enabling safe and efficient aircraft operation, both for airborne and ground personnel [13]. The NAS encompasses not only aircraft, but also infrastructure, systems, procedures, regulations, and people (see Figure 2-2). Although the NAS has continually evolved to incorporate improved technologies and procedures, the focus has always been on manned aircraft. sUAS integration into the NAS may require a major shift in the current NAS structure to adequately accommodate the new devices while simultaneously maintaining the high level of safety the FAA requires. Before considering the impacts of significant additional sUAS operating within this environment, the existing structure for the NAS and the Mode C Veil are introduced. The NAS has many characteristics and a detailed explanation of the entire system is beyond the scope of this work. However, the author highlights airspace classifications, air traffic management, and the Mode C Veil as those areas are most relevant.

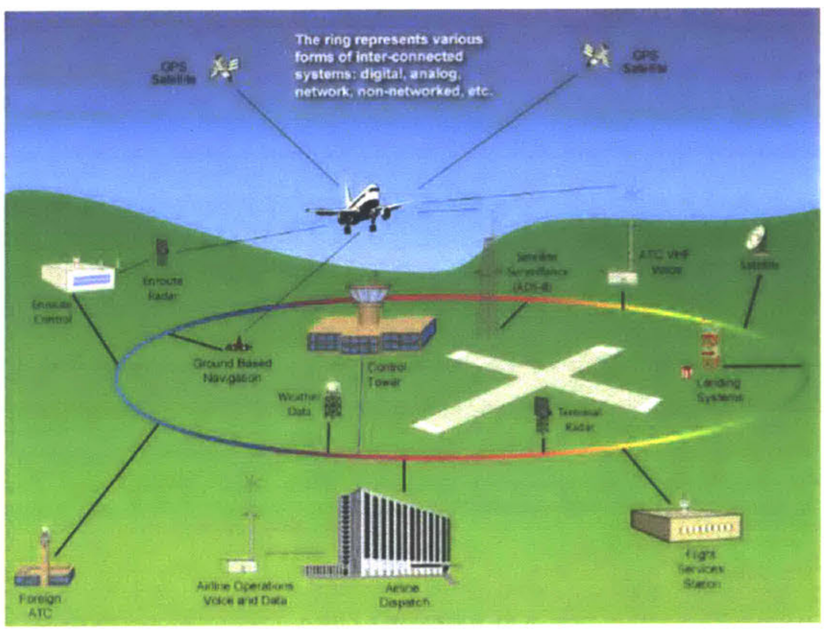

Figure 2-2: National Airspace System Elements [13, p. 2]

2.2.1. National Airspace System Classifications

The United States has two categories of airspace (regulatory and non-regulatory) and four types of airspace (controlled, uncontrolled, special use, and other airspace). The vast majority of airspace falls within the regulatory category, with non-regulatory encompassing a few special use cases (described later in this section). Within regulatory airspace, the FAA has the authority to enforce all applicable regulations to flight operations. Regulatory airspace is classified based on "complexity or density of aircraft movements, nature of the operations conducted within the airspace, the level of safety required, and national and public interest" [14, pp. 15-1]. Airspace classes also dictate the applicable mode of flight rules. Visual flight rules (VFR) permit the PIC to fly using visual cues to see and avoid other aircraft or obstacles. Instrument flight rules (IFR) mandate that the PIC use instruments within the cockpit to navigate as well as coordinate with air traffic control (ATC) to maintain separation from other aircraft [15].

Controlled airspace includes five classes of airspace (see Figure 2-3) with decreasing restrictiveness (from Class A through Class E). Table 2-7 summarizes the applicable restrictions to the airspace classes. The major restrictions that decrease with airspace class are entry requirement, pilot certificate/rating, and altitude transponder requirement. Class B and C airspaces are individually tailored to the unique terminal area requirements for an airport to account for terrain and other local features (e.g. other airports or restricted airspace). Class A airspace ranges from 18,000' mean sea level (MSL) to 60,000' MSL (or flight level (FL) 600) and 12 nautical miles (NM) of the coast of the contiguous states. Standard Class A operations follow IFR. Class B airspace applies to the 37 busiest airports in the United States and the airspace is individually tailored to each situation. Class B airspace normally covers from the surface to 10,000' MSL and resemble upside-down wedding cakes because of the layers that form. ATC manages Class B airspace, issuing clearance to operate and providing separation guidance to aircraft. Class C airspace applies to airports with operational control towers, use radar to detect approaching aircraft, and meet requirements to number of passenger enplanements. Class C airspace ranges from surface to 4,000' MSL and typically has a 10 NM radius. Unlike Class B airspace, in Class C airspace two-way radio communication can be sufficient to enter airspace, and ATC clearance is not always required. Class D airspace ranges from surface to 2,500' MSL for airports with an operational control tower and has the same entry requirements as Class C airspace. Class E airspace applies to controlled airspace not classified as Class A through D. Typically, Class E airspace begins at 1,200' MSL and extends up to 18,000' MSL. Class E also includes all airspace above FL 600 [14].

Class G airspace is known as uncontrolled airspace and is all airspace not assigned to Classes A through E. Class G airspace ranges from the surface to the beginning of Class E airspace (typically 1,200' MSL). In Class G airspace, ATC does not have any responsibility to control air traffic. Pilots must manage separation by adhering to VFR minimums (see Table 2-7). Currently, Class G is the only airspace where sUAS operations are permitted without requiring approval from ATC [14].

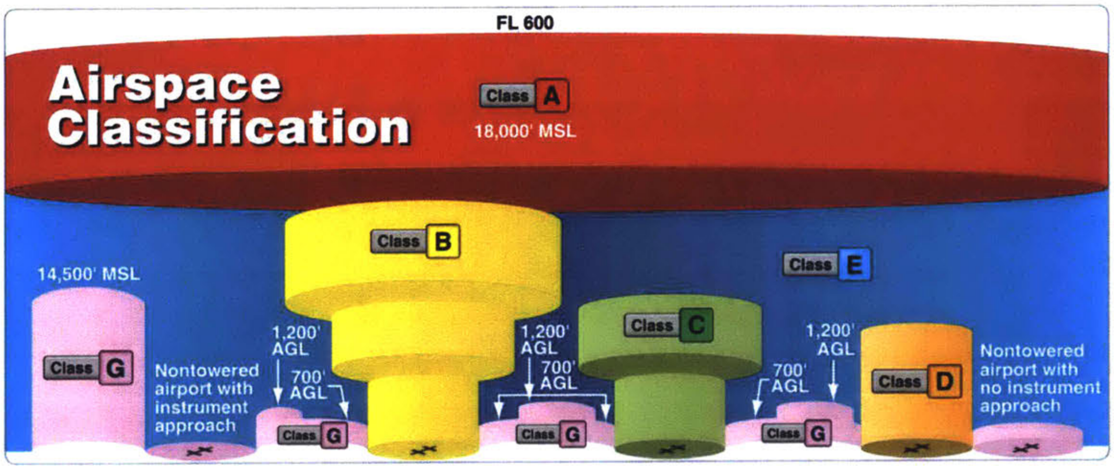

Figure 2-3: FAA Airspace Classifications [14, pp. 15-2]

Table 2-7: FAA Regulatory Airspace Class Characteristics [16]

Airspace Class	Entry Requirement	Pilot Certificate or Rating	Two-Way Communication	Altitude Decoding Transponder	VFR Min. Visibility Below 10,000 MSL	VFR Min. Visibility 10,000 MSL and Above	VFR Cloud Clearance Below 10,000 MSL	VFR Cloud Clearance 10,000 MSL and Above
A	ATC Clearance	Instrument	Yes	Yes	N/A	N/A	N/A	N/A
B	ATC Clearance	Private Certificate or student with endorsement	Yes	Yes within 30 nm of the class B primary airport[1]	3 miles	3 miles	Clear of Clouds	Clear of Clouds
C	VFR: Radio Contact IFR: Clearance	Student Certificate	Yes	Yes within C space and above lateral limits of C space[1]	3 miles	3 miles	500 below 1,000 above 2,000 horizontal	500 below 1,000 above 2,000 horizontal
D	VFR: Radio Contact IFR: Clearance	Student Certificate	Yes	No unless required by other airspace	3 miles	3 miles	500 below 1,000 above 2,000 horizontal	500 below 1,000 above 2,000 horizontal
E	VFR: None IFR: Clearance	Student Certificate	IFR only	No unless required by other airspace	3 miles	5 miles	500 below 1,000 above 2,000 horizontal	1,000 below 1,000 above 1 mile horizontal
G	None	Student Certificate	No	No unless required by other airspace	Day: 1 mile Night: 3 miles	5 miles[2]	500 below 1,000 above 2,000 horizontal [2]	1,000 below 1,000 above 1 mile horizontal [2]

[1] An altitude decoding transponder is required above 10,000 MSL.
[2] When flying 1,200 AGL or below: DAY: 1 mile visibility clear of clouds; NIGHT: 3 miles visibility, 500 below, 1,000 above, 2,000 horizontal.

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Regulatory special use airspace pertains to areas where limitations apply to aircraft operations but all FAA regulations still apply. The two types of regulatory special use airspace are prohibited areas and restricted areas. Prohibited areas are specific dimensions where aircraft operation may not occur for security reasons. Examples include the Camp David and the National Mall in Washington, D.C. Restricted areas contain unusual or invisible aircraft hazards (e.g. artillery or missile firings). Restricted areas may be active or inactive. If inactive, the responsible

ATC facility may allow operation without issuing clearances. If active, the ATC facility issues the appropriate clearance or route aircraft around the restricted area [14].

Non-regulatory airspace applies to the remaining special use airspace, and FAA regulations do not apply. There are four types of non-regulatory airspace: warning areas, military operation areas, alert areas, and controlled firing areas. Warning areas are airspaces with potential hazards beyond three nautical miles from the coast of the United States; however, the U.S. does not have sole jurisdiction in the area. Military operation areas include airspace where military aerial training activities are occurring. Alert areas may have a high volume of aerial training activity, and pilots must use caution and be alert. Controlled firing areas may include hazardous activities, but spotters suspend activities when aircraft approach [14] [17].

Other airspace refers to regulatory airspace that serve specific functions. The main types include: local airport advisory, military training routes, temporary flight restrictions, published VFR routes, terminal radar service areas, and national security areas. Local airport advisories are generated if the operational control tower is closed, but aircraft can communicate through published radio frequency. Military training routes are established routes between 1,500' AGL and 10,000' MSL that allow military aircraft to conduct high-speed training missions. Temporary flight restrictions (TFR) are issued by a flight data center to prohibit aircraft operation for a limited time period and for a specific reason. TFRs are often established to limit aircraft congestion above an incident or event (major sporting event), provide a safe environment for disaster relief efforts, and protect public figures (e.g. President or Vice President). Published VFR routes are specified routes that allow aircraft to maneuver around, under or through complex airspace. Terminal radar service areas provide additional radar to aircraft to support separation. National security areas are locations that require additional security and safety but do not meet the level of the prohibited areas. Pilots can voluntarily avoid flight in this airspace. TFRs can be established for national security areas if necessary [14] [17].

2.2.2. Air Traffic Management

Air Traffic Management (ATM) is performed by ATC, with the primary function of ensuring safe separation between aircraft and the secondary function of controlling air traffic efficiency and flow. ATC provides pilots with clear direction on where to fly when within controlled airspace and abides by detailed guidance published under FAA Order 7110.65 "Air

Traffic Control" [18]. The level of ATM service provided depends on the airspace class, as detailed in Section 2.3.1. Figure 2-4 represents a simplified graphic showing the tasks ATC performs. In addition to managing arriving and departing aircraft, ATC manages aircraft on the ground, notifies pilots of potential conflicts from projected trajectories, and alerts pilots of inclement weather or other hazards. ATC may also provide advisories to pilots in uncontrolled airspace to advise on potential hazards.

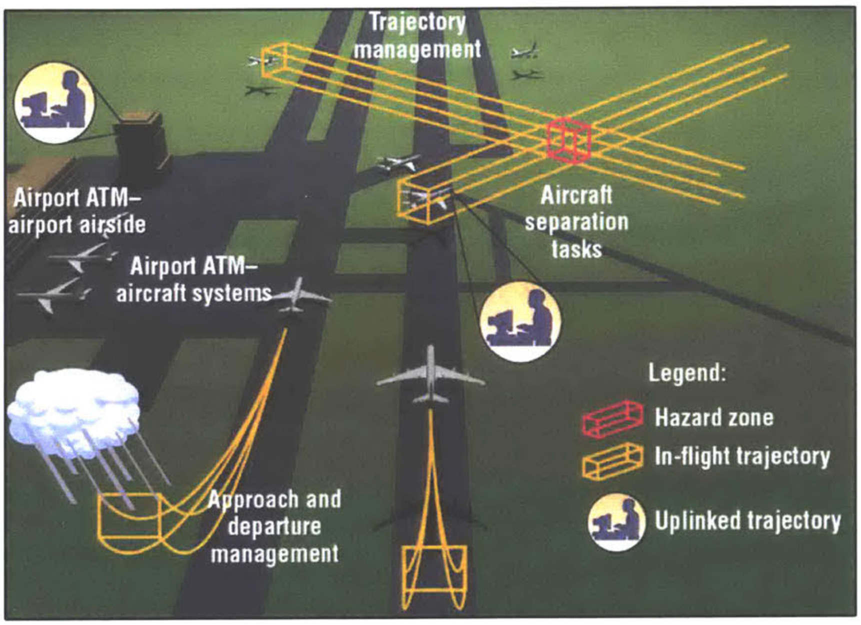

Figure 2-4: Basic ATM Tasks [19]

The human is the center of current ATM systems, although automation and communication technologies have improved efficiency, decreased error rates, and increased ATM capacity. As shown in Figure 2-5, decision aids and displays help optimize and filter the decisions ATC personnel need to act upon. These tools help to provide the individual controller with the necessary situational awareness without reaching information and task overload. As an example, a controller receives surveillance information for an aircraft and communicates with the pilot through VHF radio. The pilot uses the direction from ATC to control the aircraft and receives feedback through his/her instrument displays. Additionally, the pilot can visually scan to detect other aircraft. Current regulations require all aircrafts with a maximum takeoff weight over 12,600 lb or more than nine passengers to equip with a TCAS transponder. For most aircraft operating under 14 CFR

Part 91 (small, non-commercial operations), ADS-B Out will be required on January 1, 2020 to fly within the Mode C Veil or when operating above 10,000' MSL [20]. Traffic Collision and Avoidance System (TCAS)-equipped aircraft can surveil an area and send /receive transponder signals. If a conflicting aircraft is transponder-equipped and in the vicinity, the pilot receives an alert to execute vertical maneuvers to avoid the second aircraft [15] [21].

The two major modes of rules are VFR and IFR. Each mode has different NAS procedures for navigation, terminal operations, and aircraft separation. When operating under VFR, the PIC may rely on visual cues to see and avoid other aircraft or obstacles. For IFR operations, the PIC coordinates with ATC and uses instruments to navigate and maintain separation from other aircraft. To conduct IFR operations, the pilot requires additional training and certification as well as aircraft instrumentation. This distinction between VFR and IFR modes may influence the standards required for sUAS to avoid other aircraft. If VFR is the standard for "seeing" and avoiding other aircraft, then the sUAS sensor must replicate the capabilities of the human eye [15].

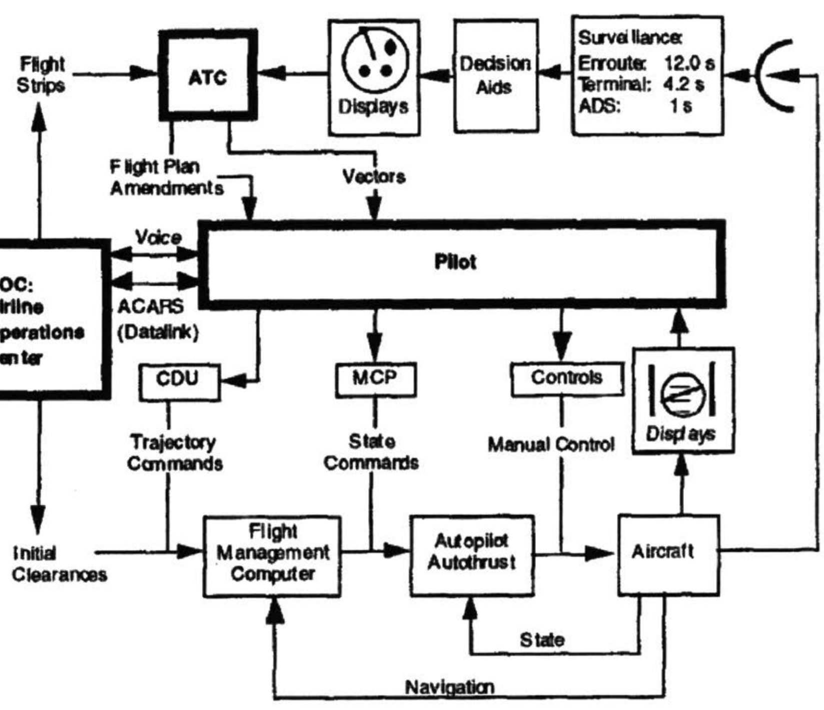

Figure 2-5: Simplified ATM System Model [21, pp. 6.3-4]

2.2.3. Characteristics of Mode C Veil

The Mode C Veil is airspace surrounding Class B airports. Currently, the United States has 37 Class B airports, which represent the most heavily trafficked airports in the country. Although the Mode C Veil was not mentioned in Section 2.2.2, the requirements for the airspace are described here. Per 14 CFR Part 91 Section 215(2), aircraft must be equipped with a transponder "in all airspace within 30 nautical miles of an airport listed in appendix D, section 1 of this part [Class B airports], from the surface upward to 10,000 feet MSL" [22]. Figure 2-6 depicts the Mode C Veil for a Class B airport. Two types of transponder operational modes are approved for use within the Mode C Veil: Mode S and Mode 3/A augmented with Mode C. The technical specifics of aircraft transponder modes are beyond the scope of this work; however, the fundamental concepts provide the level of detail to necessary for discussion. Mode S capable transponders broadcast and receive aircraft identification, position, and altitude to ATC and other Mode S-equipped aircraft. Mode 3/A broadcasts a unique identifier to ATC, and ATC can use radar to determine position. Mode C operation augments the Mode 3/A capability by also providing current altitude information in 100-foot increments. Mode S also reports altitude by 25' increments, if supported by the aircraft altimetry system [23].

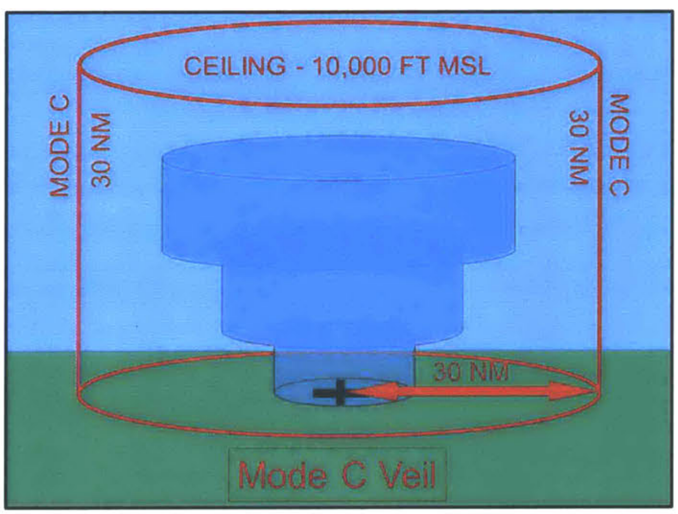

Figure 2-6: Mode C Veil [24, p. 29]

There are few exceptions to the transponder requirements within the Mode C Veil. Any type of glider or balloon does not require a transponder, nor does "any aircraft which was not originally certificated with an engine-driven electrical system…" (typically older aircraft) [22].

Of note, UAS manufactured and equipped with altitude-encoding transponders must meet the requirements of 14 CFR Part 91 Section 215(2). The vast majority of UAS do not meet this standard, and are therefore exempt. The FAA addresses this exemption explicitly, stating that "many small UAS are battery operated and therefore do not have an engine-driven electrical system and would fall under this exception" [25, p. 10]. However, the same FAA Joint Order states that "UAS operations within Class B will only be considered under exceptional circumstances" [25, p. 6], so operating sUAS within Class B (as well as the Mode C Veil) is severely restricted. While UAS may not require transponders within the Mode C Veil, regulations limit operation. Even if sUAS are equipped with engine-driven electrical systems, they are prohibited are transponder equipage because of limitations with the 1030/1090 MHz spectrum that manned aircraft use for coordination.

2.3 NAS Ecosystem Analysis

Having described the existing environment for the NAS, there are several ARIES ecosystem factors worthy of consideration. Specifically, the regulatory, political, economic, and societal factors critically affect the current NAS and the future integration of sUAS, especially in urban airspace.

2.3.1. Regulatory

The regulatory environment for the NAS is multifaceted, but ultimate authority for creating regulations resides with the FAA. The FAA is further analyzed in Section 3.2.1. Per the FAA's Office of Chief Counsel, "Congress has vested the FAA with authority to regulate the areas of airspace use, management and efficiency, air traffic control, safety, navigational facilities, and aircraft noise…" [26, p. 1]. Having one regulatory agency seeks to establish consistent regulatory system to ensure "the highest level of safety for all aviation operations" [26, p. 2]. Having state or local governments regulate aircraft flight or operation would result in a "patchwork quilt" of differing restrictions and ultimately this fractionalizing of airspace could decrease safety and efficiency. The FAA considers any device that meets the sUAS characteristics discussed in Section 2.1.2 to be aircraft, and therefore those devices are subject to its authority and regulation. This is generally accepted; however, some sUAS users find it difficult to fathom that a device purchased for a few hundred dollars must meet many of the same regulations applicable to multi-million-dollar aircraft [27]. For this thesis, the author considers compliant users who seek to abide by approved regulations, policies, and procedures. Non-compliant and/or malicious users are outside the scope of this work.

The NAS has thousands of regulations, but two most important guiding principles provide a general direction for the enterprise relating to aircraft in flight: *detect and avoid* and *certification*. 14 CFR Part 91 (General operating and flight rules) Section 113 (Right-of-rules: except water operations) requires that "each person operating an aircraft so as to see and avoid other aircraft [and remain well-clear]" and Section 111 (Operating near other aircraft) stipulates that "No person may operate an aircraft so close to another aircraft as to create a collision hazard" [28]. These requirements are more commonly referred to as *seeing and avoiding* other aircraft and *collision avoidance*. In recent years, with the addition of technologies to aid unmanned aircraft, which do not have an onboard pilot, see and avoid is more commonly referred to as *detect and avoid* for UAS.

Well-clear has historically been ill-defined and left to the judgment of the PIC. Depending on flight conditions, air traffic, and various other factors, the PIC had the autonomy to establish a flight path that did not create a collision hazard, as specified in 14 CFR Part 91.113. The introduction of UAS into the NAS complicates that issue, since there is no human aboard the UAV. Experts from MIT Lincoln Laboratory, MITRE Corporation, NASA, New Mexico State Physical Sciences Laboratory, and the U.S. Air Force Research Laboratory have worked to define what well-clear should mean for large, fixed-wing UAS to maintain the requisite level of safety and the FAA has adopted this definition (see Figure 2-7) [29]. Similar work is being done to define well-clear for sUAS [30], but at this time no standard exists.

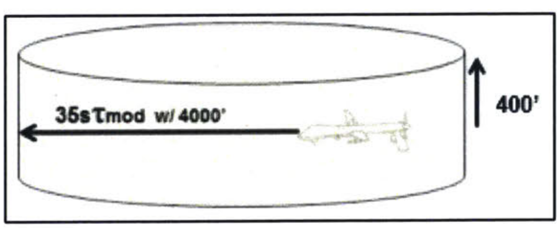

Figure 2-7: Well-Clear Definition for Large UAS [29, p. 5]

Collision avoidance is considered to provide a layer of safety if well clear is violated. The International Civil Aviation Organization (ICAO) defines collision avoidance as: a "layer of conflict management [that] must activate when the separation mode has been compromised.

Collision avoidance is not part of separation provision, and collision avoidance systems are not included in determining the calculated level of safety required for separation provision. Collision avoidance systems will, however, be considered as part of ATM safety management" [31, pp. 2-14]. For any type of UAS to meet this potential requirement, two options exist. The first (and current) option is that an UAS must remain within LOS of the PIC, allowing the user to see and avoid any hazards the UAV may encounter. The second option is to have a detect and avoid system that meets the requirement to remain well clear. At the present time, the challenge to detect and avoid hazards is both a capability limitation a regulatory issue, since there is not a set standard or certification basis for DAA on sUAS. Part 111 defines the performance requirement, but UAS presently cannot fully meet it. Detect and avoid goes beyond simply not colliding with oncoming air traffic. An aircraft must also evaluate flight paths for oncoming traffic, determine right-of-way, maneuver into a position that constitutes "well-clear," and follow all other regulations within 14 CFR Part 91 [32, pp. 21-22]. As discussed in Section 5.2, current efforts to develop the capability are underway and are critical to UAS integration into the NAS.

The other major regulatory principle of *certification* has been well-established for manned aircraft, but currently is limited for sUAS. For any manned aircraft, the FAA has strict airworthiness regulations that ensure the materials and construction of the aircraft is safe to carry personnel. The certification criteria are documented in 14 CFR Part 21 (Certification Procedures for Products and Articles), Part 23 (Airworthiness Standards: Normal Category Airplanes), Part 25 (Airworthiness Standards: Transport Category Airplanes), and Part 33 (Airworthiness Standards: Aircraft Engines). Similarly, pilots of manned aircraft must complete training that meets the requirements within 14 CFR Part 61 (Certification: Pilots, Flight Instructors, and Ground Instructors) [32, pp. 23-24]. The regulatory requirements for sUAS are evolving, and currently more relaxed. The FAA does not certify sUAS for Part 107 operations. Instead, the owner is responsible for ensuring a sUAS is safe before flying, and that all safety-related systems function before operations. To pilot a sUAS, a user must be at least 16 years old and pass an aeronautical knowledge test to receive at Part 107 remote pilot airman certificate with a sUAS rating (or be directly supervised by an individual with this certificate) [1]. Clearly, the regulatory environment for manned aircraft compared to unmanned aircraft has different levels of scrutiny. Tied to the lower certification requirements for sUAS is that sUAS operation is extremely limited, especially in the vicinity of manned aircraft.

2.3.2. Political

The political environment related to the NAS and sUAS reflects differing viewpoints from various governing bodies and organizations. The White House has put emphasis on the need to integrate UAS into the NAS to realize the economic benefits. One tangible product has been the FAA's Integration Pilot Program, which President Trump signed on October 25, 2017. The pilot program seeks to promote innovation and develop the technologies to have UAS execute the many potential mission sets [33]. However, making UAS use a reality has met several political challenges, mainly organizations attempting to influence the regulatory process and conflict between federal and state/local authorities.

Interest groups have voiced concerns both supporting and opposing the integration of sUAS into the NAS. The Association for Unmanned Vehicle Systems International (AUVSI) is the world's largest organization that promotes the use of unmanned systems and robotics. AUVSI, along with the Small UAV Coalition and similar entities have been vocal opponents of amendments and legislation that would put the ability to regulate UAS operations at the state and local-government level. Pro-UAS groups feel that some state and local governments may impose more restrictive laws and UAS operations may be severely curtailed [34]. The Air Line Pilots Association (ALPA) and Aircraft Owners and Pilots Association (AOPA) represent the general aviation and airline industry pilots. As such, these bodies support strong action by the FAA to ensure manned aircraft remain safe from any possible threat of collision with a UAS. ALPA wrote a letter to Congress on February 12, 2018, requesting advancements in UAS anti-collision technology, identification requirements, and tracking requirements before allowing any UAS operations in controlled airspace [35]. These are but a few examples of how organizations supporting UAS use and pilot safety attempt to lobby Congress regarding FAA regulation of UAS.

Another political challenge relates to ownership of low-altitude airspace. The FAA has had to reaffirm their exclusive regulatory authority over the airspace as state and local governments attempt to create their own UAS usage rules. However, state and local authorities may regulate "...land use, zoning, privacy and law enforcement operations..." [36]. As of September 10, 2018, 44 states have laws or resolutions addressing UAS use, specifically relating to law enforcement and general public use. Many of these policies regulate where a UAS can take-off and land, as well as identify critical infrastructure where UAS cannot operate. Some state and local governments desire to have increased regulatory power over low-altitude airspace (up to 500' AGL), but the FAA maintains those rights in the current system [27].

2.3.3. Economic

The potential economic benefits of UAS are significant, and a driving factor for integration into the NAS. AUVSI estimates that from 2015 to 2025, there will be more than $82.1 billion of economic impact from UAS integration. In the first three years of NAS integration, there may be over 70,000 new jobs created, and over 103,000 by 2025. Tax revenues will be more than $482 million from 2015 to 2025. More significant, for every year that UAS are not integrated into the NAS, the U.S. loses more than $10 billion in potential economic impact [37].

The UAS industry comprises many types of companies, from large firms seeking to incorporate UAS into their operations to small start-ups that attempt to innovate and develop new technologies. Since 2000, over 300 new firms have entered the UAS space, mainly focusing on hardware, support services, and operations. Operations encompasses software and navigational services, unmanned traffic management systems, threat mitigation, and infrastructure construction. While current sUAS use cases are addressed in Section 4.9, the primary current use of sUAS in industry is for short-range surveillance. This is mainly because of the existing regulations and technology limitations that exist [38]. Industry is making compelling economic arguments advocating for the integration of UAS into the NAS.

2.3.4. Societal

Like the economic environment, the societal impacts of UAS integration may be substantial. However, there exists a dichotomy of potential impacts, both positive and negative concerning UAS use. The potential economic benefits and convenience that UAS offer is appealing to the general public. The proven uses have also been well-documented, and include successful search and rescue efforts, drug interdictions, and fugitive investigations. The opportunity for package delivery and safer working conditions also add to the appeal of UAS [39]. However, with the impending proliferation of UAS, safety, security, and privacy are major societal concerns. As mentioned, risks to the public resulting from UAS flights is a major concern. Mid-air collisions with aircraft are an obvious safety issue for passengers aboard aircraft. However, sUAS weighing up to 55 lb can also create a safety hazard to ground personnel if one were to crash into a person, vehicle, or structure. Another concern relates to privacy. With the possibility of sUAS being used to deliver packages or take long-range imagery, many individuals worry about privacy. Recent events from technology companies (e.g. Facebook) have highlighted the need to properly secure data to maintain some level of privacy. There are also concerns about law enforcement's use of sUAS to collect data, or someone flying a sUAS and collecting imagery of a person's home [39]. The areas of security, safety, and privacy deserve attention and solutions to get increased societal support for sUAS integration.

3. CHAPTER 3: STAKEHOLDER ANALYSIS

To meaningfully understand an enterprise, a critical element is the stakeholders. Per Nightingale and Rhodes, "enterprise stakeholders are individuals and groups who contribute to, benefit from, and/or are affected by the enterprise. Stakeholders may be either exogenous or endogenous to the enterprise, depending on the perspective you take" [4, p. 16]. Using this stakeholder definition, the NAS as an enterprise has many diverse stakeholders having complex interactions and interdependent relationships. Hundreds of organizations have vested interests in having sUAS integrated into the NAS (or not), specifically within dense-traffic areas such as the Mode C Veil. Not only are there a large number of stakeholders, but also a wide variety, ranging from individual sUAS pilots to policy makers in Congress [32]. Using the System Design principle of abstraction, we can group entities with similar motivations to make stakeholder analysis valuable and not overly detailed so as to become incomprehensible [40, p. 229]. Abstraction allows for clustering of stakeholders into meaningful groups without being overly prescriptive and identifying individual organizations by name (e.g. specific businesses, universities, etc.). The generalized behaviors can be analyzed even as individual players enter or leave the enterprise. It is important to note that stakeholder analysis involves qualitative rankings and relative prioritizations, which can be inexact. All stakeholders considered have some level of importance and interest with regards to sUAS integration within the Mode C Veil, else, they would not merit discussion. However, determining stakeholder saliency and value exchanges provides insight about relationships and influence.

3.1. Stakeholder Saliency Methodology

The analysis method developed by Mitchell et al. seeks to identify stakeholder salience by considering three specific attributes: power, legitimacy, and urgency [41]. Considering the relative levels of power, legitimacy, and urgency among stakeholders allows for conclusions about overall saliency to the enterprise being considered, and "the greater the stakeholder salience the more powerful position it will embody, allowing this stakeholder to modify the behavior of the integrated enterprise according to its...will" [42, p. 78] Stakeholders exhibit power by being able to "bring about the outcomes they desire" [41, p. 865], either through coercion (using political means), utility (using material/financial resources), or norms (using symbolic resources). Legitimacy is "a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions" [41, p. 866]. Urgency is a combination of time sensitivity and criticality to the stakeholder.

Building upon the three attributes of stakeholder saliency allows for further classification. As shown in Figure 3-1, the saliency attributes intersect to form a Venn diagram. Stakeholders can then be classified based on the number of attributes they display. For this analysis the author relied on literature review and knowledge-gathering from experts to classify stakeholders. Latent stakeholders display only one attribute and are deemed "low salience" stakeholders (dormant, discretionary, or demanding). Moderately salient stakeholders display two attributes and are classified as "expectant stakeholders" since they expect an output/value from the enterprise (dominant, dependent, or dangerous). Highly salient stakeholders exhibit all three attributes and are the definitive stakeholder(s) of the enterprise [41, p. 873].

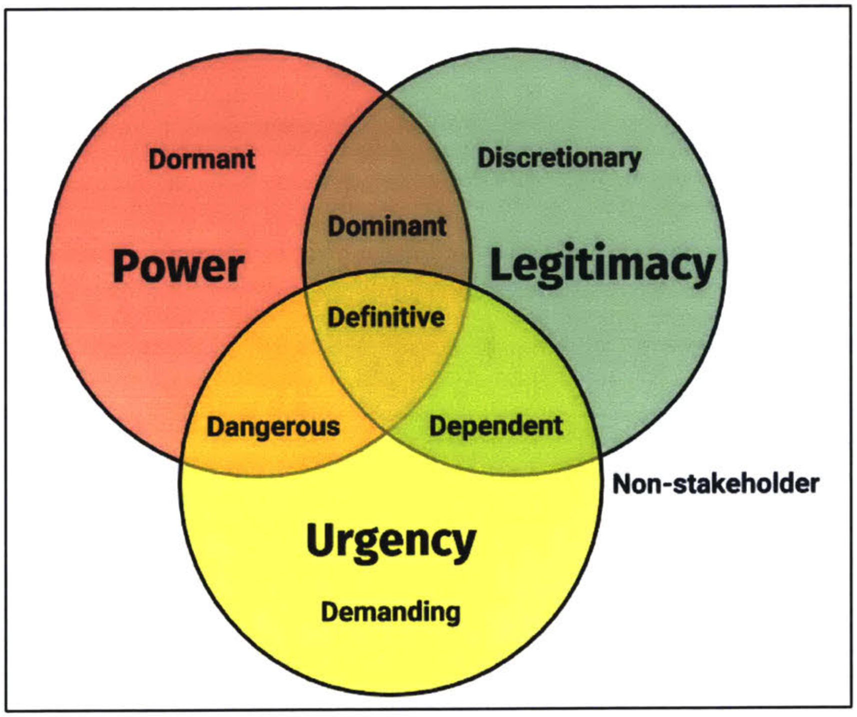

Figure 3-1: Saliency Method for Stakeholder Classification [43]

Stakeholders were selected based on having a direct impact or being directly affected by increased sUAS integration. For example, the FAA clearly meets this standard since sUAS integration directly impacts NAS operations. However, battery manufacturers are not included because they are subsidiary to the primary sUAS manufacturers (who are included in the analysis).

While the author recognizes that some stakeholders may not be represented, this analysis captures the major stakeholder groups and classifies them. After classifying each relevant stakeholder into one of the seven categories shown in Figure 3-1, prioritization becomes clearer. Since a stakeholder's saliency is not binary, a certain amount of judgment is required. Even so, latent stakeholders cannot be ignored, as they may have significant influence within/on the enterprise. The views of all salient stakeholders must be included, with increased emphasis and attention paid to any definitive stakeholders that emerge.

3.2. Stakeholder Descriptions

3.2.1. FAA (A)

The FAA serves as the regulatory authority for the United States for all aviation operations and has the stated mission of providing "the safest, most efficient aerospace system in the world" [44]. As such, the introduction of sUAS into the Mode C Veil falls under the FAA's purview. The FAA is a large organization that "would regulate all aspects of drone traffic... and their integration into the airspace" [45, p. 6]. The FAA would also certify any UTM system before its being put into operation, manage restrictions, and grant permission for sUAS to operate. The FAA has many responsibilities, ranging from airport design to pilot licensure to environmental impacts, among many others (as shown in the FAA Organizational Chart (Figure 3-2)). The FAA is also the air navigation service provider (ANSP) for the U.S. While each office, division, or department may have some role in sUAS integration in controlled airspace, focusing on entities with direct input into the decision-making is most impactful.

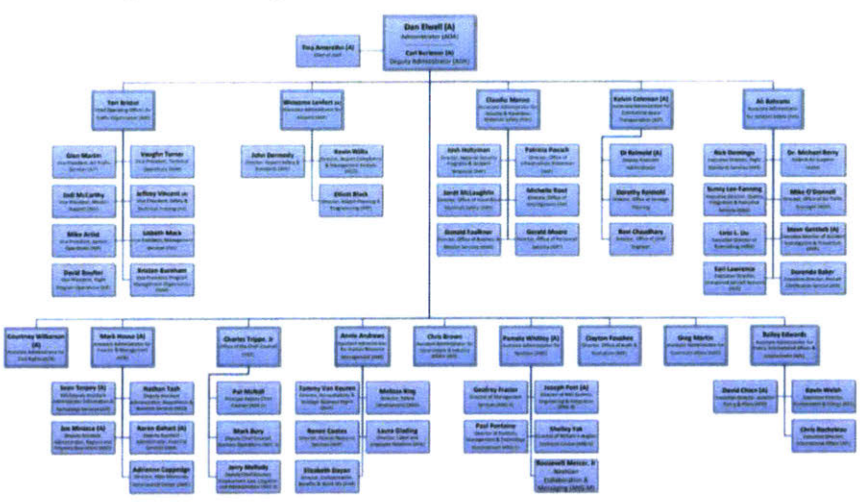

Figure 3-2: FAA Organizational Chart [46]

UAS Integration Office (AUS)

The UAS Integration Office was created in 2013 and reports to the Aviation Safety Office of the FAA. AUS "coordinates the development of regulations, policies, programs, and procedures to enable safe integration of UAS into the National Airspace System" [47]. AUS works closely with other offices throughout the FAA for UAS certification, rulemaking, testing, and standards.

UAS in Controlled Airspace (UASCA) Aviation Rulemaking Committee (ARC)

Established in November 2017, the UASCA ARC generates regulatory recommendations to the FAA for integrating UAS into the controlled airspace of the NAS. This ARC is comprised of members from the aviation community, industry, and government organizations to provide a holistic perspective. The UASCA ARC's main focus is on aircraft capability, air traffic separation, and air traffic control requirements as related to UAS in controlled airspace [48].

Drone Advisory Committee (DAC)

The DAC is a committee of CEO/COO-level individuals from UAS-interested organizations (industry, academia, retail, technology, and aviation) charged with developing the overall strategy and vision for UAS integration. The DAC reports directly to the FAA Administrator, providing him recommendations on UAS integration issues and priorities [49].

UAS Integration Pilot Program (IPP)

The IPP is working to accelerate UAS integration. Nine state and local governments and one university awardees are actively working with the FAA to address security, privacy, and safety risks. These organizations have access to expedited approval processes that normally require special authorizations in an effort to improve and expand UAS operations [50].

The FAA is a stakeholder with high levels of the three saliency attributes. The FAA has the power to affect the regulatory landscape for sUAS use. The FAA's legitimacy is unquestioned, having been tasked to provide a safe aerospace system. Its urgency has increased with the rapid development of technology and pressure from both industry and government. Therefore, the FAA is considered a *definitive* stakeholder.

3.2.2. NASA (B)

NASA is a major UAS research partner for the FAA and works closely to conduct studies that inform rulemaking. While NASA is concerned with aircraft and flight operations within the NAS, its core mission also includes operations related to humans in space, space technology, and scientific exploration. The Aeronautic Research Mission Directorate (ARMD) has put a concerted effort to developing a UAS Traffic Management System (UTM) that addresses major technical challenges related to UAS integration. NASA has many subject matter experts (SMEs) whose research on technical challenges and solutions is valuable to the FAA and others stakeholders. NASA's UTM concept is a contender to become the framework that allows UAS increased access to the NAS [51]. Through its influence on the FAA, NASA demonstrates power, and through its expertise and capabilities related to aerospace, NASA has legitimacy. However, NASA lacks the urgency to rapidly integrate UAS into the NAS, since pressure (political, industrial, and societal) is directed toward the FAA. Therefore, NASA is a *dominant* stakeholder.

3.2.3. UAS Executive Committee (EXCOM) (C)

The UAS EXCOM is composed of executive-level individuals from the multiple government agencies (FAA, DOD, NASA, DHS, DOJ, DOI, and DOC) tasked with coordinating efforts to achieve routine and safe UAS operations in the NAS. By having leadership present from major agencies concerned with UAS integration, redundancies can decrease and policy and procedural issues can resolve rapidly. The UAS EXCOM is chaired by a senior FAA official, and emphasizes innovation through "partnerships with the industry, academia, and federal agencies" [52]. Considering its senior leadership, well-defined objective, and desire to promptly institute changes, the UAS EXCOM exhibits all three saliency attributes and is a *definitive* stakeholder.

3.2.4. UTM Service Providers (D)

UTM Service Providers are vendors that support UTM services for users. A National Beta test of Low Altitude Authorization and Notification (LAANC) began in April 2018. LAANC is a service that provides approval for sUAS airspace authorization requests for controlled airspace. Fourteen FAA-approved vendors verify sUAS user requests to the FAA Data Exchange and provide a near-real time response. The goal of UTM is to include more than authorization to operate sUAS, but also collision avoidance and early warning of manned aircrafts for PICs [53].

UTM Service Providers exhibit legitimacy since they provide a desired service to the NAS, and they display urgency by working with the FAA to implement LAANC and future UTM as quickly as possible. UTM Service Providers lack power since their technologies and services still require FAA authorization before use. Therefore, UTM Service Providers are *dependent* stakeholders.

3.2.5. Standards Organizations (E)

Standards Organizations support the FAA (and many other government agencies) by developing standards that inform regulatory requirements. The National Institute of Standards and Technology (NIST) has been assigned the role of deciding which standards organizations will be given specific roles for UAS integration. Most applicable to UAS integration efforts are: RTCA, ASTM International, SAE International, ANSI, IEEE, CTA, and ITU. These organizations focus on standards for aviation, safety, engineering, electronics, consumer technologies, and telecommunications [54]. These organizations generate value by validating performance standards, enabling industry representatives to have input to the standard development process, and providing vetted standards to the FAA before implementation [55]. Standards organizations have expertise and urgency relating to airspace and UAS operations. However, volunteers comprise most of these organizations, and ultimately, they provide a well-informed recommendation to the FAA. This lack of power causes standards organizations to be considered a *dependent* stakeholder.

3.2.6. Research Organizations (F)

With the complexities and challenges associated with the NAS, many research partners outside of the FAA conduct meaningful research and analyses related to UAS integration. These research organizations include government agencies, industry, and academia such as the Air Force Research Lab, MITRE Center for Advanced Aviation System Development, and MIT Lincoln Laboratory. Research partners include sponsored and non-sponsored research efforts and focus on a wide range of challenges, both immediate and future [54, p. 19]. The work ultimately benefits the research organizations (through grants and funding), industry (through faster UAS adoption), and government (through decreased time and cost to integrate UAS). Research partners demonstrate legitimacy and urgency through expertise and initiative to integrate sUAS, but mainly work on a collaborative basis with the FAA, and lack decision-making power. This view classifies research organizations as *dependent* stakeholders.

3.2.7. sUAS Pilots (G)

sUAS pilots are the individuals who will actually control and fly the UAV in compliance with 14 CFR Part 107. Pilots have different potential motivations, from commercial use to the support of public efforts (emergency services or law enforcement). There is an expectation that sUAS pilots attain a certain level of expertise, demonstrated by passing the Part 107 exam and maintaining this certification [45, pp. 7-8]. Individual pilots seek to have sUAS integrated rapidly to support their individual motivations, without as much concern for the greater NAS or the objectives of the FAA. sUAS pilots have clear urgency, but have minimal power and legitimacy because of the low decision-making ability for UAS policy and low barrier to entry to becoming a sUAS pilot. In the stakeholder saliency framework, sUAS pilots are *demanding* stakeholders.

3.2.8. sUAS Operators (H)

sUAS operators are the stakeholders accountable for the sUAS operations of organizations. An analogy is that the sUAS operators are to the sUAS pilots like the airlines are to manned aircraft pilots. sUAS operators will generate the expertise, relationships, and technology to interface with the FAA for sUAS operations in a routine and established manner [45, p. 8]. sUAS operators also include individuals who independently own/operate personally-owned sUAS. The sUAS operator arena will undergo rapid expansion as sUAS integration, especially in the Mode C Veil, becomes imminent. Some examples of sUAS operators include: FEMA, DHS, UPS, Amazon, and many other companies and government organizations. At this time, sUAS operators exist, but have limited power or legitimacy. They demonstrate urgency, because sUAS integration represents a significant market opportunity. Therefore, sUAS operators are *demanding* stakeholders.

3.2.9. sUAS Manufacturers (I)

sUAS manufacturers encompass the stakeholders that produce the sUAS that operate within the NAS. These organizations have a strong interest in understanding the requirements and specific interfaces set forth by the FAA that will allow their devices to comply. sUAS manufacturers may need to provide the physical flight characteristics and some user and location data to the FAA. This depends on whether a recommended solution is accomplished with after-market avionics, or via a system that is fully integrated with the sUAS. sUAS manufacturers want to ensure they implement the proper standards without having significant rework, so they demonstrate urgency [45, p. 11]. The major sUAS manufacturers have been able to show the significant benefits (both economic and social) from sUAS implementation, meeting the requirement for legitimacy. However, like the sUAS pilots and operators, sUAS manufacturers have limited power to influence the design and implementation of sUAS within the Mode C Veil and the greater NAS. They are *dependent* stakeholders.

3.2.10. Manned Aircraft Pilots (J)

Manned aircraft pilots include a large number of individuals, as well as the organizations that represent them, such as the AOPA and ALPA. Manned aircraft pilots and the organizations that represent them have expectations of safety from the NAS. When operating under IFR, they rely on ATC for separation from aircraft, and expect ATC (or another entity) to provide the same level of separation and safety from sUAS traffic. They seek a solution for sUAS integration that allows the devices to be capable of implementing collision avoidance logic and maneuvers with minimal, if any, impact to existing manned aircraft operations. As the current and primary users of the NAS, manned aircraft pilots have legitimacy relating to sUAS integration. Manned aircraft pilots and their representative organizations do not have urgency for sUAS integration. They generally feel that sUAS are a safety concern and want significantly more technology development and stricter regulations before being amenable to the integration [45, p. 9]. However, manned aircraft pilots belong to powerful unions (ALPA and AOPA) that have significant influence with lobbyists and policy decisions, and manned aircraft pilots have clear legitimacy as sUAS may impact their safety and operations. They are a *dominant* stakeholder.

3.2.11. National Air Traffic Controllers Association (NATCA) (K)

The National Air Traffic Controllers Association (NATCA) is the labor union representing the FAA's air traffic controllers and other aviation safety-related specialists within the aviation industry. NATCA has over 15,000 members and actively seeks to advance working conditions, professionalism, and safety across the industry. NATCA's primary tools to achieve these goals are: collective bargaining, political action, and lawful concerted activity. NATCA has agreed to never support an illegal ATC strike but have significant influence with Congress and the FAA with matters related to ATC working conditions and upgrading ATC equipment and systems [56]. NATCA's primary concern related to UAS integration relates to how UAS traffic will be managed. ATC already has significant burdens and NATCA seeks to keep the workload for individual air traffic controllers focused on manned aircrafts. As mentioned, NATCA has power with its ability to influence the FAA and Congress, and it has legitimacy with its clear ties to ATC and safety specialists. Like manned aircraft pilots, NATCA lacks urgency as it seeks a robust solution for sUAS integration that has minimal impact on ATC operations. They are a *dominant* stakeholder.

3.2.12. Law Enforcement (L)

Law enforcement plays a role in sUAS integration because any violations must be attributed to the offender. The FAA has made it clear that it is a regulatory agency, but enforcement of its regulations requires support from federal, state, and local law enforcement. Upon integrating sUAS into controlled airspace, law enforcement will need to monitor and understand violations of sUAS regulations. They will require information about traffic violations and be able to identify sUAS pilots and impose fines. Additionally, law enforcement may require an ability to send out notifications and intercept advisories should an emergency arise or a sUAS be noncompliant [45, p. 10]. Law enforcement has legitimate use and they will use system information to enforce regulations and prosecute violators. Law enforcement will have power by their ability to enforce, fine, and further prosecute to keep the NAS safe. They do not have clear urgency, as they are not overly time sensitive to when this integration occurs. Law enforcement is a *dominant* stakeholder.

3.2.13. Emergency Services (M)

Emergency services are stakeholders that rely on the NAS to provide life-saving care or respond to urgent situations. Examples of emergency services include air ambulances and dropping fire-retardant chemicals. As current users of the NAS to react to emergencies, they have expectations similar to the manned aircraft pilots: the level of safety for manned aircraft cannot be compromised by the introduction of sUAS in controlled airspace. Emergency services differ from manned aircraft pilots because of the time sensitivity and criticality of their missions. For sUAS to be permissible in controlled airspace, emergency services may require a UTM that can provide a "drone-free corridor/zone" to allow for rapid response without obstruction [45, p. 10].

Emergency services are also very interested in using sUAS to support some missions such as monitoring for hot spots in a wildfire situations or damage assessment/victim location during floods, hurricanes, or earthquakes. During natural disasters they may have more power via an on-scene commander decision to allow certain operations [45, pp. 10-11]. Emergency services have urgency and legitimacy based on their mission set, but lack power to significantly influence the decision-makers for how sUAS can be successfully integrated into controlled airspace. They are *dependent* stakeholders.

3.2.14. Department of Defense and Department of Homeland Security (N)

The Department of Defense and Department of Homeland security are federal entities with similar needs from the NAS. Both departments have a legitimate need to operate sUAS within the NAS, either for training purposes (DOD) or for mission surveillance and execution (DHS). DOD and DHS have shown the ability to influence policy and negotiate exemptions with the FAA for some UAS operations already, which demonstrates they have power. However, DOD and DHS have not yet demonstrated clear urgency for increased sUAS integration. Therefore, they are *dominant* stakeholders.

3.2.15. State and Local Governments (O)

As discussed in Section 2.3.2, state and local governments have sought to establish their own regulations related to sUAS operations within their jurisdictions. The FAA has made clear that it is the sole regulator of the NAS and there will not be a disjointed set of regulations defining the airspace. Per the definitions for stakeholder saliency, state and local governments lack power and legitimacy for sUAS integration into controlled airspace. They do have urgency, since they want rapid resolution that addresses their expectations of privacy, safety, and security. State and local governments are *demanding* stakeholders.

3.2.16. Ground Traffic and Personnel (P)

Ground traffic and personnel represent the general public who do not regularly operate in the NAS but have an expected level of safety. Like other stakeholders considered, ground traffic and personnel will rely on sUAS being detectable and having a collision avoidance mechanism [45, p. 10]. The general public has a level of urgency for sUAS integration, as they seek to maximize benefits from the developing technology. However, they do not have power or legitimacy in the NAS arena. At this time, they desire rapid sUAS integration and are *demanding* stakeholders.

3.3. Stakeholder Saliency Application to sUAS Stakeholders

Having considered the 16 stakeholders with varying levels of power, legitimacy, and urgency, the results can be visually displayed on the Venn diagram of the stakeholder saliency attributes (see Figure 3-3). Two stakeholders demonstrate the characteristics of "definitive stakeholders" (FAA and UAS EXCOM). The NAS enterprise and sUAS operations is significantly shaped by the decisions and guiding principles these two stakeholders establish. Expectant stakeholders have two saliency characteristics. NASA, manned aircraft pilots, NATCA, law enforcement, Department of Defense, Department of Homeland Security are expectant and dominant stakeholders, since they have power and legitimacy. UTM service providers, standards organizations, research organizations, sUAS manufacturers, and emergency services are expectant and dependent stakeholders, showing legitimacy and urgency, but lacking the power to bring about desired outcomes. sUAS pilots, sUAS operators, state/local governments, and ground traffic/personnel are latent demanding stakeholders, since they have urgency but limited power and legitimacy. Although subjective, classifying stakeholders based on these saliency attributes highlights the need for the FAA and UAS EXCOM to establish themselves as the leaders of enterprise change for controlled airspace relating to sUAS integration. While other entities may desire integration, the FAA and the UAS EXCOM have the power, legitimacy, and urgency to make it a reality. When considering the current and future vision for the NAS, special attention must focus on what is within their ability to control and influence, since they are the most important stakeholders in the enterprise.

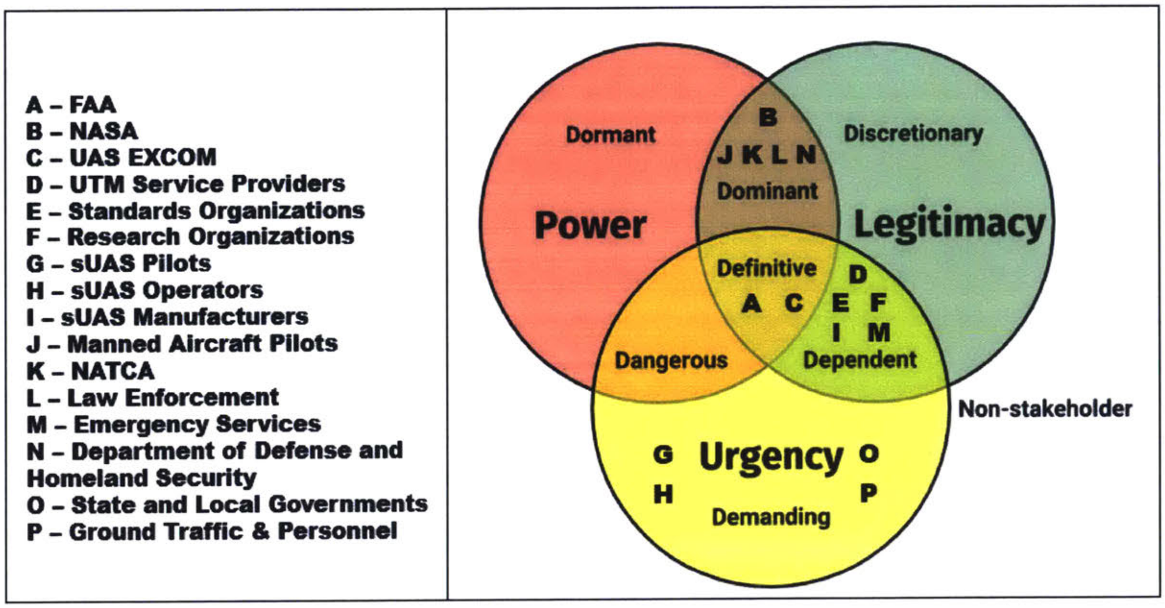

Figure 3-3: sUAS Stakeholder Saliency

3.4. Stakeholder Value Exchanges

When considering the NAS as an enterprise, an important consideration is stakeholder value. Identifying values is important because what a stakeholder values may contribute to their motivations and behaviors. Similarly, an efficient enterprise causes the stakeholders to return some value as well. Value can take many forms, and can range from financial to informational to experiential among many others. To succinctly capture the values to/from the stakeholders for the NAS, one can arrange the value expectations and the value contributions [4, pp. 42-46].

Table 3-1 identifies the value exchanges, which helps inform and focus efforts for sUAS integration. This set of value exchanges is based on the expert judgment and the strategic statements and key values published by the stakeholders. Any recommendation for sUAS integration should attempt to address the value exchanges to ensure that expectations are met and stakeholders are contributing to the enterprise.

Table 3-1: NAS Value Exchanges

Value Expectations from NAS Enterprise	Stakeholders	Value Contributions to NAS Enterprise
- Maintain/improve level of safety for NAS - Compliance with regulations and procedures - Controlled innovation and technology to integrate sUAS	**FAA**	- Grant airspace authorizations and clearances - Develop regulations and procedures - Maintain/improve level of safety for NAS - Manage air traffic efficiently
- Maintain/improve level of safety for NAS - Data/collaboration to conduct testing for UTM and other programs/initiatives	**NASA**	- UTM research and implementation plan - Technology for ATC and aircraft to improve safety - Solution development for technical sUAS integration challenges
- Maintain/improve level of safety for NAS - Well-defined standards/regulations and technology for sUAS - Phased sUAS integration until sUAS operations become routine	**UAS EXCOM**	- Executive leadership and direction for sUAS integration into the NAS - Decision-making authority - Collaboration between industry, academia, and government
- Data collection from un/manned aircraft - Contracts/funding for UTM services - Establishment of standards for sUAS - Rapid sUAS integration through technical and regulatory development	**UTM Service Providers**	- UTM services providing UAS identification, position, and communication - UTM incorporated into collision avoidance solution
- Maintain/improve level of safety for NAS - Adoption of performance standards recommendations by the FAA	**Standards Organizations**	- Public-private collaboration for developing standards - Consensus-based recommendations improve NAS relating to efficiency and safety [57]
- Maintain/improve level of safety for NAS - Data/collaboration to conduct testing for programs/initiatives	**Research Organizations**	- Public-private collaboration for innovative aviation solutions - Consensus-based recommendations improve NAS relating to efficiency and safety
- Reasonable standards for sUAS use - Approval to operate in authorized airspace - Collision avoidance and UTM that permit sUAS use without undue safety requirements	**sUAS Pilots**	- Provides sUAS services to customers - Compliance with regulations related to training, safety, licensing, and identification - Develop innovative solutions/best practices for sUAS implementation
- Reasonable standards for sUAS use - Approval to operate in authorized airspace - Collision avoidance and UTM that permit sUAS use without undue safety requirements	**sUAS Operators**	- Provides sUAS services to customers - Management and coordination of sUAS pilots - Compliance with regulations related to training, safety, licensing, and identification - Develop innovative solutions/best practices for sUAS implementation

Value Expectations from NAS Enterprise	Stakeholders	Value Contributions to NAS Enterprise
- Well-defined standards and regulations - Well-defined interfaces with UTM	**sUAS Manufacturers**	- sUAS devices in compliance with regulations and standards - Develop innovative solutions for sUAS integration and safety
- Maintain/improve level of safety for NAS - Well-defined standards/regulations for aviation operations - Approval to operate in authorized airspace	**Manned Aircraft Pilots**	- Provide aviation services to customers (transportation, package delivery) - Compliance with regulations related to training, safety, licensing, and identification - Develop innovative solutions/best practices for manned aircraft operations
- Maintain/improve level of safety for NAS - Well-defined standards/regulations for ATC operations - Modern equipment and systems to manage aircrafts	**NATCA**	- Provide traffic management services to manned aircraft - Support safe aviation operations throughout the NAS - Provide notifications and information to pilots as needed - Coordinate aircraft during departure, en route and approach/landing at airports
- Maintain/improve level of safety for NAS - Data collection from un/manned aircraft to identify violators - Emergency corridors/zones to support law enforcement operations	**Law Enforcement**	- Enforcement of all applicable regulations (fine/prosecute violators) - Support regulatory compliance through monitoring
- Maintain/improve level of safety for NAS - Emergency corridors/zones to support emergency services operations	**Emergency Services**	- Life-saving care for individuals - Support for urgent disaster relief efforts
- Maintain/improve level of safety for NAS - Authorization to conduct training and missions without significant restriction	**Department of Defense and Department of Homeland Security**	- Provide security services for nation - Conduct R&D and evaluation of new technologies impacting NAS
- Maintain/improve level of safety for NAS - Ensure security and privacy of general public is maintained	**State and Local Governments**	- Provide state/local law enforcement to ensure regulatory compliance - Develop innovative solutions for sUAS integration through FAA-led initiatives
- Maintain/improve level of safety for NAS - Ensure security and privacy is maintained - Increased convenience and services provided by sUAS	**Ground Traffic and Personnel**	- Develop innovative solutions/best practices for sUAS implementation - Provide funding to FAA via federal taxes

4. CHAPTER 4: AS-IS ARCHITECTURE

This chapter captures the as-is architecture of the NAS as related to sUAS integration, examines current use cases of sUAS, and highlights current efforts by organizations to integrate sUAS. The ARIES elements are the main tool used for capturing the current architecture, discussed in Sections 4.1 to 4.8. Use cases investigate the current uses across industry and government in Section 4.9.

As discussed, the NAS is a complex enterprise and capturing the salient architecture can be daunting. The ARIES framework provides elements that allow for a structured decomposition of the enterprise (see Figure 1-1). The ARIES elements are designed to be crosscutting and research has supported their use for enterprise architecting. These lenses allow for focused analysis of singular aspects of the enterprise and highlight potential strengths and weaknesses of that element. However, there are significant interrelationships of the enterprise elements (see Figure 4-1). These relationships can be reciprocal or may provide direction for one element to another. Therefore, considering the interactions between elements provides useful insights as to emergent properties of the enterprise and if certain elements have greater influence and impact than others [4, pp. 17-20]. The author examines the NAS enterprise architecture as it relates to sUAS integration with the following elements: policy, strategy, products/services, process, organization, infrastructure, information, and knowledge. The ecosystem and stakeholder elements have been addressed in Chapters 2 and 3.

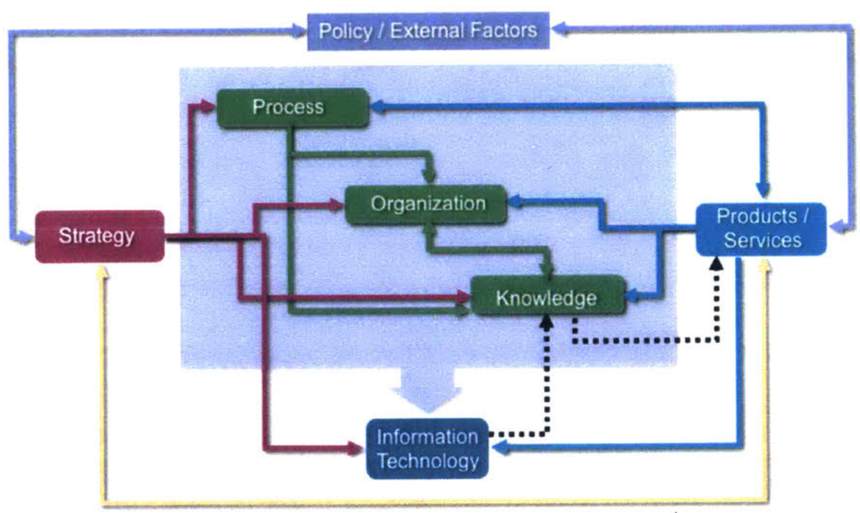

Figure 4-1: Enterprise Element Interrelationships [32, p. 51]

4.1. Policy

While many different policies and regulations govern the NAS, the primary authority on sUAS operations is 14 CFR Part 107. This rule was published to improve sUAS operations relative to the older process of Section 333 exemptions for all commercial and public sUAS uses. This policy section addresses the current policies that impact sUAS operations and notes the limitations and restrictions imposed on operations within controlled airspace.

4.1.1. 14 CFR Part 107

Established by the FAA in June 2016, 14 CFR Part 107 is titled "Small Unmanned Aircraft Rule" and regulates sUAS certification and operations. The regulation has allowed for the increased use of commercial and public sUAS within the NAS, mainly in uncontrolled airspace (Class G). Part 107 directly addresses sUAS operational limitations, pilot certification and responsibilities, and aircraft certification requirements [1].

The operational limitations set forth by Part 107 are straightforward but restrictive for sUAS operations in the NAS. Many publications and organizations summarize the Part 107 rule, which permits daytime operation of sUAS in Class G airspace below 400 feet AGL while remaining within VLOS and not flying over people [58, pp. 4-4]. However, there are additional limitations within Part 107. Below are the relevant aspects of Part 107 relating to operations:

- VLOS only; sUAS must remain within VLOS of the PIC/flight controller/designated visual observer (VLOS only permits use of corrective lenses for vision, no other devices or aids may be used).
- No operations over people; sUAS may not operate over any individuals not directly involved in the flight operations, and may not fly under a covered structure or inside a stationary vehicle.
- Daylight operations only; sUAS may operate 30 minutes before official sunrise through 30 minutes after official sunset, local time.
- Right-of-way; sUAS must yield right of way to all other aircraft.
- Maximum groundspeed is 100 mph (87 knots).
- Maximum altitude is 400 feet AGL, or within 400 feet of a structure if above 400 feet AGL.
- Minimum weather visibility from the sUAS control station must be three miles.
- Class G airspace operations are allowed without ATC permission.
- Class B, C, D, and E airspace operations require ATC permission and coordination.

- One sUAS per PIC/visual observer; No individual may act as the PIC or visual observer for more than one sUAS at a given time.
- No operations from aircraft or moving vehicles, unless the moving vehicle is located in a sparsely populated area.
- PIC must conduct a preflight inspection of sUAS for safety and operational functionality.
- A PIC may not operate a sUAS if physically/mentally impaired.
- External loads are permitted as long as flight characteristics and controllability of the aircraft are not affected.
- Transporting property for hire is permitted given:
    - sUAS and payload combined remain under 55 pounds.
    - sUAS remains within VLOS.
    - The flight remains within a single state/district/territory. [1, pp. 1-2]

Part 107 has requirements for the remote pilot in command relating to certification and responsibilities. To summarize: a remote PIC must hold a sUAS certificate (based on knowledge and experience level), inspect the sUAS, and take responsibility for the actions and damage from sUAS operations. Pertinent requirements for a sUAS PIC are below:

- A user must hold a valid remote pilot airman certificate with a sUAS rating or be under the direct supervision of an individual with this certificate.
- To obtain a remote pilot certificate, an individual must:
    - Pass an aeronautical knowledge test at an approved test center; or
    - Hold a non-student Part 61 pilot certificate, complete a flight review within 24 months, and complete a FAA-developed sUAS online training course.
    - Be vetted by Transportation Security Administration (TSA).
    - Be at least 16 years old.
- PIC must provide sUAS to the FAA upon request for inspection and testing.
- Report any property damage or bodily injury to the FAA greater than $500 within 10 days.
- Conduct preflight inspections to ensure communication with the control station is operating correctly and sUAS can operate safely.
- Register the sUAS with the FAA [1, pp. 2-3].

Part 107 briefly addresses aircraft requirements and model aircraft. The salient points are that airworthiness certification for sUAS is not required and model aircraft do not have to comply with Part 107. Below are the details set forth by the Part 107 rule regarding aircraft certification and model aircraft:

- sUAS do not require an airworthiness certification. The only requirement is the above-listed inspection by the remote PIC to ensure safe operations.
- Model aircraft fall under Section 335 of Public Law 112-95 and are exempt from all aspects of Part 107 [1, p. 3].

Though not explicitly stated as constraints, a few principles drive the specific limitations set forth in the Part 107 rule. The principles of command and control and detect and avoid underlie the need to maintain VLOS with the sUAS during all operations. Command and control is the ability to maintain an active communication link between the control station, remote PIC, and the unmanned aircraft. The primary concern with current command and control technology relates to range and continued connectivity. To mitigate this issue, the sUAS must remain within VLOS. By requiring sUAS to remain within VLOS, the remote PIC is able to see-and-avoid any potential hazards. Technologies that can effectively detect and avoid aircrafts and obstacles are under development, but the FAA has not approved any for sUAS to date. Since a precise definition for sUAS well-clear is still being developed, coupled with the lack of an approved SAA device/technology, the FAA requires VLOS with a ground observer to meet Part 91.113 requirements. This relates to the second principle that grounds the Part 107 rule: safety. The risk of injury to people, in aircraft or on ground, may increase by introducing sUAS into the NAS. To maintain the level of safety for the NAS, Part 107 allows sUAS to operate mainly in uncontrolled Class G airspace, and never over people. While safety may motivate Part 107, it also constrains how entities may employ sUAS for commercial and public purposes. The majority of use cases (as discussed in Section 4.9) center around urban and suburban areas. These population centers can fall within some class of controlled airspace. While a waiver process exists, over 50% of FAA-approved authorizations and waivers are for Class D and E airspace (see Table 4-1). The FAA does not publish the percentage of denied requests for operations within Class B and C airspace, where demand from users and operators is likely much higher.

Table 4-1: 2017 Controlled Airspace Waiver Approvals [5, p. 44]

Total Approvals	Auths	Waivers	Total
Class B	1,823	18	1,841
Class C	2,715	49	2,764
Class D	6,905	97	7,002
Class E	1,351	22	1,373
TOTAL	12,794	186	12,980

4.1.2. JO 7200.23A

Joint Order 7200.23A is an FAA-issued order that supplements 14 CFR Part 107 and provides guidance to ATC regarding sUAS. JO 7200.23A became effective on August 1, 2017. Per this policy, ATC does not provide any services (to include separation services) to any sUAS operating in controlled airspace. ATC may intervene if a sUAS is operating in controlled airspace and endangering the NAS by contacting the PIC. ATC can notify the PIC and terminate the sUAS operation immediately [59, p. 4].

JO 7200.23A also includes the requirements for receiving a waiver to operate in controlled airspace. The waiver process is discussed in Section 4.4 (Process), but the order requires use of the pre-determined UAS Facility Maps (UASFM) for evaluation. UASFM is discussed in Section 4.3 (Products/Services), but essentially, these categorizations of controlled airspace provide a screening criterion for whether a waiver request to fly a sUAS in controlled airspace will be approved (along with factors such as mission type and duration). Waivers must be requested and processed through a centralized waiver request forum through the FAA's web site, local ATC and facilities may not approve sUAS operation requests. However, if the headquarters office cannot approve the waiver request using UASFM parameters, local facilities may evaluate waiver requests and authorize as deemed appropriate (or provide mitigations). Mitigations may include adjusting altitude, date/time, or location of the sUAS operation [59, pp. 8-10].

4.1.3. AC 107-2

Advisory Circular 107-2 is an FAA-issued notice that provides guidance to pilots to properly conduct sUAS operations in the NAS. AC 107-2 was published on June 21, 2016. Most of this AC provides examples of how to properly register, inspect, maintain, and operate a sUAS. However, one area specifically addresses privacy laws. While the Part 107 rule and the FAA do not regulate privacy, such as gathering imagery and data of people or property, state and local laws still apply to sUAS users. For example, state and local authorities may generally enforce laws related to "land use, zoning, privacy, trespassing, and law enforcement operations" when sUAS operations interfere [26, p. 3]. AC 107-2 recommends a "Best Practices" document for sUAS users to review to promote "privacy, transparency, and accountability for the private and commercial use of UAS" [60, p. 1].

4.2. Strategy

The FAA's strategy regarding sUAS integration has centered on the need to keep the NAS of the United States safe. In an interview the former FAA Administrator, Michael Huerta, discussed how within the aviation industry, competitors "don't compete on safety. This is such a foundational view: that we share information, that we work together, because the whole industry thrives when we have a safe system" [61]. This mindset has carried over into the UAS integration field, and the FAA and its partners have continued to emphasize safety as the primary value delivered to the NAS from their work. The FAA's stated mission is to "provide the safest, most efficient aerospace system in the world," and its stated core values are: safety, excellence, integrity, strength in its people, and innovation [44]. These values help drive the mindset throughout the organization and for partners and stakeholders who must work with the FAA. In most cases related to NAS, the FAA is the key decision-maker so its values extend beyond its own organization. Additionally, the FAA's sUAS integration effort must generally maintain the status quo for manned aircraft, which has become the standard for aviation safety throughout the world.

The FAA publishes a guiding document for UAS integration titled "Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap." The first edition was published in November 2013, with a second edition published in July 2018. The 2018 strategy for sUAS integration incorporates a phased approach, depicted in Figure 4-2. The intent is to have a gradual integration of sUAS into the NAS, and with each step have technologies continue to develop. The NAS will first accommodate, then integrate, and finally, evolve with sUAS being fully incorporated [62, p. 20].

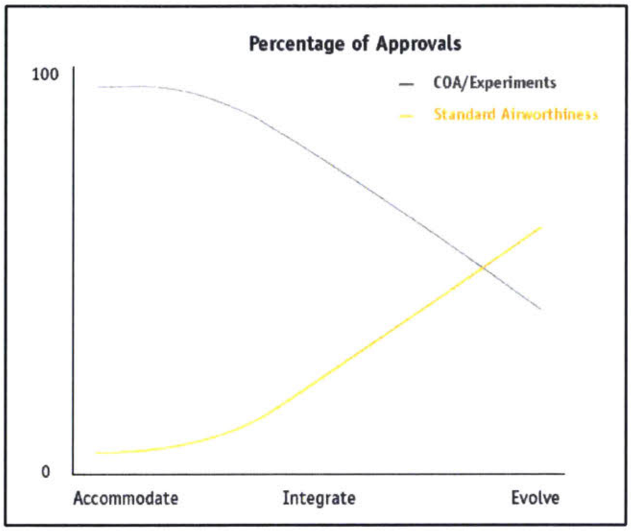

Figure 4-2: FAA Strategy for sUAS Integration [62, p. 20]

Accommodation is the first (and current) step in the way ahead for sUAS integration. The FAA is attempting to develop set criteria that establish airworthiness for sUAS, but at this time, no such criteria exist. Instead, individual users determine airworthiness of the sUAS with pre-flight inspections and maintenance checks. One issue with establishing airworthiness is the variety of configurations that sUAS encompass (see Table 2-4). Setting minimum operational performance standards (MOPS) is extremely difficult when trying to be applicable to so many different aircraft. Because sUAS cannot currently meet requirements for DAA or IFR, they must operate separately from manned aircraft. Pilots and operations still require certification/approval in order to be valid. Using current operational and safety data, the FAA is working to validate a safety case for sUAS in the NAS. A major effort in research and development is part of accommodation, with specific efforts in SAA, control and communications, modeling and simulations, and human factors [62, pp. 22-30].

Integration is the second phase in the sUAS integration strategy. During integration, many aspects from accommodation will be finalized from the result of research and development. Some potential requirements are under development, such as establishing airworthiness requirements and minimum performance standards for detect and avoid systems. Integration phase allows for increased sUAS autonomy, although a human may remain in the loop. No new airspace classes or types will be created for sUAS operations. A complete and integrated set of regulations, guidance, procedures, and standards will encompass sUAS operations. Finally, the FAA will address privacy, security, and environmental concerns that sUAS create [62, pp. 32-34].

Evolution looks forward to continue to have the NAS evolve based on emerging ideas. It is the least-defined of the strategic phases. Many efforts (e.g. air certification, standards, and rulemaking) focus on using the experience gained during accommodation and integration to refine and improve requirements. The FAA also seeks to have seamless sUAS operations throughout the NAS [62, p. 39].

4.3. Products/Services

This section highlights current products and services provided to sUAS operating within the NAS. While the products and services continue to slightly evolve, the functionalities remain fairly static until a major technological or regulatory change emerges.

4.3.1. Low Altitude Authorization and Notification Capability (LAANC)

LAANC is a service that provides airspace authorization within controlled airspace near airports. In near-real time, requests for operations in controlled airspace can be processed and approved through automation. Users submit requests through a mobile application or a website. Beta testing for LAANC began on April 30, 2018, and continued through 2018 to approximately 500 airports. This service provides an alternative to the manual application process to fly within controlled airspace. A user submits a flight plan (which must comply with all aspects of Part 107 except airspace classification) and an FAA-approved LAANC service supplier provides automated approval or disapproval. A sUAS user must still operate below 400 feet, in accordance with Part 107. A request that complies with UAS Facility Map is more likely to be approved and does not require additional coordination. UAS Facility Maps establish altitude ceilings around airports. The major benefit provided by LAANC is the significant decrease in wait time for approval of sUAS operations in controlled airspace [53].

4.3.2. UAS Facility Maps

UAS Facility Maps are a product that establish altitude ceilings for sUAS operations near airports. When submitting a request to operate a sUAS in controlled airspace (via LAANC or manually) the user should consult the UASFM. While the UASFM do not permit sUAS operations without authorization, they provide guidelines for flights that may be approved without additional safety analysis [63]. Figure 4-3 shows an example UASFM for the Greater Boston Area. UAS flight restrictions (red shaded areas) exist over the U.S. Coast Guard Base and Boston National

Historic Park. Additionally, the altitude ceiling at Logan International Airport is zero feet and gradually increases at further distances from the airport. The FAA worked with ATC and other employees to review manned aircraft approach and departure routes to determine safe areas for sUAS operations. The grids containing altitudes represent approximately a one-mile by one-mile area. Although the UASFM provide guidance for sUAS operations, FAA approval is necessary to ensure the airspace is not overwhelmed and becomes too dense for safe operations [64].

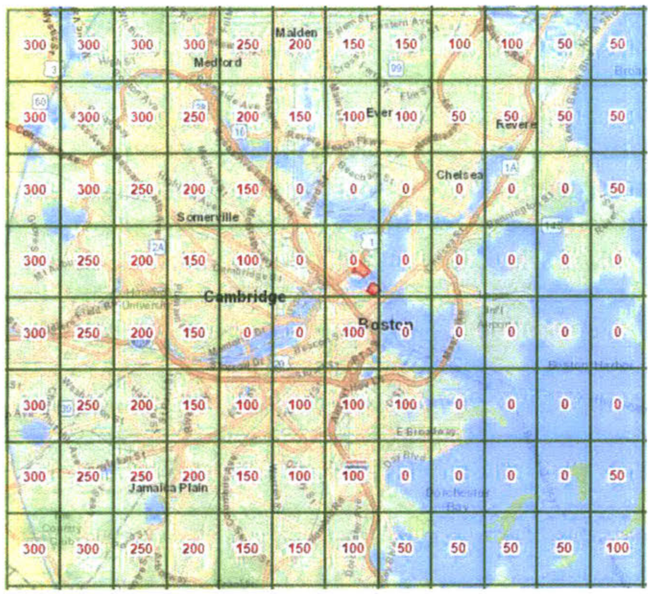

Figure 4-3: Example UAS Facility Map (Greater Boston Area) [65]

4.3.3. B4UFLY Mobile Application

The B4UFLY Mobile Application provides situational awareness to sUAS users about where they can and cannot fly. The mobile application uses FAA data sources and provides a flight status indicator (red, orange, yellow) to indicate potential conflicts or violations in an area. While the application is designed for hobbyists, Part 107-certified pilots may also use B4UFLY to gain awareness and quickly identify flight restrictions. Like the UASFM, B4UFLY does not absolve a sUAS user from submitting an authorization request if flying in controlled airspace [66].

4.3.4. Registration

Part 107 requires sUAS to be registered, and the FAA imposes a five-dollar fee for registration services. After providing basic information, such as the device manufacturer, model, and serial number, the FAA assigns a registration number to affix to the unmanned vehicle. While there is discussion about having remote identification of sUAS so law enforcement and other agencies can identify non-compliant sUAS, at this time no such capability exists.

4.3.5. ATC Services

ATC provides minimal services to the sUAS community at this time. While ATC provides separation services and manages traffic flow and aircraft trajectory for manned aircraft, it does not for sUAS. ATC may coordinate for sUAS authorization requests that violate UASFM ceilings, depending on workload and capacity. However, under the current architecture ATC has no visibility of sUAS operations or authorizations.

4.4. Process

While many processes are part of the NAS, this section focuses on selected processes applicable to sUAS integration. First, the risk assessment method employed by the FAA, which contributes to the current operational approval procedures for sUAS. The other processes are requesting a Part 107 authorization in controlled airspace and receiving a waiver.

4.4.1. Risk Assessment

The FAA has a sUAS risk assessment process that is used to identify hazards, likelihood of occurrence, and consequence severity. This process is designed for sUAS users for specific flight operations, not for assessing or approving new operational policies or procedures. A remote PIC's aeronautical decision-making ability is determined by considering his/her ability to identify and analyze hazards, cope with stress, use available resources, communicate effectively, and prioritize tasks. While there are pamphlets and guides to help sUAS pilots improve these skills, there is currently no performance test required to be a remote PIC, only the knowledge test to receive the Part 107 certificate. sUAS pilots are taught to follow the "Hazard Identification Process" (see Figure 4-4), which focuses on identifying potential hazards. Pilots then estimate severity and likelihood by asking "what if" a hazard interferes with operations, and implement mitigations to reduce risk. Finally, a PIC verifies that the mitigating response does not create new hazards. AC 107-2 also recommends that a PIC use a safety risk matrix to determine if a hazard creates conditions that are unacceptable (red), acceptable with mitigations (yellow), or acceptable (green). However, the advisory circular fails to provide tangible examples of likelihood or severity, leaving the risk assessment process very much up to an individual pilot's judgement [60, pp. A-3-8].

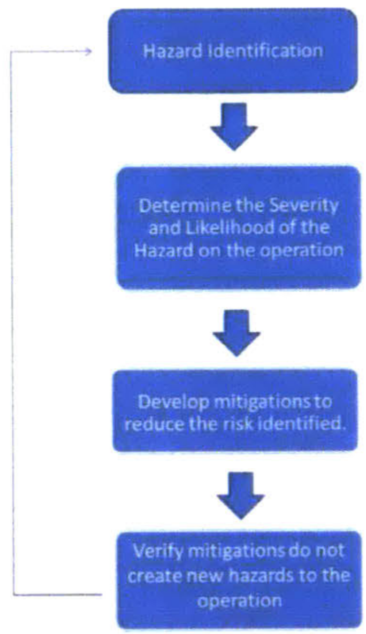

Figure 4-4: Hazard Identification Process Chart [60, pp. A-3]

Risk Likelihood		Risk Severity				
		Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely Improbable	1	1A	1B	1C	1D	1E

Figure 4-5: Safety Risk Matrix [60, pp. A-6]

4.4.2. Authorization Process

The authorization process for sUAS use within controlled airspace currently is straightforward but relatively restrictive. A certified user with a registered sUAS can use LAANC to submit an authorization request via an approved LAANC UAS service supplier. Users consult the UAS Facility Maps prior to submission for near real-time responses to flight requests. If the request violates the altitude ceilings provided by the UAS Facility maps, any temporary flight restrictions, or special notices to airman, the authorization request is delayed in approval and additional safety analysis is done for that mission, potentially taking up to 90 days. However, if the request meets requirements, the user receives a positive response from the FAA to operate the sUAS [53].

4.4.3. Waiver Process

A remote PIC may request a waiver to specific requirements of Part 107 but must follow the waiver process. An applicant must demonstrate that he/she can operate the sUAS without endangering any people or property. While first responders and other government organizations may receive expedited waiver processing, waivers currently take up to 90 days for review and decision [67]. There are nine waivable sections of Part 107:

- Operation from a moving vehicle/aircraft (Section 25)
- Daylight operations (Section 29)
- Visual line of sight aircraft operation (Section 31)
- Visual observer (Section 33)
- Operation of multiple sUAS (Section 35)
- Yielding the right of way (Section 37.a)
- Operations over people (Section 39)
- Operation in certain airspace (Section 41)
- Operating limitations for sUAS (Section 51)

After selecting a requirement to waive, applicants submit the request through the FAA DroneZone site. Applications include details about the operations (location, altitude, airspace type), sUAS (power source, maximum flight time, range, speed, size), and pilot (experience, training). Waiver applications must address the proposed operation, all possible risks the operation may encounter, and appropriate mitigation techniques for identified risks. The FAA analyzes the residual risk level, renders a decision, and notifies the requestor about approval status [67]. Depending on the nature of the sUAS waiver request, the FAA's Air Traffic Organization or Flight Standards Service reviews and approves waivers [59, p. 8]. The majority of waiver approvals (>85%) are for daylight operations and over 99% of BVLOS waiver requests have failed to be approved [5, p. 43] [68].

4.5. Organization

While many organizations and entities are interested in the integration of sUAS into controlled airspace, the FAA is the primary and salient stakeholder (see Chapter 3). While the organization is understandably vast to accomplish their many tasks and responsibilities, focusing on the culture of the FAA may add some value beyond number of employees and offices.

A recent study by the Committee on Assessing the Risks of UAS Integration, part of the National Academy of Sciences, found that the FAA's risk culture is "overly conservative, particularly with regard to UAS technologies, which do not pose a direct threat to human life in the same way as technologies used in manned aircraft" [58, pp. S-2]. The extremely high level of safety in the NAS is a result of the FAA's strict risk-based decision-making processes. The former FAA Administrator, Michael Huerta, gave a recent interview where he echoed the same sentiment, saying that "cautiousness is deeply ingrained in aviation and aerospace" [61]. Figure 4-6 depicts the dilemma the FAA faces by being overly cautious regarding sUAS integration into controlled airspace. While too little rigor can increase the risk of accidents from having an inadequate safety program, being overly conservative can increase accident risk because of the lack of safety innovations. Thus far, the FAA has remained relatively conservative with sUAS integration, limited operations to uncontrolled airspace with the Part 107 limitations (without FAA authorization or waiver). Moving forward, it will be interesting to see if the mindset adjusts to incorporate the new technologies sUAS offer.

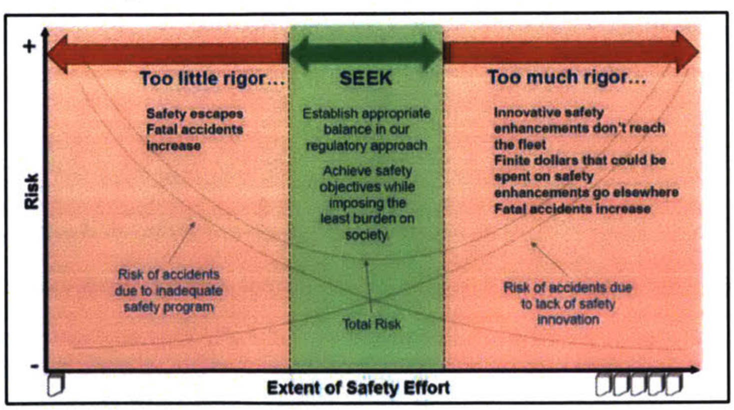

Figure 4-6: FAA UAS Safety Continuum [58, pp. 3-5]

4.6. Information

The information shared throughout the NAS is critical for ATC and manned aircraft to operate safely. Under the current architecture, there is limited operational information sharing between the NAS and sUAS. ATC is notified when a sUAS airspace authorization is approved, but that authorization provides only general information about where the unmanned aircraft may be at a given point in time. Similarly, manned aircraft flying in controlled Class B airspace are (or will soon be) equipped with ADS-B transponders, which communicate with other manned aircraft and ATC about aircraft location; however, manned aircraft have no awareness of sUAS operations. Likewise, sUAS have no visibility into manned aircraft operations [69]. There is significant debate in the aviation community about whether manned aircraft pilots and ATC should have any visibility of sUAS, as the security and workload requirements may become overwhelming.

The FAA has worked to make sUAS information more transparent for users and pilots, having established education and outreach programs. The FAA Safety Team has regular meetings with the public and general aviation pilots to discuss the changes in regulations and how sUAS may operate in the NAS. As discussed in Section 4.3, products and services to improve the situational awareness of sUAS users have been released, and the FAA's educational "Know Before You Fly" campaign targets sUAS pilots so they fully understand their responsibilities. The FAA has also collaborated with AUVSI to host annual UAS Symposiums that allow for the sharing of information from industry to academia to government. The FAA has made a concerted effort to inform the public and aviation community about sUAS integration progress [69, pp. 15-17].

4.7. Infrastructure

The NAS infrastructure supports safe aviation operations and efficient traffic flow. The infrastructure has continued to evolve with new technologies and changing policies, but currently it consists of federal airways, radio navigational aids, airports, surveillance systems, and ATC service facilities [15, p. 25]. All of these elements of NAS infrastructure (see Figure 2-2) enable manned aviation operations, and improvements continue (see Section 5.2.2 for discussion of FAA NextGen). The NAS Enterprise Architecture Infrastructure Roadmaps address UAS integration. The focus, however, is on FAA "basic rulemaking and standards development" for UAS [69, pp. 40-41]. sUAS operations have minimal reliance on the NAS infrastructure in its current form.

4.8. Knowledge

The FAA has great expertise in aviation systems, and its employees have created infrastructure, regulations, policy, equipment, and procedures that manage the complexities of the NAS. The FAA's Aircraft Evaluation Groups (AEG) directly coordinate with aircraft certification and airworthiness programs. For example, AEG pilots provide meaningful feedback for aircraft design related to cockpit alerts and displays [70]. There is significant standardization for how manned aircraft are designed and what they must be capable of doing to be deemed airworthy. However, this level of standardization and knowledge does not currently exist for any type of UAS, large or small. The FAA does not have dedicated test pilots, nor does it have set standards for how a sUAS must perform to be deemed airworthy. ATC has knowledge and experience deconflicting airspace and aircraft, but at this time, it receives limited information about sUAS in its vicinity, so its expertise has limited application.

4.9. Current Use Cases

Possible use cases for sUAS continue to increase with improvements in technology and initiatives to integrate into the NAS. For many sectors, sUAS use represents significant cost-savings, decreased safety risk, and convenience. Figure 4-7 represents the mission types executed by sUAS as reported by the FAA. Presently, aerial photography and inspection represent over 75% of mission justifications; however, end-users have adjusted their behaviors to the current situation. The FAA waiver applications for operations beyond Part 107 are onerous, and the majority of waiver approvals (>85%) are for nighttime operations [5, p. 43]. Unless the approval rate increases for other Part 107 exceptions, the status quo for sUAS use will likely remain.

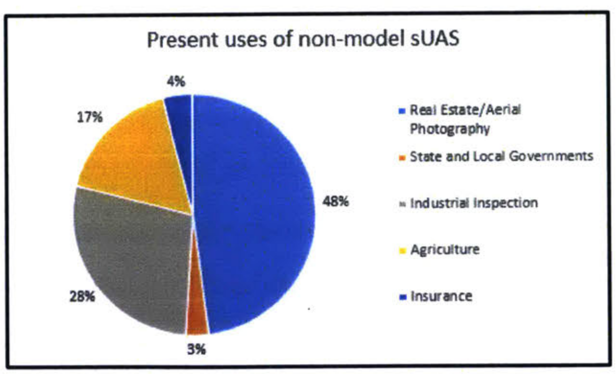

Figure 4-7: Present Uses of Non-Model sUAS [5, p. 43]

Several initiatives both in the U.S. and internationally have the potential to demonstrate the capability of sUAS to operate in the NAS. The FAA's *Pathfinder Program* is actively working with industry partners to expand UAS operation. CNN is the lead partner for flying UAS safely over people; PrecisionHawk is exploring extended LOS operations for precision agriculture; and BNSF Railway is using UAS to inspect rail systems BVLOS [71]. In May 2018 the FAA's *UAS Integration Pilot Program* selected nine state and local governments and one university to partner with private sector entities to help address existing risks and accelerate UAS integration by evaluating operational concepts [72]. Internationally, the World Economic Forum initiated the *Drone Innovators Network* in June 2018 to allow aviation experts to collaborate and share best practices in hopes of realizing UAS benefits faster [73].

Aerial Photography/Imagery/Sensing

The use of sUAS for aerial imagery (photography/videography) and sensing is currently the most popular application of sUAS, accounting for 48% of reported sUAS missions (see Figure 2-5). One major driver contributing to imagery and sensory employment is that sUAS users can easily operate within the current regulations set out by 14 CFR Part 107 and other applicable regulations. For example, real estate agents can easily deploy a sUAS to capture photo and video of a property to display to potential clients without needing a waiver or exception. The payloads for sUAS performing imagery and sensory missions are well-developed and able to provide high resolution outputs to the users, be it photography, video feedback, or a wide variety of sensory data, such as infrared, light detection and ranging (LIDAR), or chemical detection, among many others. In many situations sUAS can effectively replace helicopters or low-flying airplanes being used to collect the aerial imagery and sensory data. The convenience and cost savings to organizations from using sUAS compared to manned aircraft are significant (often <10% of manned aircraft operating costs [74]), and this use case for sUAS will likely remain for the foreseeable future.

State and Local Government (to include Law Enforcement)

State and local governments have a wide variety of uses for sUAS, both now and into the future. Volpe projects that state and local governments (to include law enforcement) will operate 70,000 sUAS by 2035 [7, p. 119]. There are many news stories documenting the benefits sUAS provide to state and local government. One example is from Sherman, Texas, where the city government claims a $1,500 sUAS provided over $50,000 of use, mainly from capturing video of ongoing projects and informing the public on progress. The sUAS also aided fire department investigations to identify the source of the event [75]. Law enforcement agencies across the country are using sUAS to monitor crash scenes, SWAT standoffs, and major public events in their jurisdiction [76]. State governments are also hoping to incorporate sUAS. The Massachusetts Department of Transportation (MassDOT) is investigating the potential use of sUAS for bridge inspection, construction site inspection, roadway inspection, railway inspection, and airport inspection [77]. While inspecting bridges and construction sites can occur immediately under current regulations, the other applications require BVLOS operation and potentially operation over people.

Industrial Inspection (Centralized)

Industrial inspection using sUAS represent both a current (centralized) and future (decentralized) use cases. Centralized infrastructure inspection involves sUAS flight around a fixed site, for example wind turbines, solar arrays, dams, power plants, steel mills, communications towers, and other similar facilities. In this use case, the PIC may remain in a fixed location and fly the sUAS to inspect the structures for progress or damage [2]. The sUAS may also collect data indicating maintenance requirements. For a standard wind turbine inspection (typically \$1,500 per tower), a sUAS inspection costs about 50% of a manned inspection. Similar cost savings exist for other industrial inspections [78]. BNSF Railway is the FAA's industry partner in the Focus Area Pathfinder Program responsible for exploring the BVLOS capability expansion for railway system inspection [71]. Centralized inspections provide significant benefits to the end user: cost savings, decreased disruption to facility operation, and decreased safety risk for inspectors.

Agriculture

Agricultural sUAS use currently represents 17% of all non-model sUAS missions, but experts anticipate growth in this sector. Precision agriculture uses sUAS coupled with a variety of sensors to inspect crop development and soil conditions. Range management incorporates sUAS for herd counting, sick/injured animal identification, birth detection, and other tasks. Aerial application uses sUAS to dispense chemicals and other substances to crops. Vascik and Jung forecast that the agriculture sector will provide a direct economic impact of over \$2 billion by 2020 with current sUAS regulations. Direct economic impact consists of operational savings, revenue recovery, capital investment, and serviceable addressable market [2]. A major benefit of the agricultural use case is location. Being relatively distant from major Class B airports allows for fewer applicable FAA regulations, which allows sUAS use to be more liberal and waivers/exemptions easier to obtain.

Insurance

Although only 4% of current sUAS use, the insurance sector has great potential for expansion. Two negative trends facing the insurance sector are increasing fraud and increasing damage from natural disasters. By increasing use of sUAS, insurers can have increased risk monitoring, risk assessment, and claims management. Risk monitoring involves working with local and national government agencies to monitor and alert citizens of imminent natural disasters. sUAS can be incorporated into risk assessment after an incident to aid with property damage calculations. With about 10% of insurance claims involving some type of fraud, sUAS can help to provide detailed property data before and after an incident, providing clear documentation to dispute fraudulent claims. PricewaterhouseCoopers (PwC) forecasts that the insurance industry market for sUAS is $6.8 billion [78].

4.10. Summary of Current Architecture

Having considered the current NAS architecture as it relates to sUAS using the ARIES element views, it becomes clear that the main emphasis has been placed on policy and products/services. There are processes in place to allow for exceptions to Part 107, but receiving waivers is onerous and can take up to 90 days. The authorization process has significantly improved with the implementation of LAANC, but the UAS Facility Maps are a major constraint on sUAS operations in controlled airspace. The strategy is reasonable; however, it fails to consider that sUAS integration may provide economic and societal benefits that may exceed increased level of risk. The organization's mindset is very safety-centric, and that mentality may prevent some sUAS benefits from being realized. The NAS information, infrastructure, and knowledge relating to sUAS is minimal compared to manned aircraft. While an air traffic controller lacks the capacity to visualize and process every sUAS within controlled airspace while simultaneously monitoring and managing manned air traffic approaches and departures, the limited information and infrastructure prevents almost any situational awareness of sUAS. The knowledge for sUAS is limited partly because sUAS is still a relatively new system, individuals in government, industry, and academia are working to close the knowledge gap. Even with the current constraints and limitations, sUAS use and implementation has continued to evolve and bring benefits to many diverse industries.

5. CHAPTER 5: ENVISIONING A HOLISTIC FUTURE

With a clear understanding of the current NAS architecture, the next step in the ARIES process is to establish the envisioned future as it relates to sUAS. Describing the envisioned future is not a trivial task, as it provides direction for how the enterprise will transform. A clearly defined future needs to consider the appropriate time horizon. This is a critical aspect for sUAS integration in the Mode C Veil. Long-term horizons may allow for a science fiction-like future that lacks realism, constraints, or technological limitations. Conversely, if the planned horizon is too short, expectations may fail to be met because of capacity or time limitations [4, pp. 71-81]. This chapter examines the current vision and strategy set forth by the FAA and its partners for how sUAS will integrate into controlled airspace in the mid-term (three to five years). Current efforts by government, industry, and academia demonstrate how different entities are viewing the future of sUAS operations. Using the ARIES element views highlights key changes that are required to reach the envisioned future. The author discusses illegal use cases and public acceptance barriers and externalities that may arise from the envisioned future state. Finally, after considering the ongoing efforts, key changes needed, and potential barriers and externalities, the author defines criteria for the evaluation of future architectures.

5.1. Vision and Strategy

Five years after publishing the "Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace (NAS) Roadmap" the FAA published the second edition in July 2018. This document sets out the long-term vision for UAS operations in the NAS as well as the FAA's strategy to reach its goals. While many visions and strategies exist for UAS integration, the FAA has clear influence and power in this arena. Its direction will likely guide the way forward for UAS integration, so examining it provides value for informing the strategy for sUAS in the NAS.

The FAA's long-term vision is to have a NAS with UAS fully integrated. Large UAS will operate side-by-side with manned aircraft, regardless of airspace, and share air traffic management systems. Small UAS will remain segregated, either by altitude or by airspace type and have limited, if any, air traffic management services provided. However, the strategy to reach this vision relies on incremental changes to maintain safety for people and property [69, p. 4].

The main strategy for UAS integration relies on slow expansion of regulations to allow sUAS to gradually operate within the NAS. The FAA wants to build upon Part 107 and continue to allow slightly more complex sUAS operations at the appropriate times. Figure 5-1 shows the major steps the FAA has laid out from present to the long-term future of transporting passengers with UAS. Each phase of this strategy has associated sub-tasks (listed below each phase) to realize the identified goal (e.g. Operations Over People). While the strategy involves incremental changes to sUAS in the NAS, the FAA and its many partners will work many of these efforts in parallel to minimize the time between phases. Rulemaking, standards development, and technology testing/approval are time intensive and require coordinate with many entities [69]. Notable is that the FAA does not set out projected dates for these incremental stages to be complete, as there are many uncertainties that can affect schedule. It is the FAA's hope that working with motivated organizations in industry, government, and academia that sUAS integration can progress rapidly.

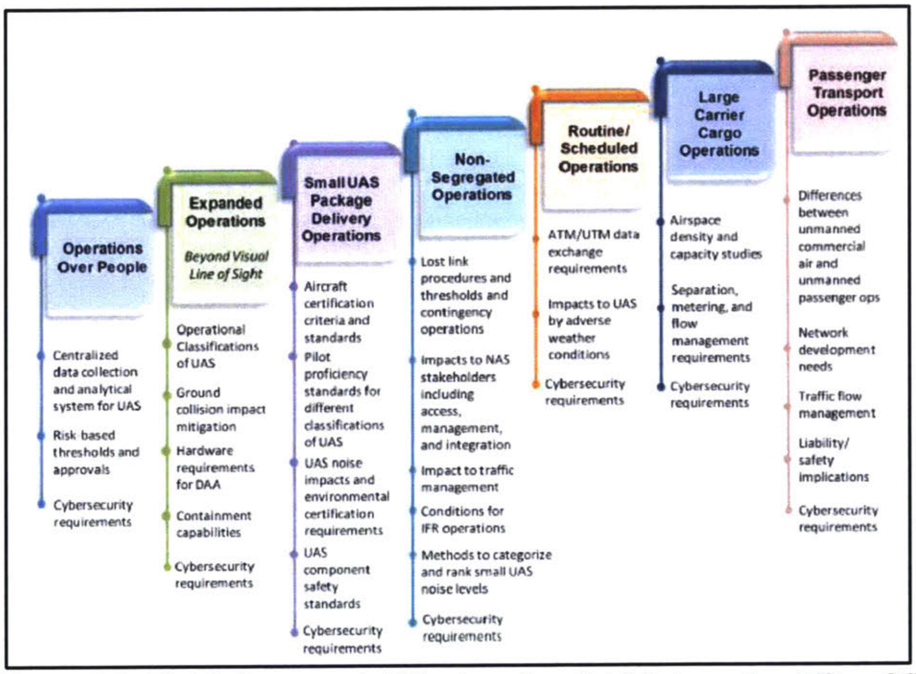

Figure 5-1: FAA's Incremental Strategy for sUAS Integration [69, p. 36]

5.2. Current Efforts to Integrate sUAS

Before identifying key elements of the envisioned future state, it is useful to consider the major efforts already underway. These initiatives illustrate how various organizations are viewing sUAS operations, although motivations and requirements may differ depending on perspective and values.

5.2.1. NASA UTM

A major program to enable sUAS to operate BVLOS is the NASA-led UAS Traffic Management (UTM). UTM seeks to fill the void of having no dedicated ATM infrastructure for low-altitude sUAS operations. NASA is partnering with the FAA to develop UTM and the two agencies have developed design principles and specific services that UTM will provide (see Table 5-1). These principles are consistent with the current architecture, which is reasonable because manned aircraft operations and ATM services will continue with limited, if any, disruptions.

Table 5-1: UTM Principles and UAS Services [79, p. 6]

Principles	UAS Services
Operate in authenticated airspace	Authorization/Authentication
UAS stay clear of other UAS	Airspace config. and geofencing
UAS/manned aircraft stay clear	Track and locate
UAS operator situational awareness	Command and control (spectrum)
Public safety UAS have priority	Weather and wind sensing, prediction
	Conflict avoidance
	Demand/capacity management
	Large scale contingency management

After determining the principles and services UTM will support, NASA established potential roles/responsibilities and interactions between systems. Figure 5-2 shows the architecture and information flow for UTM, and NASA has focused on three main entities: the regulator/ANSP (FAA), UAS operators, and the general public. The UAS Service Supplier (USS) network plays a critical role in sharing information throughout the UTM and with UAS users. Information may range from weather updates to TFRs to emergency notifications. USS will transmit and receive data from the NAS and communicate constraints to the UAS users. The FAA will establish the interfaces and standards for data/information transmission, and provide notifications through the USS network. UTM plans to still have limited access to controlled airspace, and the FAA will manage/authorize access. Consistent with FAA values, public safety remains a top priority. The public may also have access to the USS network to have situational awareness of UAS operations [80].

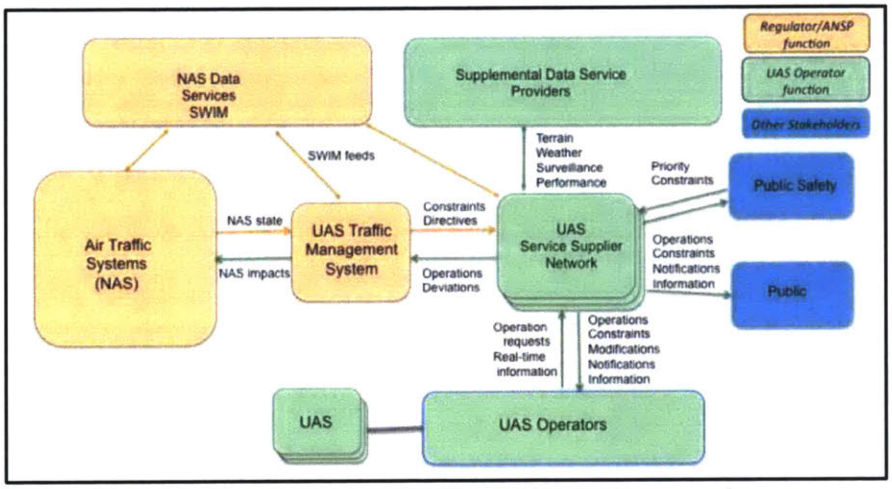

Figure 5-2: NASA UTM Architecture [80, p. 8]

Progress on UTM has been steady and test flights have shown promise. NASA established four technical capability levels (TCLs) (see Figure 5-3) that continually extend the proceeding TCL. TCLs are based on level of risk to people and property and density of aircraft (manned and unmanned) in the area of operations [80, pp. 13-14]. In May 2018, tests for TCL 3 were successful at the six FAA UAS Test Sites. NASA has not published specific technologies tested that enabled the operations for TCL 3, so it is difficult to know how scalable potential solutions may be. However, achieving TCL 3 indicates progress and will help validate systems and inform standards moving forward [81].

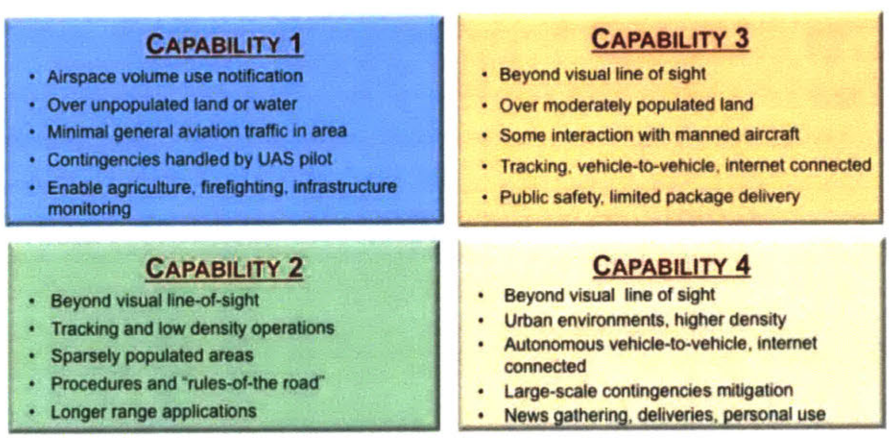

Figure 5-3: UTM Technical Capability Levels [80, p. 14]

5.2.2. *FAA NextGen*

NextGen is an FAA modernization effort that seeks to improve NAS capacity, efficiency, and predictability. It is a massive undertaking, with initial investments beginning in 2007 and an expected completion date of 2030. While some new technologies have already been introduced, NextGen continues to implement new technologies, procedures, and policies that can improve the NAS. Demand for NAS access has steadily increased, and new entrants, such as UAS and commercial spacecraft, represent additional types of operations in already dense airspace. NextGen hopes to improve communications and information sharing, enabling NAS users to have fewer disruptions and less impact on the environment. While several simultaneous NextGen efforts are ongoing and already in operation (e.g. Performance Based Navigation), the author will focus on how NextGen may impact sUAS operations in controlled airspace [82].

Several NextGen technologies and platforms may play a role in sUAS integration into the NAS. ADS-B is the key technology for NextGen, enabling manned aircraft to transmit position, ground speed, and other data to ATC. ADS-B has greater coverage and accuracy than traditional radar systems, and on January 1, 2020, ADS-B Out (outgoing transmissions) are mandatory for most controlled airspace. ADS-B In (incoming transmissions) remains optional, but manned aircraft pilots can increase situational awareness about other aircraft traffic in their vicinity (see Figure 5-4) [83]. There is no requirement for sUAS to equip with ADS-B, although this surveillance capability (or similar) has potential to provide sUAS users with valuable information about manned aircraft operations in the NAS. However, spectrum limitations and the lack of a clear concept for ADS-B Out may make ADS-B Out for sUAS infeasible [84].

Figure 5-4: ADS-B In Display [83]

NextGen is also modernizing the communications infrastructure, which may benefit sUAS operations in the future. System Wide Information Management (SWIM) consolidates how information is shared between aviation partners onto one digital platform, compared to the old system of multiple computer interfaces and communication methods [85]. Data Communications (Data Comm) allows for quick messaging from ATC to pilots via text message in addition to traditional auditory message. Data Comm currently supports departure instructions for manned aircraft, but the goal is to send messages for en route aircraft as well to improve operations [86]. NAS Voice System (NVS) upgrades the analog telecommunications systems to a digital configuration and allows for quick transitions from one ATC facility to another during peak workload conditions [87]. These upgrades to the NAS communications infrastructure increase capacity and transmission speeds and may allow for sUAS users and operators to have direct communication with ATC, although this capability may not be necessary or required. The NVS upgrade increases flexibility and may allow for an underutilized ATC facility to provide support to more dense Class B airspace with sUAS operations. The shared common operating picture from NextGen may promote further sUAS integration.

5.2.3. ACAS Xu

The FAA has sponsored MIT Lincoln Laboratory and partners to work on ACAS sXu as a sUAS-DAA solution. The ACAS Xu team concept for a sUAS-DAA requires it must be able to perform on low performance vehicles and have alternate surveillance methods to track non-cooperative traffic and other sUAS. Because of the wide variation of aircraft performance capabilities, the sUAS-DAA system must also support horizontal maneuvers [88]. ACAS sXu will locate other aircraft via ADS-B, primary radar, electro-optical or infra-red signature, or other sensors and provide alerts and resolution advisories to have the PIC or vehicle flight control system resolve a potential conflict. This system will provide sUAS the ability to remain well-clear and meet collision avoidance requirements. As shown in Figure 5-5, ACAS Xu (with blended vertical and horizontal avoidance logic) is safer than TCAS and ACAS Xa and provides manned aircraft with a similar number of alerts (based on simulations). TCAS has been the FAA and international standard for collision avoidance systems for since 1989 and ACAS Xa for manned aircraft was published in 2018. ACAS sXu can be located on either the vehicle or the ground and is meant to be complementary to UTM and mitigate residual collision risk. It can also provide DAA independent of UTM. While ACAS sXu still needs minimum operational performance standards to be developed and there are questions about how it will detect other UAS or non-cooperative aircraft, ACAS sXu is a promising technology for sUAS DAA [88].

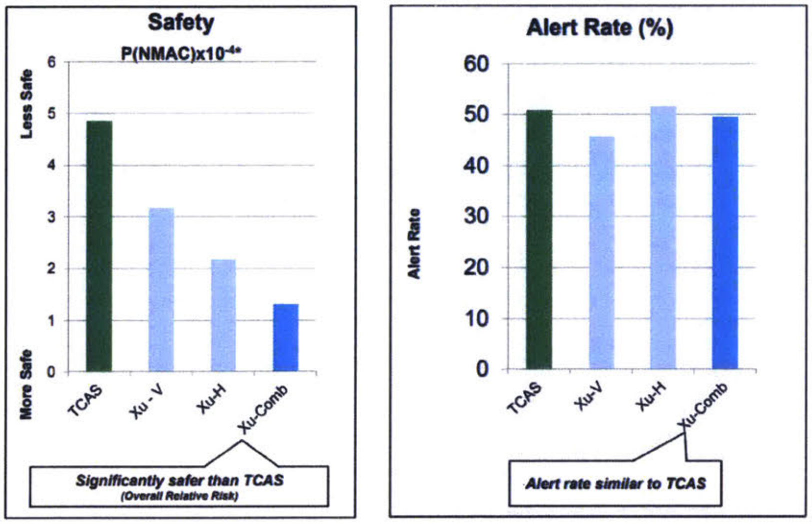

Figure 5-5: ACAS Xu Safety and Alert Rates [88, p. 18]

5.2.4. Airbus

As one of the world's major manufacturers of commercial airliners and a leader in the aviation industry, Airbus has developed a way forward for autonomous vehicles. Figure 5-6 depicts Airbus's vision of having digital systems that coordinate between multiple types of aircraft (manned aircraft, helicopters, UAS, eVTOL, etc.). Because of the increase in air traffic density, Airbus recommends a distributed authority system that decentralizes and privatizes aspects of decision-making. Certified service suppliers can coordinate throughout the network to make safe, efficient decisions [89, p. 6]. Additionally, Airbus proposes a few new airspace principles for unmanned vehicles. While several are generally accepted (e.g. "safety and security are paramount"), a few principles are worth noting. One principle is that "drones must be allowed to self-pilot" so that air taxis and commercial UAS services can achieve economies of scale. Having human pilots restricts the economic feasibility of UAS businesses. Devices not capable of self-piloting will not be permitted to operate in certain types of airspace. The major issue with self-piloting is that traditional certification and safety approval processes are based on the presence of a manned pilot or UAS operator. New policies, research, and procedures will be required to enable self-piloted vehicles. Another principle Airbus proposes is that "airspace must be shared" between manned and unmanned aircraft. Airspace access will depend on equipage and performance rather than mission [89, p. 13].

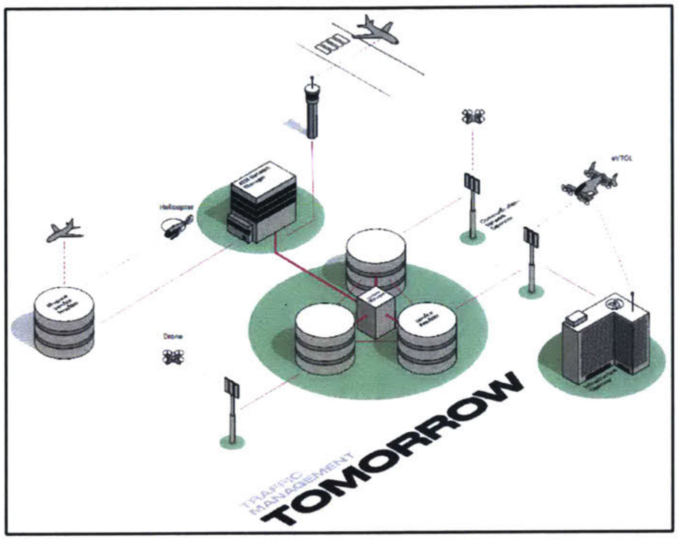

Figure 5-6: Airbus Concept for Future Air Traffic Management [89, p. 7]

5.2.5. Amazon Prime Air

Amazon Prime Air, the division of Amazon focused on drone delivery services, has developed a concept that could enable sUAS operations in controlled airspace based on segregation. Gur Kimchi, the vice president of Amazon Prime Air, has advocated at NASA's Ames Research Center for increased cooperation in the NAS. Amazon Prime Air seeks to simplify the NAS, with dedicated altitudes for different purposes (see Figure 5-7). Below 200 feet AGL would be reserved for low-speed traffic and final stages of package deliveries. From 200 to 400 feet AGL would be a "drone highway" with autonomous sUAS flying BVLOS. These sUAS would have to communicate with each other and have standardized DAA technologies. From 400 to 500 feet AGL would be a no-fly zone to separate manned aircraft and sUAS [90].

Figure 5-7: Amazon Concept for sUAS Operations [90]

Beyond its concept for NAS, Amazon Prime Air has continued to develop possible solutions to enable delivery operations. A few of these concepts may seem like science fiction, such as "airborne fulfillment centers" that could serve as flying warehouse locations where sUAS could retrieve packages ready for delivery. Street lights or cell towers could serve as docking stations to allow sUAS to recharge when not in use. More practically, Amazon Prime Air works to improve automated collision avoidance and noise reduction technologies [91]. Although not selected to participate in the FAA's Integration Pilot Program, Prime Air has significant motivation to have sUAS more fully integrated into the NAS to allow for increased commercial opportunities.

5.2.6. DHL

DHL considers rapid urbanization to be a continued trend into the future and thinks that sUAS can help slow congestion and pollution effects. Using a "first and last-mile network," facilities outside of city limits could sort packages based on set criteria (to include road congestion), and sUAS could rapidly deliver prioritized packages. The sUAS could pick up packages for delivery in route back to the sorting facility, significantly increasing efficiency (see Figure 5-8). Actual delivery of packages to locations could utilize building roofs, balconies, or scanning a QR code from a customer's smartphone. DHL already has delivery locker facilities (called Packstations) throughout many cities, and locations could be upgraded to receive shipments from sUAS. DHL's efforts have been on improving delivery speed and network flexibility for logistics operations rather than necessary NAS changes [92].

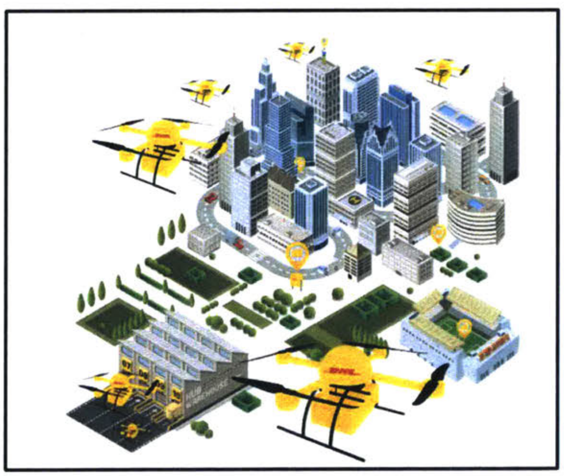

Figure 5-8: DHL Concept for sUAS Operations [92, p. 14]

5.2.7. Harris

Harris Corporation is a leader in communications and air traffic management systems and its RangeVue system is a technology that provides BVLOS for UAS by using electronic means in lieu of visual see and avoid. According to Harris, RangeVue provides "UAS operators, UAS fleet managers, public safety agencies and regulators have complete awareness of their airspace" [93]. The system combines FAA surveillance data with local infrastructure surveillance (see Figure 5-9). FAA surveillance data includes ADS-B data, ASDE-X data (Airport Surface Detection Equipment), Wide Area Multilateration systems, and En Route and Terminal radar. Local surveillance data includes local ADS-B sensors, ground and airborne primary radars, and UAS ground control station telemetry. This emerging technology represents a potential solution to improved situational awareness and continued safe operations in the NAS [93].

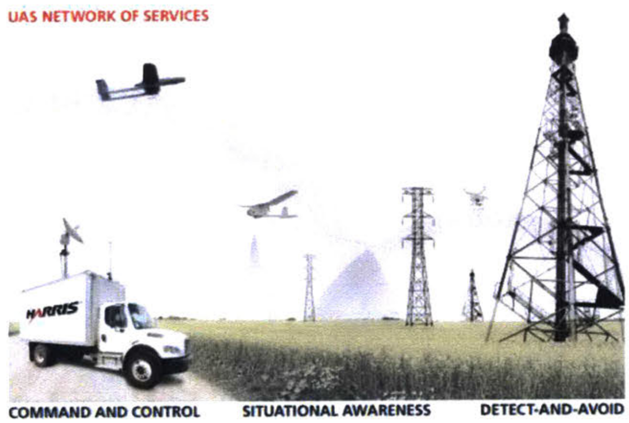

Figure 5-9: Harris Concept for sUAS DAA System [93]

5.3. Envisioned Holistic Future

Having considered several ongoing efforts supporting sUAS integration, the author frames the envisioned future in terms of the ARIES elements. The envisioned holistic future incorporates aspects of current initiatives as well as attempts to address other constraints and externalities that arise from sUAS operations in controlled airspace. Since the envisioned future for sUAS operations is three to five years, discussion will focus on BVLOS in urban areas at low altitudes (see boxed area of Figure 5-10). Many aspects of the envisioned future are normative and do not have specific solutions. Instead, the envisioned future represents the ideal state of the NAS, incorporating sUAS within controlled airspace in the Mode C Veil. During the future architecture generation (see Chapter 6), the author adjusts specific policies, technologies, and other elements to attain some extent of the envisioned future.

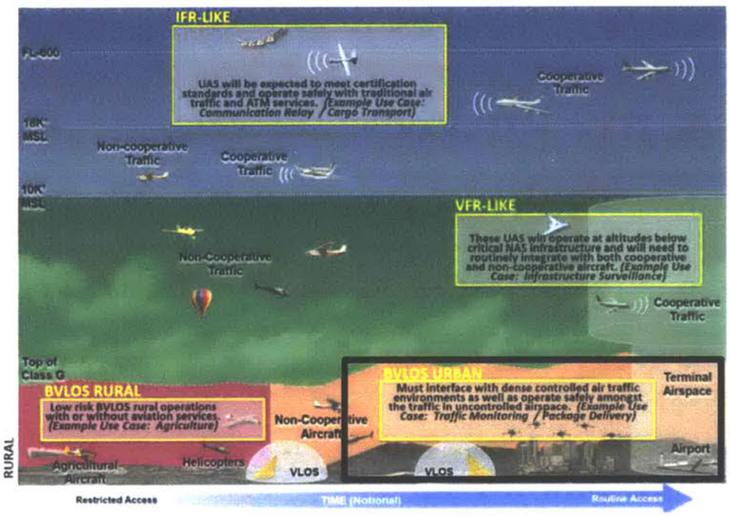

Figure 5-10: Envisioned Future for NAS [94, p. 13]

5.3.1. ARIES Elements

5.3.1.1. Policies

For the idealized envisioned future of sUAS integration, some NAS policies require adjustment. Safety certainly remains a top priority, but current policy in 14 CFR Part 107 is too restrictive for operations and lack adequate standards for pilots and aircraft. sUAS policies are considered in terms of operational limitations, pilot certification, and aircraft certification.

In the near term, sUAS operations in controlled airspace have decreased constraints. Segregation between manned and unmanned aircraft remains the consensus best practice to enable sUAS operations. Until technology advancements in DAA and command and control occur, having sUAS operate in dense urban airspace fully integrated with manned aircraft is a considerable safety risk. Similarly, manufacturer-established performance limitations on maximum groundspeed helps to mitigate unsafe actions, either by malicious or negligent actors. sUAS continue to yield right of way to any manned aircraft (e.g. general aviation or helicopters), even when operating BVLOS. However, the limitations on BVLOS, operations over people, daylight operations, operations from moving vehicles, and ATC coordination lessen with improved sensor technological capabilities (see Section 5.3.1.2) and processes (see Section 5.3.1.3). Not all sUAS will have the capabilities required for unlimited access to controlled airspace, but other ARIES elements (products, services, processes, and organization) contribute to maintaining safety while enabling sUAS operations.

Pilot and aircraft certification policies for the envisioned future are more refined and specific. While remote PIC still must hold a sUAS certificate, the requirement includes both a knowledge-based test (as currently established) and a performance-based test to operate in controlled airspace. The performance-based test would only be required for sUAS users whose unmanned vehicle is not fully autonomous. This more closely aligns with FAA requirements for manned aircraft pilots. The remote PIC now must demonstrate understanding of limitations imposed on his sUAS as well as execute pre-defined tasks to operate in the NAS. Pilots may also obtain a BVLOS rating based on their performance on both the knowledge and performance tests. Similarly, airworthiness standards establish minimum acceptable thresholds for a sUAS to be deemed airworthy. These standards encompass the entire sUAS system (UAV, command and control link, and ground control station) to eliminate unsafe unmanned aircraft from endangering people and property.

Additional certification policies must exist for DAA systems. The FAA needs to establish the certification and approval standards for sUAS surveillance. This policy directly affects the DAA system as a product, and sensors that support the overall system.

5.3.1.2. Products/Services

The products and services supporting sUAS operations in controlled airspace in the envisioned future contribute to safe operations at low altitudes. Maintaining an acceptable safety level with additional aircraft in the NAS requires products with *improved performance capabilities* and services that *increase information sharing.* These principles allow for sUAS users to responsibly conduct public and commercial operations.

In the near-term envisioned future, a product provides the ability to detect and avoid other aircraft and provide real-time flight information. While the sUAS may not be fully autonomous, a certified DAA system alerts the remote PIC about manned aircraft in the immediate vicinity of his aircraft(s). The PIC then has a fixed time to respond. Responses may include horizontal or vertical maneuvers, and the DAA system alert will cease as soon as the sUAS re-establishes itself to be well clear. Should the remote PIC fail to adequately respond, the sUAS performs automated evasive maneuvers to avoid a mid-air collision. The sUAS also provides information to the ground control station (location, airspeed, registration number), and the ground control station communicates with other sUAS ground control stations, law enforcement, and the general public to provide situational awareness of sUAS operations. As noted by the Aeronautical Surveillance Working Group, ADS-B In/Out currently lacks the capability to serve as the solution for sUAS DAA at scale. The United States only has approximately 910,000 Mode S aircraft addresses available, with over 350,000 already assigned to manned aircrafts. That leaves fewer than 600,000 available addresses for sUAS to have assigned to a corresponding ADS-B transponder. Furthermore, sUAS operating in urban airspace would overwhelm the surveillance system operating at 1090 MHz [84, pp. 2-3]. Having a suitable DAA capability and real-time sUAS flight information helps other sUAS users proactively avoid any near-miss incidents, enables law enforcement to identify and pursue violators, and provides transparency of operations to the general public (similar to current consumer products like FlightAware).

Another envisioned future product is a command and control link that is robust and minimizes off-nominal situations. The ground control station provides feedback to the remote PIC about the connection strength with the aircraft via a display. The connection status limits the range of sUAS operations. An additional factor that may impact connectivity strength may be the presence of electromagnetic interference. If connectivity falls below a designated threshold, the sUAS ground control station will establish a secondary connection and return the aircraft to the remote PIC or a pre-designated landing location. The command and control link demonstrates a level of robustness to the remote PIC (via the ground control station), and, during times of low signal strength or high network demand, the command and control link has a degree of flexibility (to switch to an alternate method).

A potential service for the envisioned future is the expansion of LAANC for controlled airspace to approve sUAS operation requests. The UAS Facility Maps have greater altitude limits (maximum remains 400' AGL) and allow for operations closer to airports (although operations within the direct approach and departure routes are still off-limits for sUAS). As highlighted by Vascik when analyzing Los Angeles controlled airspace, commercial operations, general aviation, and helicopter flights only ever utilize 24% of controlled airspace [95, p. 211]. This justifies additional analysis of UAS Facility Map altitude ceilings and the reasonable expansion of approved flight areas. LAANC now provides the ability to rapidly (within minutes) receive waiver approvals for Part 107, instead of the current wait of up to 90 days. Waiver approval could utilize the concept of *risk rating* (see Section 5.3.1.3) to determine if a requested operation is appropriate for the airspace. This expansion of LAANC relies on establishing operational DAA to maintain safe separation from medical, law enforcement, and news helicopters. Since LAANC is the approval mechanism for sUAS operations, it also determines when the airspace has reached capacity and halts approvals until ongoing operations conclude. This extension of LAANC allows for increased sUAS use without a modification to Part 107 (which is a time-intensive process).

As briefly mentioned above, a major service of the envisioned future is an increase in information sharing. Ground control systems securely communicate with each other, ATC, law enforcement, and the general public. Information about sUAS position, performance, and registration is available, and provides a level of both situational awareness and accountability. Additionally, this network allows for real-time communication updates from ATC, such as major events, natural disasters, TFRs, and impending weather. This information network provides recommended flight paths to sUAS users to maximize safety to people and property, while attempting to minimize noise over residential areas. Remote PICs have a display as part of their ground control system that clearly provides this real-time information so they can act accordingly.

Remote identification is a service that enables sUAS to operate with a level of accountability for the remote PIC. A good analogy for remote identification is the license plate on a motor vehicle, which provides law enforcement a way to identify the owner/user, but not the general public. While many concepts for remote identification currently exist, the envisioned future relies on networked cellular broadcasting from the sUAS to an FAA-approved database. Remote identification is fulfilled by transmission through the data network that simultaneously transmits telemetry information. Law enforcement can track a specific remote identification number from a vehicle to its owner, which is especially useful when a user is careless or criminal in his actions. For redundancy, remote identification direct broadcast using WiFi 5.0 in areas with poor 5G coverage. However, the majority of controlled airspace surrounds airports with significant infrastructure and built-up urban areas, so 5G coverage will be the primary broadcast mechanism. For the previously discussed real-time information feed, a major feature available to law enforcement and the general public is the ability to remotely identify a sUAS remote identifier. Additionally, law enforcement may determine from the remote identifier who the remote PIC is, as well as relevant vehicle performance/tracking data. This removes the anonymity factor that may otherwise entice individuals to violate the privacy of individuals or perpetrate criminal acts. All sUAS must register via the FAA site to obtain a remote identification number before operations may commence.

5.3.1.3. Processes

Envisioned future processes for sUAS within controlled airspace include faster waiver approvals and assignment of risk ratings. These two processes effectively balance increased sUAS operations with safety.

The expanded LAANC allows for approval of waiver requests to Part 107 in minutes rather than weeks. Remote PICs may submit a mission plan into LAANC, coupled with their pilot certification number and sUAS registration number. An approved LAANC UAS Service Supplier (currently the FAA recognizes 14 approved LAANC vendors) first verifies that the flight plan does not conflict with any restricted flight areas. The LAANC vendor also verifies the risk rating for the operation type, pilot certification, and sUAS classification (process detailed below). If the risk rating is acceptable, the sUAS operator/user receives an affirmative message for the request.

Another operational factor for the envisioned future is the assignment of a *risk rating* to all sUAS. The author has developed an initial concept for risk, although developing the criteria requires further work. Other organizations, such as Altiscope and JARUS, are already developing risk assessment frameworks to classify threats and residual risk [89, p. 22]. A standards organization committee, such as ASTM Committee F38, which specifically focuses on issues related to sUAS safety, is well-suited to mature this concept. This risk rating considers the risk scores for operation type (based on airspace classification and desired route), sUAS classification (based on aircraft weight and performance capabilities) and pilot certification (based on hours flown and BVLOS rating) to generate an overall risk rating (see Figure 5-11). If the risk rating is below the designated risk threshold, then expanded LAANC approves the mission. Operational type considers the airspace classification and the operational route. Routes that traverse significant distances where other sUAS likely operate (e.g. package delivery operations) may receive a higher risk score than a sUAS operation for infrastructure inspection within controlled airspace. Routes that generally travel over roads or structures receive a lower risk score than routes over open air (e.g. parks) because most types of shelter provide adequate protect from any type of sUAS strike [96]. sUAS classification risk score is assigned to an aircraft based on its characteristics and performance capabilities. sUAS weight factors into lethality in the event of an incident, and sUAS performance capabilities allow the ability to evade potential hazards [96]. Finally, the pilot risk score considered total flight hours and whether the pilot has a BVLOS rating. The BVLOS rating is required for any BVLOS operation, and more flight hours lower the pilot risk score.

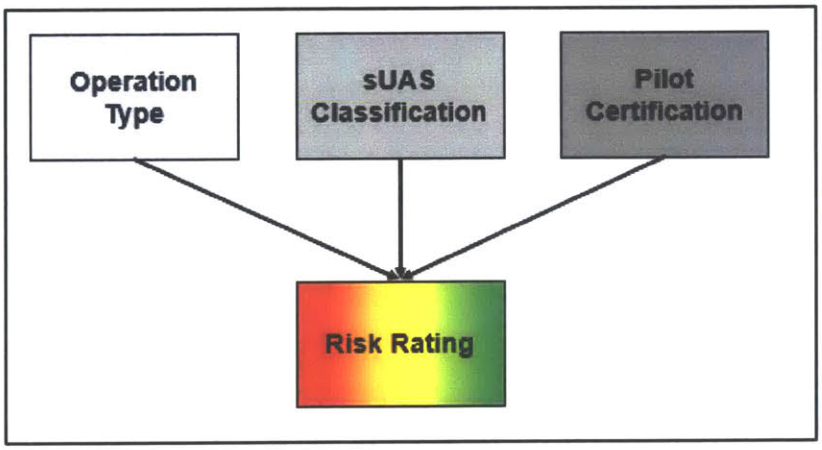

Figure 5-11: sUAS Risk Rating Concept

5.3.1.4. Organization

The envisioned future organization regulating the NAS has experienced a cultural shift and has embraced sUAS operations within controlled airspace. The FAA has elevated the *UAS Integration Office* so that it serves as the lead for all UAS-related matters and is at the same level as the Aviation Flight Standards, Aviation Safety, and Air Traffic Organization Offices. This resolves many of the internal organizational issues the FAA faces with uncertainty about which division or office should resolve a UAS-related question (since many issues are multi-faceted). The FAA has fully funded the effort to develop required technologies that enable sUAS to safely operate without impacting manned aircraft and the level of safety is still extremely high. Similarly, existing products and services (UAS Facility Maps and LAANC) have expanded to allow for increased sUAS operations. The FAA collaborated with experts across the aviation industry to refine a risk rating methodology to ensure the safety of controlled airspace and required a remote identification system to enable law enforcement to have awareness of violations. While the FAA still prioritizes safety, the willingness to gradually increase sUAS operations has motivated industry to generate new ideas and products that enhance performance capabilities and information sharing. If the FAA had taken the converse approach and waited until a perfect solution emerged, the pace of innovation would have slowed significantly.

5.3.1.5. Knowledge

The knowledge relating to sUAS continues to expand in the envisioned future. The FAA has begun increasing its number of sUAS subject matter experts and test pilots across the organization. Their expertise is invaluable in establishing definitions for this emerging field of operations. Major contributions from the sUAS expert team (along with partners across the aviation industry) include an approved definition for well-clear for sUAS. This definition supports the development of DAA products, since manufacturers now have clear requirements for which to design. There is also the expansion of certification for pilots (performance-based test) and aircraft certification. These additional certification requirements add much needed structure and promote safety for sUAS operations in the NAS.

5.3.1.6. Information

The envisioned future has increased information sharing across the NAS. sUAS users have a display that has a real-time aircraft data feed that visually depicts other aircraft (manned and unmanned) in the vicinity of his device. This display also receives notifications from ATC about TFRs, weather advisories, and other pertinent events. ATC and manned aircraft do not have the ability to see sUAS to avoid workload oversaturation. The sUAS is continually transmitting its registration information, position, and airspeed, which informs others in the NAS, as well as law enforcement about the actions taken by the remote PIC. This information remains segregated from the ATM system, so air traffic controller's requirements and duties are unchanged. Having many sUAS in controlled airspace while directing and managing manned aircraft would become a major distraction, so sUAS information remains separated from ATM.

5.3.1.7. Infrastructure

Similar to the present state, the envisioned future does not have major infrastructure to support sUAS within controlled airspace. NAS infrastructure has upgraded to include many NextGen systems, but most of these technologies do not directly support sUAS. The main change from the present is the development of a real-time information feed that provides users, law enforcement, and the general public with information about ongoing sUAS operations. Rather than establish a separate infrastructure for this feed, it is derived from the expanded LAANC service and accessible from the FAA DroneZone site. A UAS Service Supplier is responsible for establishing and maintaining the feed, and utilizes 5G for communications. The USS utilizes SWIM as the information exchange network. Requiring minimal infrastructure changes is a major reason why sUAS operations are able to enter the NAS relatively quickly.

5.3.1.8. Interrelationships of ARIES Elements

Considering the envisioned future using the ARIES elements, it is clear that no individual element acts in isolation. This concept of entanglement is visually depicted in Figure 4-1. However, several needs continually emerge across elements as critical for sUAS integration (see Table 5-2). To adequately meet any one of these needs requires the synchronization of multiple elements, which generally requires collaboration across organizations. Although not present in Table 5-2, these stakeholder interactions highlight the importance of an organizational mindset shift within the FAA. Being overly cautious about sUAS within the NAS may inhibit aviation industry partners from fully developing technologies because of decreased motivation. For sUAS integration in controlled airspace to become reality all stakeholders should remain positive and promote innovation and solutions.

Table 5-2: Needs Derived from Envisioned Future

Need	Functions Supported
Detect and Avoid System	BVLOS operations Acceptable NAS safety level
Communications System (Command and Control System)	BVLOS operations Information sharing Acceptable NAS safety level
Remote Identification	Accountability and transparency Information sharing
Certification Standards	Acceptable NAS safety level Requirements definition

For BVLOS operations to occur in controlled airspace, three critical systems need to be in place: a Detect and Avoid system, a source of surveillance information for other traffic, and a reliable communication system. These systems are considered products/services but must meet requirements set forth in Part 107 (policy). The communications system supports processes (e.g. waiver approval) and information sharing across the enterprise. Knowledge from subject matter experts informs the sUAS definition of well-clear, which establishes a critical requirement for DAA systems. DAA and communications systems may support sUAS with minimal infrastructure required (depending on the selected surveillance system), which keeps cost and time to implement more manageable. This is possible because the communications system may be an extension of the existing FAA LAANC and DroneZone products/services. The surveillance feed may require infrastructure investments, pending the decision on type (e.g. ground-based sensors).

Remote identification and certification standards provide needed structure to sUAS operations. The remote identification service is an extension of the existing registration process that requires sUAS users to pay a five-dollar fee and label their devices after obtaining a registration number. Remote identification eliminates the relative anonymity that current sUAS users have, which will help alleviate security and privacy concerns from the general public. However, this issue has caused significant consternation within the sUAS user community and civil liberty organizations. Allowing law enforcement to have the ability to quickly identify the unmanned aircraft and its remote PIC increases accountability within the sUAS community and increases transparency to the public. Certification standards also provide accountability by having standards organizations and ultimately the FAA define sUAS airworthiness. Without certification standards it is difficult for DAA systems to provide meaningful alerts or recommended maneuvers, because an aircraft may not even be capable of performing the action. This again highlights how a policy element (certification standards) impacts a product element.

Having described the envisioned future, it is useful to consider how several entities anticipate sUAS operations to increase in the near-term future. The author uses projections from across government and industry to describe the potential growth of operations and use cases as the NAS allows for sUAS expansion.

5.3.2. Increased Use of sUAS

While model airplanes and UAS have long been flown by hobbyists, the growth in commercial sUAS has been rapid in recent years. On April 1, 2016, the FAA launched an online registration system, improving the speed and ease of registering non-model sUAS. Using the available FAA data, from April 2016 through December 2017, non-model sUAS registration increased to 110,604 (Figure 5-12, left). This represents a five-fold increase from all previous registrations, which can be attributed to the increased desire for commercial sUAS use, the simplified online registration system, and the passing of 14 CFR Part 107. During this same time period, non-model sUAS registrations were dispersed throughout the U.S. in both urban and rural areas, major metropolitan areas showed a higher registration density (Figure 5-12, right). The FAA projects continued growth, forecasting over 450,000 registered non-model sUAS by 2022. However, many users do not register their sUAS, and there may be over one million total sUAS sold by 2022 [5, pp. 41-42].

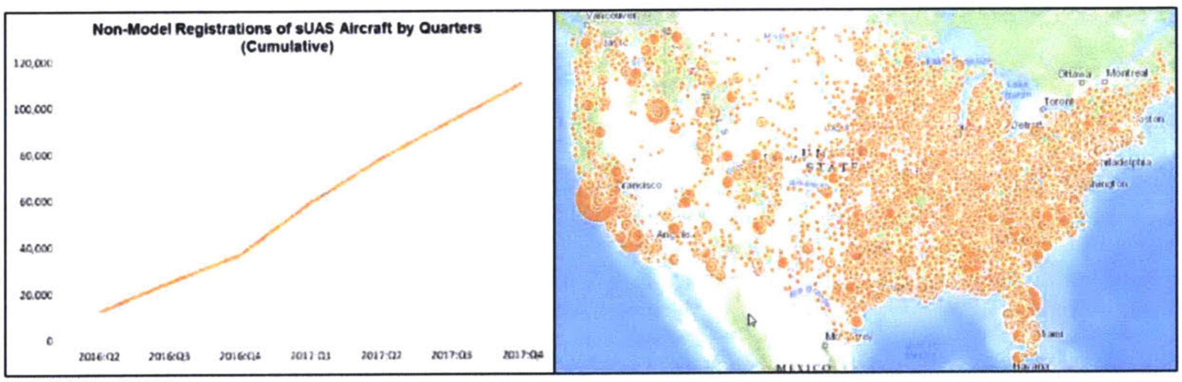

Figure 5-12: Non-Model Registrations of sUAS Aircraft [5, pp. 41-42]

Many other projections exist for sUAS growth, both for public and commercial use. Other government organizations, such as the Volpe National Transportation Systems Center, forecast slower sUAS growth, with the total number of sUAS reaching 250,000 by 2035 (see Figure 5-13, left). This projection is based on the notion that as UAS usage becomes more commonplace, major DOD suppliers will begin producing sUAS for commercial and public consumption. DOD suppliers entering the marketplace will serve as an accelerator to sUAS adoption [7, pp. 124-125]. New business models will likely emerge providing sUAS services such as imagery, aerial inspection, or other innovative use cases.

AUVSI is a nonprofit organization that advocates for the advancement of unmanned systems in collaboration with industry, government, and academia. Like the Volpe and FAA forecasts, AUVSI expects significant growth in sUAS use in the coming years. However, AUVSI projects over 1.2 million total sUAS sales from 2015 to 2025 in the U.S. (see Figure 5-13, right) [37]. While not all vehicles will remain in the NAS for that entire period, it is clear that both government and non-government entities recognize the rapid growth in the sUAS field.

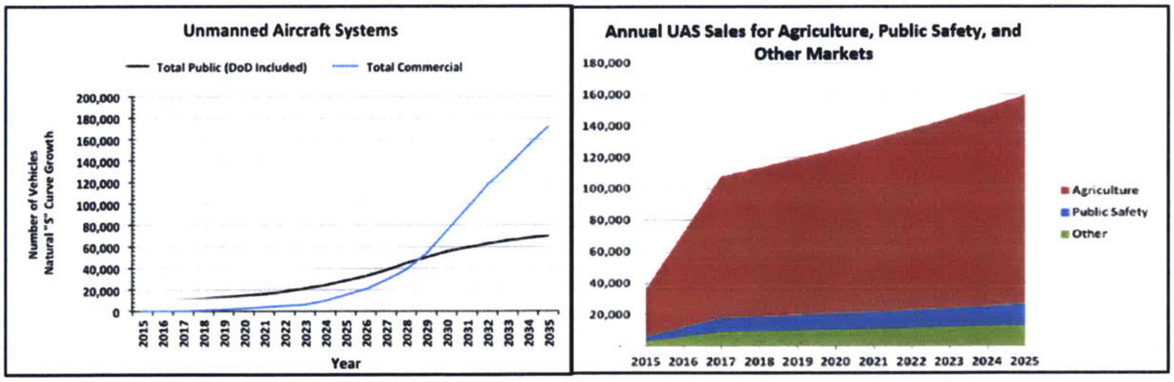

Figure 5-13: sUAS Forecasts [7, p. 124] [37, p. 6]

Industry projections generally align with the advocacy groups and government agencies. The Boston Consulting Group anticipates rapid growth through 2030 and beyond, with the U.S. having over 700,000 sUAS in use by 2030 (see Figure 5-14). BCG lays out three waves of innovation that will contribute to the increased use of sUAS. The first wave is ongoing and limits sUAS to line of sight operations and low-level airspace. A human must also be in control of the sUAS. Wave two will occur within approximately five years and regulations will allow sUAS beyond visual line of sight (BVLOS) operations and parcel delivery. The third wave remains 25 years away and hinges on autonomous technologies. This frontier will likely utilize lessons learned from the self-driving cars and trucks to develop the necessary technologies for this to become reality [97, pp. 2-3]. With anticipated growth expected from multiple perspectives comes the need to understand potential use cases and the environment where these systems will operate.

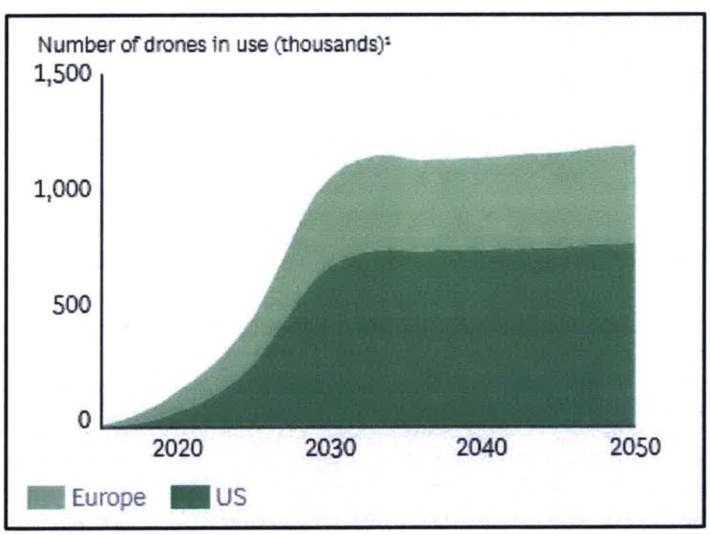

Figure 5-14: sUAS Commercial Forecast [97, p. 2]

5.3.3. Future Use Cases for sUAS

While the present use cases of sUAS can be assigned to the five categories shown in Figure 2-5, future use cases should be addressed as well. In reviewing literature considering future sUAS use cases, different notions of potential use cases exist because of different perspectives [2] [5] [7] [12] [30] [37] [78] [97] [98]. Some experts broadly define use cases depending on the population density and secondarily on the mission objective [12]. BCG and PwC separate use cases by industry and specific application [78] [97]. The Drone Advisory Committee (DAC) and MIT LL consider the flight patterns of the sUAS as well as the mission objective [30] [98]. Other contributors consider many specific use cases and group them based on both sector and mission type [2] [37]. With many varying notions of use cases, we can use the FAA's existing use cases as a foundation (current use cases) and incorporate future use cases as identified by the organizations and experts in the sUAS field.

Table 5-3 shows the current and future sUAS use cases and the succeeding sections give a brief description.

Table 5-3: Current and Future sUAS Use Cases

Current sUAS Use Cases	**Aerial Photography / Imagery / Sensing**
	State and Local Government (to include Law Enforcement)
	Industrial Inspection (Centralized)
	Agriculture
	Insurance
Future sUAS Use Cases	**Industrial Inspection (Decentralized)**
	Package Delivery
	Communications Relay
	Search and Rescue
	Media Coverage

Package Delivery

The use of sUAS for package delivery has been highlighted by high profile projects such as Amazon Prime Air, Google's Project Wing, and DHL's Parcelcopter. These initiatives may represent the future of sUAS delivery, but the final concept still needs refinement. "Last-mile" questions exist as to whether sUAS would deliver packages to a final destination, a central drop box, or a distribution center. BCG expects sUAS package delivery to still be several years away, projecting 1% of package deliveries to be via sUAS by 2022 [97]. There is ongoing discussion as to whether sUAS package delivery should be regulated under Part 107 (Small Unmanned Aircraft Regulation) or Part 135 (Air Carrier and Operator Regulation). The economic benefit to businesses by using sUAS for delivery is significant, with estimates for ground transport to be between $2 - $8 for a two-kg package traveling 10 km while the same package delivered via sUAS would cost 10 cents [78, p. 8]. With this cost-saving incentive to industry and improved delivery time to consumers, sUAS will eventually deliver packages.

Communications Relay

Another future use case for sUAS is as communication relays. The sUAS would be remain in a relatively fixed position and serve as a network repeater. The telecommunications network could then be distributed to a broader customer base. The concept of using sUAS as communication relays could potentially replace satellites to transmit communication signals, as UAS costs are only a fraction of the cost to manufacture, launch, operate, and maintain compared with traditional geosynchronous satellites [7, p. 76]. Facebook has made some initial attempts at developing lighter-than-air solar-powered large UAS that would provide internet access around the world, and sUAS could potentially serve a similar function. Facebook's Project Aquila was halted on June 26, 2018, mainly because of setbacks encountered by the aircrafts during test flights. The goal of Project Aquila was to have solar-powered UAS flying continuously for 3-6 months. Moving forward, Facebook still seeks to increase access to the internet, but intends on having aviation companies develop the airframes [99]. The other use of sUAS related to communications is to help provide temporary cellular network coverage to remote locations, or locations where network service is degraded. This "Cell on Wheels" concept could provide temporary and portable cellular service for major events or during natural disaster relief efforts [78, p. 14].

Search and Rescue

Search and rescue is an emerging use case for sUAS that has been successful in limited employment to date. For a search and rescue mission, sUAS can serve to relay communications, but also to provide detection capability and transportation of equipment in austere terrain [2, p. 4]. A sUAS can fly at lower altitudes than helicopters, and the safety risk is much lower since the aircraft is unmanned. Additionally, sUAS can fly in pre-programmed search patterns (similar to patterns used for precision crop monitoring) to ensure all terrain is covered when participating in a search and rescue mission. While Part 107 still applies, the FAA sometimes will grant an emergency waiver to allow for BVLOS to support a search and rescue effort. On June 25, 2018, the Salt Lake City County Search and Rescue team employed a sUAS and successfully located a lost hiker. The team then moved to his location and escorted him to safety [100]. The U.S. Coast Guard working to acquire its own fleet of UAS to perform search and rescue missions [101], and the opportunity for sUAS to provide detection and transport capability to this mission is growing.

Media Coverage

Using sUAS for media coverage is attractive to news agencies and use will increase in the future. In June 2016 the FAA partnered with CNN to investigate sUAS flight operations over people through the FAA's *Pathfinder Program.* Even with the support of the FAA, it took until October 2017 for CNN to receive a waiver to fly a sUAS over people [102]. However, the advantages gained by sUAS use are numerous. sUAS have lower costs than news helicopters or airplanes and can fly closer to the event to capture higher quality video. They also can capture images not normally available to agencies, such as rare wildlife in their natural habitat [78, p. 12].

5.4. Illegal uses cases

The envisioned holistic future attempted to account for potential illegal use cases as well. Although bad actors will certainly find ways to innovate and use sUAS for nefarious purposes, the author considered three broad types of illegal use: negligence, malicious intent, and cyber threats. Each illegal use case is briefly addressed, but these topic areas are vast and worthy of multiple theses on their own. Discussion here is not meant to be exhaustive, but instead to emphasize the issues that exist and recognize that individuals will seek to use this emerging technology to their advantage, even if that includes violating established laws and regulations.

Negligent sUAS users inadvertently fail to comply with current regulations for operations or certification, but their actions pose a threat to safety in the NAS. From June 2007 to May 2018, the FAA has sought action against 518 sUAS operators for non-compliant operations, and in 2017 the number of sUAS sightings by manned aircraft pilots increased by 19 percent. In recent analysis of controlled airspace near Daytona Beach, Florida, 21.5% of sUAS detected violated UASFM altitude limits [103]. Of the three illegal use cases identified, sUAS users neglecting to follow regulations represents the significant majority of incidents. FAA registration requirements currently provides a level of anonymity for sUAS users, making them potentially feel less responsible for sUAS incidents. To mitigate this illegal use case possible solutions include: increased pilot education, improved situational awareness tools, remote identification, and additional geofencing [103].

Malicious actors are sUAS users who intentionally violate regulations with an intent to commit crimes or harm people and/or property. Recent examples include several sUAS implementations by terrorist groups, such as when ISIS had explosive-laden sUAS attack military bases or surveil U.S. troop movements [104]. In August 2018, then Venezuelan President, Nicolas Maduro, accused political opponents of a failed UAS attack armed with an explosive device. sUAS have also been used by criminal organizations to smuggle drugs and weapons [105]. In December 2018 and January 2019, the United Kingdom's two largest airports (Heathrow Airport and Gatwick Airport) suspended operations following sUAS sightings, which caused extensive disruptions and affected over 120,000 passengers. The Transport Secretary, Chris Grayling, said the disruption was "deliberate, irresponsible and calculated, as well as illegal" [106]. Unlike negligent users, malicious actors directly violate regulations and laws, so increasing pilot education and situational awareness is futile. Rather, emplacing limitations on sUAS operations (e.g. geofencing) and directly countering actions is the proposed solution. Much work to develop counter UAS technology is ongoing, and the DOD and DHS have employed such systems both within and without the United States to deter malicious sUAS.

A third threat related to sUAS use is the cyber threat. Cyber-attacks on UAS have been primarily isolated to military UAS, but the expected increase in sUAS use makes it likely they will become targets. A major cyber-related threat is a malicious actor taking control or interfering with an sUAS. This is primarily accomplished in three distinct ways: malfunctioning/jamming command and control systems, hijacking the aircraft by taking over its command and control link, or spoofing GPS transmitters [107]. As technologies and networks evolve, sUAS will become more integrated with massive amounts of data, which presents another vulnerability. Big data sets have significant value for criminals and large-scale data breaches have become increasingly common (e.g. Facebook, Target, etc.). Approaches to uphold the integrity and confidentiality of UAS and related data while limiting the availability are continuing to evolve [107]. Cyber security needs to remain a high priority as attacks can manifest themselves in both the physical and informational domains.

5.5. Public Acceptance

A constraint not directly addressed by the FAA when discussing required safety levels and technical requirements is the general public acceptance of sUAS use. Unlike manned aircraft, sUAS will operate closer to the general public and thus be far more conspicuous, raising both awareness and noise pollution. Additionally, there may be the public perception that sUAS pose safety, security, and privacy threats. While mitigation efforts can lessen these issues, the general public will more likely embrace sUAS operates in urban and suburban areas (controlled airspace) if they understand the potential benefits delivered. Acceptance will hinge on whether benefits gained exceed social costs. The intent is to identify the benefits and costs so they may be considered in architecture evaluation. The author recognizes that this is an extensive area of ongoing research that is worthy of further analysis.

5.5.1. Societal Benefits

The societal benefits from sUAS use in controlled airspace are significant and additional use cases will emerge as sUAS become more commonplace. While the use cases discussed highlight the current and potential employment of unmanned aircraft, there are several benefits that extend beyond economic. One popular concept is the idea that sUAS will replace humans for tasks that fall into the "3 D's." Missions that are overly *dull, dirty,* or *dangerous* are/will be better accomplished with a sUAS controlled by a remote PIC. Many potential missions combine more than one of these characteristics. One such example is the dull task of collecting data for a land management firm, often done today using a manned helicopter. In an off-nominal scenario (e.g. environmental changes), this task becomes dangerous to the pilot. sUAS are suited for such tasks [108]. Safety benefits extend to many other tasks, from inspections of infrastructure to monitoring natural disasters. sUAS provide the benefit of having humans receive and process information without needing to be physically present.

Society also benefits from efficiencies gained from sUAS use. Georgia Tech's Aerospace Systems Design Laboratory simulated package deliveries in the San Francisco/San Jose region of California. Comparing the time for trucks versus sUAS, the simulations demonstrated that sUAS averaged 11 minutes faster per package (38 minutes compared to 27 minutes) and cost 45 cents less per package ($1.72 per package compared to $1.27 per package) [109, p. 11]. These cost and time efficiencies will become more valuable as urbanization and congestion continue to increase across the globe. Once BVLOS becomes a reality, sUAS will replace manned aircraft and satellites for many tasks. The lower altitude of sUAS operations will improve the resolution when collecting data. In a recent case study by PrecisionHawk, implementing BVLOS sUAS for electric utilities inspections would be between four to twelve times more cost effective than manned helicopters (depending on several cost uncertainties), and this cost reduction does not factor in the safety benefits or improved quality of data [68]. Increased sUAS use will shift employment opportunities from performing the dull, dirty, and dangerous, to performing sUAS-related services, such as operations, maintenance, data analysis, and software development. While these efficiencies and benefits have not all been fully quantified (e.g. safety benefits for firms), they will be clear and transparent to the general public.

5.5.2. Societal Costs

Societal costs are the negative externalities that emerge with the increase of a product or service. With the current architecture sUAS operations are relatively limited, so these sUAS negative externalities have little impact on the general public. However, expanded sUAS use may intensify the issues if a recommended future architecture does not adequately address them. The major social issues can be classified into four groups: safety, security, privacy, and noise pollution.

Safety is a major concern to the general public when considering sUAS use. Academic studies and the news media have many accounts of near mid-air collisions between manned aircraft and sUAS. Embry-Riddle Aeronautical University's recent analysis of Class C airspace near Daytona Beach concluded that "data suggests that more than one in five sUAS flights presented an unmitigated risk to nearby manned aviation operations" [103, pp. 25-26]. This analysis highlights the need for training and improved technologies for sUAS. Many sUAS users have limited tools providing situational awareness of aviation operations, leading to such safety risks. Research about sUAS safety has demonstrated that for ground-based personnel, sUAS weighing more than two kilograms (4.4 lb) are most likely fatal without shelter or protection. "Population density is the single overwhelming driver of risk for sUAS flight over people," which underscores the need to have robust command and control links and shared information [96, p. 16]. The two causes for a loss of flight (and crash) are lack of airworthiness (e.g. engine failure or lost link) and external cause (e.g. weather effects, collision with fixed or moving obstacle) [96, p. 13]. By ensuring proper airworthiness standards, having robust communications systems, sharing relevant information, and having DAA systems, sUAS safety for the general public will be greatly enhanced.

Another societal cost is potential security degradation from sUAS integration. As discussed in Section 5.4, malicious actors may intentionally employ sUAS as a weapon, either by directly controlling them, or by exploiting a security vulnerability. Many sUAS manufacturers are not using encryption schemes in their software or at access points, which leaves the sUAS open to cyber attacks [110, p. 2]. Many new technologies bring possible security threats, and sUAS are no different. Steps to decrease likelihood are available. The TSA conducts background checks as part of issuance of a Part 107 certification. Geofencing and restricted flight zones are in place over critical facilities, and robust cybersecurity measures can minimize cyber exploitation. More advanced counter UAS measures and regulations will emerge to defend against malicious actors and limit any issues to the general public.

Protection of data and privacy is a third societal cost that emerges from increased sUAS use. The general public has concerns about both government and private entities misusing sUAS to collect data and invade their privacy. Several court decisions have established precedents that may impact how privacy is regulated in regards to sUAS. *California v. Ciraolo* established that a private property is not protected by the Fourth Amendment (right to unreasonable search and seizure) "as long as an aircraft is in navigable airspace" [111, p. 25]. *Dow Chemical Co. v. United States* also established that aerial photographic evidence is permissible as long as the photographic equipment is "readily available to the public" [111, p. 26]. While no formal regulations exist protecting the public's privacy from intrusive sUAS users, sUAS users are educated and provided an industry-developed "Voluntary Best Practices for UAS Privacy, Transparency, and Accountability" document. While civil liberty unions will advocate for privacy, state and local law enforcement remains empowered to enforce privacy laws, even relating to sUAS abuse of privacy [26, p. 3]. If a transparent sUAS network allows law enforcement to observe operations, they could be able to identify sUAS users who violate individuals' privacy and take appropriate legal action.

Noise pollution is another externality that imposes a societal cost. sUAS in controlled airspace will operate close to the public, especially for take-off and landing, and the noise pollution generated must be considered. The public has protested airline routes that produce excessive noise pollution over residential areas, causing airlines to re-route and impacting departure rates [95, p. 218]. Simulations have sought to model large-scale sUAS operations in urban areas, and preliminary results are that noise levels are relatively low (55 dB) when sUAS are operating between 150 and 250 ft AGL [112, p. 4]. While this noise level is comparable to light traffic in a suburban area, it does not account for public perception of the added noise pollution [113].

Pending public acceptance or protest of potential noise pollution from sUAS, two mitigations exist: technological solutions and operational solutions. sUAS manufacturers may reduce the noise generated by the aircraft (technological solution). Alternatively, sUAS users may operate aircraft in operating modes that produce less noise (e.g. slower speeds), or emit noise in locations further from bystanders (operational solutions) [95, p. 219]. The willingness of the general public to accept noise pollution is closely tied to the level of benefit gained from sUAS.

5.6. Evaluation Criteria

Having developed the holistic envisioned future and considered potential externalities that emerge, the final step before generating future architectures is to establish evaluation criteria. The set of evaluation criteria attempts to capture both the needs of the major stakeholders and the desired capabilities of the future enterprise [4, p. 81]. These criteria are meant to judge the future architectures holistically, taking into account the differences in ARIES elements and overarching design principles used to generate each alternative. With this mindset, the author designed evaluation criteria to be comprehensive, although this approach admittedly inserts a higher level of subjectivity into the later evaluation of alternatives.

Based on stakeholder needs and capabilities required for sUAS to safely operate in controlled airspace within the NAS, evaluation criteria are required to compare alternative architectures. Table 5-4 lists the criteria that are representative of stakeholder needs and enterprise requirements. Each criterion is explained to justify its relevance and importance.

Table 5-4: Evaluation Criteria for Alternative Architectures

Evaluation Criteria
Safety (for air/ground personnel and property)
Robustness (ability to withstand adverse conditions)
Transparency (promotes accountability and information sharing)
Scalability (ability to expand sUAS use over time)
Social Acceptability (willingness of society to accept architecture)
Impactability (change to current NAS operations)
Implementability (considering time and cost)

The seven criteria listed above capture importance attributes that the future NAS architecture needs to demonstrate for sUAS integration and expansion. *Safety* has been well documented as being a major value generated from the NAS architecture. Ensuring that sUAS operations continue to allow the NAS to maintain an extremely high level of safety has been a significant constraint, and any future architecture has to be evaluated on its ability ensure safety for all people and property. *Robustness* is the ability of the future architecture to withstand disruptions and continue to perform in adverse/off-nominal situations. This criterion evaluates how susceptible the alternative is to degraded conditions such as lost communication links, cyber threats, or other contingencies. *Transparency* is the level to which the alternative allows for a shared understanding for stakeholders. The extent to which the NAS has a common operating picture serves as a deterrent to bad actors, and also enables NAS users to have improved situational awareness. *Scalability* is the extent to which the alternative can continue to expand over time. This criterion considers that an alternative may only allow for a limited capacity of unmanned aircraft before a constraint (e.g. safety, noise pollution, etc.) halts continued expansion. *Social acceptability* is the willingness of society to accept the increase of sUAS within low-altitude controlled airspace. Without support from the general public, sUAS and the organizations operating them may be stigmatized. *Impactability* considers how significant of a change the alternative architecture is from the current architecture. Impactability is important because the increased integration of sUAS into controlled airspace is not a greenfield design, and manned aviation operations must continue with minimal impact. *Implementability* is the final criterion and considers the time horizon and potential costs associated with an alternative. Time and cost are important factors for any enterprise, and this criterion will capture the extent to which an alternative is feasible.

With descriptions of the current architecture and envisioned holistic future and this set of evaluation criteria, the next step in the ARIES framework is to generate alternative architectures and select a future architecture. Chapter 6 addresses the development of alternative architectures that promote sUAS integration within controlled airspace and the evaluation and final recommendation.

6. CHAPTER 6: GENERATING A FUTURE ARCHITECTURE

Having described an envisioned future and developed evaluation criteria, the next steps in the ARIES process are to generate alternatives and select a future architecture. This chapter captures three alternative architectures the author developed, the evaluation methodology used to compare the alternatives, the recommended future architecture with an example operational concept, and feedback on this recommendation from aviation and surveillance system subject matter experts. During this process of developing, evaluating, and recommending a future architecture, the author maintains a holistic view by considering each architecture in terms of the ARIES elements. This approach prevents the author from favoring one element or focusing on only one aspect of a proposed architecture.

6.1. Methodology for Alternative Architecture Generation

To generate alternative architectures, the author began with a wide view before down-selecting to three viable concepts. The four-step approach for ideation (see Table 6-1) provided motivation and direction [4, p. 84]. First, a brainstorming exercise generated possible solution fragments. Second, ideas were considered based on experience and existing transportation systems. For example, the concept of having well-defined routes may be applicable both for sea, ground, and air-based vehicles. Third, informal discussions with other individuals spawned other ideas, such as providing a website or mobile application to allow different classes of stakeholders to view the current sUAS operations in a geographic area. The fourth step, thinking of extreme enterprises generated some interesting concepts, such as having no defined architecture for sUAS operation and instead making sUAS frangible and/or parachute-equipped so that any collision has minimal safety impact. After discussing and generating concepts ranging from standard to novel to extreme, the feasibility of concepts led to down-selection. The author down-selected by separating the "could be" concepts from the "couldn't be" and "shouldn't be" options [4, p. 87]. Concepts were then merged to create complete architectures.

Table 6-1: Four-step Approach for Ideation [4, p. 84]

Step 1	Generate ideas
Step 2	Learn from experience
Step 3	Ask for suggestions
Step 4	Think of extreme enterprises

6.2. Boundaries and Assumptions for Alternative Architectures

When developing alternative architectures for low altitude sUAS operations BVLOS in urban airspace, the author scoped the exercise by specifying boundaries and assumptions for the operational environment. Many of the boundaries are synced with current definitions and limitations placed on sUAS; this allows for consistency for aspects that remain unchanged across architectures.

For the proposed alternative architectures, sUAS operations remain somewhat limited to be feasible in the three to five-year time horizon. The definition of a small unmanned vehicle remains the same, with it being between 0.55 lb and 55 lb and only allowed to travel up to 100 mph (87 knots). No sUAS is permitted to operate above 400' AGL or within 400' of a structure, which is consistent with today's regulations and the strategy to segregate sUAS and manned aircraft. The requirement to detect and avoid other aircraft is applicable only between sUAS and manned aircraft, not other sUAS. This aligns with the current requirement for DAA. No sUAS may use a transponder for ADS-B Out because of the oversaturation of the 1090 MHz frequency that would occur, although sUAS may have receivers for ABS-B In to identify cooperative aircraft. If the sUAS is able to operate BVLOS, operations over people are acceptable, as are operations at night. There is no longer a visibility requirement (currently three miles), since the vehicle may operate BVLOS. Alternative architectures must have limited interaction with ATC, as air traffic controllers already have task saturation concerns.

As discussed, it is beyond the scope of this work to significantly analyze hostile/malicious actors, sUAS propulsion systems, and cybersecurity issues. While some of these areas are briefly addressed, each represents a substantial research field worthy of separate analysis.

6.3. Constant ARIES Elements across Alternative Architectures

When generating alternative architectures for sUAS within controlled airspace, one interesting insight emerged: several of the ARIES elements remained constant across the alternative architectures. Regardless of the overall driver for an architecture, certain gaps seem to exist in the current architecture that require attention for sUAS operations to expand. This section addresses the ARIES elements the author found to be consistent across the alternative architectures. Since these elements remain constant across the three architectures, they are identified and addressed once, rather than repeated in subsequent sections.

6.3.1. Strategy

The FAA's strategy for UAS integration provides a clear long-term vision for UAS and sUAS operations within the NAS. Incrementally integrating sUAS into the NAS dominates the alternative strategy of waiting for future technologies, processes, and policies to be in place before moving forward. The time required for all elements to be near-perfect before moving forward makes this strategy impractical as it disincentivizes industry partners from developing innovative solutions. Maintaining a clear segregation between sUAS and most manned aircraft (with sUAS operating at 400' AGL and below) is a major contributor to upholding an acceptable level of safety for people and property. The FAA then can expand Part 107 to include more complex sUAS operations over people, BVLOS operations, and package delivery operations. Figure 5-1 depicts strategic phases and associated tasks. While this progression flows logically overall, one recommendation is to focus on "UAS noise impacts and environmental certification requirements" sooner [69, p. 36]. Enabling sUAS operations over people without considering sUAS noise pollution has the potential to stigmatize the devices and create an avoidable public support barrier. Addressing the noise impacts should be incorporated early in the process rather than adjusting the architecture to account for possible negative effects. The overall strategy for sUAS integration is reasonable and consistent for all alternative architectures.

6.3.2. Policy

Policy remains consistent for sUAS across different architectures. 14 CFR Part 107 remains the primary regulation for all sUAS, but additional refinement increases the ability of sUAS to operate within controlled airspace and BVLOS.

One significant policy addition is a sUAS well-clear definition. To date the FAA allows pilot judgment to determine well-clear for manned aircraft and has defined well-clear for large UAS based on vertical and horizontal distance and time components (see Figure 2-7) [29]. MIT Lincoln Laboratory has developed a robust well-clear recommendation for sUAS considering unmitigated collision risk. Maintaining well-clear allows sUAS to avoid having to take any collision avoidance action. Generating 13 potential flight trajectories for BVLOS operations based on various use cases allowed for over six-million sUAS encounter simulations [30]. Interestingly, sUAS collision risk was not sensitive to different performance characteristics (cruise airspeed, max airspeed, climb/descend rate), allowing for a "hockey-puck" definition based only on horizontal and vertical separation criteria and not a temporal criterion [30]. Figure 6-1 illustrates the recommended horizontal and vertical separation for sUAS with a horizontal separation of 2000' and vertical separation of 250' between a sUAS and any other aircraft (manned or unmanned). Based on airspeed limitations of sUAS (slow vertical rate changes), even a low-performance sUAS can resolve an encounter and re-establish well-clear separation in sufficient time to avoid concern (less than 10 seconds). Based on the compelling simulation and modeling results and analysis, this sUAS well-clear definition applies to all alternative architectures.

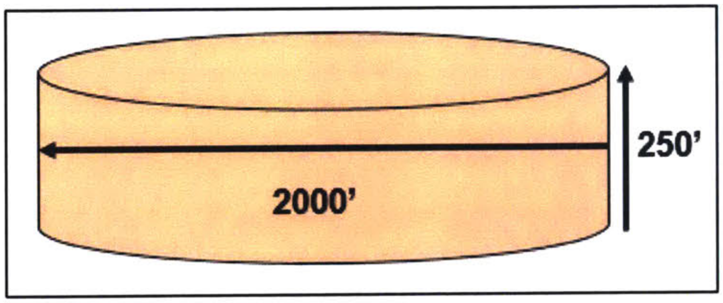

Figure 6-1: sUAS Well-Clear Recommendation [30, p. 118]

Detect and avoid is a second requirement that remains constant across alternative architectures. While architectures may utilize different products/services and processes to achieve separation, all sUAS must DAA other aircraft (both cooperative and non-cooperative). DAA is a product/service, but the requirement to avoid other manned aircraft, along with performance targets and system requirements, is a policy. Additionally, the FAA must certify the DAA solution, which needs to detect and avoid potential obstacles besides aircraft, such as power lines, terrain, and structures, and provide the PIC adequate time to respond (if the sUAS does not autonomously avoid the hazard). While establishing a sUAS well-clear definition is important, the detect and avoid capability represents the technical requirement to maintain sUAS well-clear. As mentioned, DAA requires more than evasive maneuvers to avoid a mid-air collision, and DAA solutions must evaluate flight paths for oncoming traffic, determine right-of-way, and maneuver to re-establish well-clear [32, pp. 21-22]. While the policy to detect and avoid is constant, alternate ways to achieve this requirement emerge in products/services and processes.

Remote identification is a third policy that is stable across all alternative architectures, although the products/services used to realize it vary. The concerns of sUAS violating individual privacy and decreasing security significantly motivate the need for remote identification. The FAA requires manufacturers to emplace remote identifiers that must be activated before a new sUAS may operate. Remote identification instills an increased level of accountability for the remote PIC. Although useful to law enforcement, technology limitations make it infeasible to have a requirement that the remote identification system also identify the real-time location of the remote PIC. However, armed with device and user information, law enforcement can still rapidly locate violators. Remote identification also should share state information for attribution and with law enforcement, while not violating existing spectrum concerns.

6.3.3. Organization

The organization across alternative architectures has consistency, with two main differences from the current formation: decision authority and culture. The current FAA structure for UAS integration has decisions relating to sUAS made in many different offices across the agency. For example, the approval authority for sUAS waivers can be made by the Air Traffic Organization or Flight Standards Service. Meanwhile, the UAS Integration Office is a subordinate office to the Aviation Safety Office [59, p. 8]. To improve the NAS enterprise and better position it for sUAS integration, the FAA should elevate the importance and level of the UAS Integration Office. Similar to the Office of Aviation Safety or other FAA offices, the UAS Integration Office should consolidate the FAA's knowledge, expertise, and decision-making for all UAS-related issues. This office would resolve the uncertainty that currently exists in other FAA offices relating to UAS, either because of a knowledge gap or a lack of decision authority. This would have the additional benefit of increasing the pace of decision-making, since most applicable parties would work in a closer proximity and have more frequent communication exchanges. Major decisions that involve air traffic management, aviation safety, or other specific field would still require approval from those entities, but with the expected growth in UAS operations, the elevating the UAS Integration Office puts renewed emphasis on this effort.

The second organizational aspect that requires attention is the FAA's perceived aversion to sUAS integration in controlled airspace. This conservative safety culture was highlighted by the National Academy of Science, Engineering, and Medicine and could potentially inhibit industry innovation [58]. Figure 6-2 illustrates the perception of the FAA and aviation industry. With increased cohesion and better-informed decision-making (from elevating the UAS Integration Office), the FAA becomes more agile and able to bring change to the NAS in the form of sUAS in controlled airspace. There are significant differences between the technology and aviation industries, so expecting both to have similar safety mindsets is not reasonable. However, bringing government experts together into one office, as well as increasing partnerships with industry, helps to lessen the perception that the FAA is focused solely on safety to the detriment of innovation. Both pillars are important for sUAS integration to move forward and succeed.

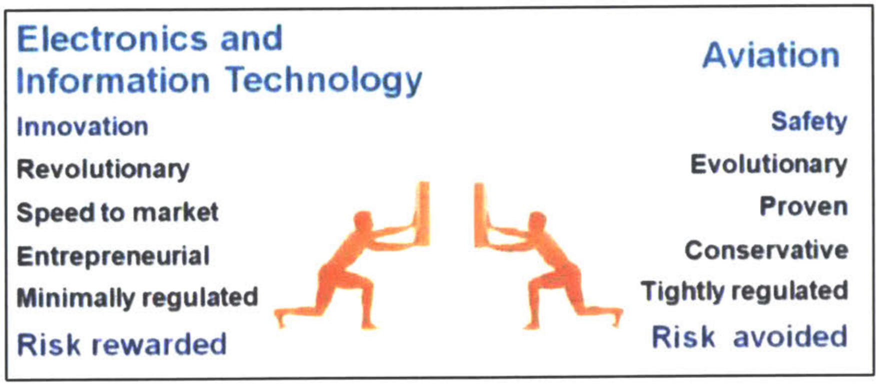

Figure 6-2: EIT vs. Aviation Risk Culture [58, pp. 3-3]

6.3.4. Knowledge

Knowledge is the final ARIES element that remains consistent across alternative architectures. To further increase its knowledge, the FAA needs to hire talented individuals from industry and academia to bring in current and emerging UAS ideas as well as experts in UAS operations. Understanding that the pay structure in the federal government may be a deterrent, the FAA should consider contracting specific items to outside firms. This knowledge increase is critical for developing requirements and definitions that the UAS arena needs for large-scale operations to become viable (and limit the need for waivers). The knowledge increases on the user side as well, with the instituting of a performance-based test for sUAS users who seek to operate beyond Part 107. This certification requirement ensures that sUAS remote PIC that operate more complex missions (BVLOS, controlled airspace) are fully capable of performing required tasks, not simply knowing the information for the written exam. This change makes the remote PIC requirements similar to the existing manned aircraft pilot requirements and increases the ability to avoid hazardous scenarios during flight operations.

Another knowledge factor that remains constant is the need for standardization across the NAS for sUAS. Developing MOPS for unmanned aircraft, DAA systems, and command and control systems has been ongoing. Regardless of the alternative architecture selected, having established performance standards is essential to providing guidelines and structure to the rapidly expanding sUAS community. MOPS provide established targets for manufacturers to meet as well as inform future testing and simulation work with clear baselines. The FAA, NASA, and many standards organizations and academic institutions are working to develop and implement MOPS, which better defines the sUAS future.

6.4. Architecture 1 – Independent Flight

Independent Flight is an alternative architecture that allows for sUAS users to operate with the most freedom and limited structure. Individual sUAS users are responsible for maintaining separation from all manned aircraft, as well as obstacles and other sUAS. For the *Independent Flight Architecture*, there is no coordination between other aircraft, manned or unmanned. The architecture is straightforward to implement and has less infrastructure required (relative to other alternative architectures) to make it operationally feasible. Figure 6-3 illustrates the overall concept that drives this architecture. A sUAS is able to operate with limited restrictions imposed on flight operations. Table 6-2 has the specific ARIES elements that compose the Independent Flight Architecture, which are explained in Sections 6.4.1 through 6.4.4.

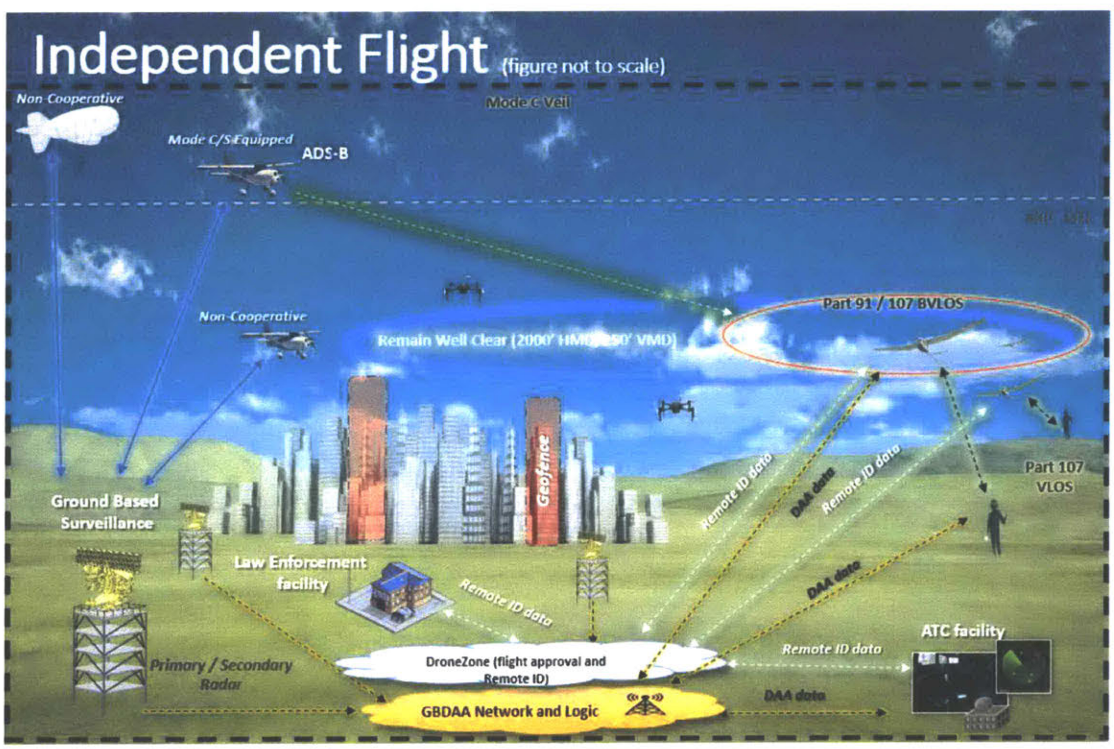

Figure 6-3: Independent Flight Architecture Concept (adapted) [114, p. 6]

Table 6-2: ARIES Elements for Independent Flight Architecture

Architecture 1 – Independent Flight	
Strategy	•Incremental integration •Segregation between sUAS and manned AC •Focus on noise impacts and societal acceptance
Policies	•Adopt sUAS well-clear recommendation •Maintain requirement for DAA obstacles •Require remote identification for all users
Organization	•Elevate UAS Integration Office to consolidate knowledge, expertise, and decision-making •Increased partnerships with industry to promote innovation
Knowledge	•Increased hiring of experts for UAS Integration Office from industry and academia •Performance-based test for sUAS BVLOS users with not fully autonomous systems •Development of MOPS for sUAS, DAA, and C2
Products/Services	•DAA via Ground-Based DAA sensor network •Remote ID registration through FAA DroneZone (transmit via cellular & Bluetooth/WiFi) •Extensive geofencing •Expand/repurpose UAS Facility Maps
Processes	•Authorization through DroneZone •Waivers through DroneZone < 24 hrs •DAA commands issued to user via DAA network •All notifications through DroneZone to user (email/text)
Information	•No coordination between aircraft (before/during flight) •DAA commands issued to user via DAA network •sUAS continually transmits remote ID to GBDAA sensors •All notifications through DroneZone to user •Remote ID accessible to LE
Infrastructure	•Transmission of data via cellular/WiFi (adequate service level required) •Ground-Based DAA sensor and data network required

6.4.1. Products/Services

Architecture 1 has several specific products that support independent sUAS flight within urban airspace. The primary services provided via products and infrastructure are: detect and avoid with manned aircraft, remote identification, geofencing, and expanded UAS Facility Maps.

Establishing detect and avoid capability is a clear requirement for sUAS to operate BVLOS, and this architecture accomplishes this using a ground-based DAA sensor network. A GBDAA system includes several components: surveillance, tracking, threat logic, and user alerting. An example of a GBDAA solution could incorporate LSTAR® ground sensors and ACAS sXu logic. LSTAR® ground radar sensors can be configured to feed ACAS sXu with non-cooperative surveillance data. This surveillance data allows ACAS sXu to track and determine the projected flight path and potential threat from an intruder. ACAS sXu can alert the remote pilot to perform specific maneuvers to avoid the non-cooperative manned aircraft and enable the remote pilot to remain well-clear. LSTAR® is manufactured by SRC, Inc., who has already received certification in accordance with DO-178. The LSTAR® sensors provide 360-degree coverage for up to 35 km and may be easily mounted or installed throughout an urban area [115]. In urban airspace with many obstacles (buildings, bridges, etc.) several GBDAA sensors would need to be installed, but compliance with 14 CFR 91.113 (see and avoid) is feasible, even in degraded conditions (low-visibility/nighttime) [115]. The cost to install a network of sensors would be a large capital investment. In addition to the ground sensors, ACAS sXu logic must be integrated to provide remote PIC commands about required maneuvers once GBDAA sensors detect a manned aircraft. ADS-B In information can be fed into the LSTAR® system as well, providing transponder information as well as radar information for DAA. This system or similar represent a GBDAA solution for sUAS in urban airspace.

Remote identification is a second major service required for sUAS to operate and becomes more critical as sUAS operate BVLOS. Architecture 1 requires remote identification registration through the FAA DroneZone site. A sUAS transmits via cellular network its remote identification information to ground-based radar sensors. The general public is able to identify (via enhanced FAA DroneZone site) anonymized sUAS operations in specific areas to allow them transparency and to identify unwanted trends and users in an area. Law enforcement has access to additional near real-time information provided by sUAS remote identification that can be used to identify the remote PIC and pertinent performance data. While most urban airspace has robust cellular networks, Bluetooth 5.0 and WiFi 5.0 provide redundant links for remote identification.

A third major service for the Independent Flight Architecture is extensive geofencing. With sUAS operating both autonomously and manually throughout urban airspace with no coordination, geofences prevent sUAS operations in flight-restricted airspace (e.g. TFRs, special access areas, airports, etc.). Geofences are based on the FAA's current authorized airspace access for sUAS, and manufacturers update software for their sUAS. Several major manufacturers already update geofences for end users via updates. Geofences also incorporate altitude limits in accordance with the UAS Facility Maps. Although current UASFM are fairly restrictive, additional analysis to expand the permitted elevations (up to 400' AGL) allows sUAS to operate in greater areas throughout the Mode C Veil. UASFM are also repurposed. No longer are they providing guidance to sUAS users, but instead provide limitations on where sUAS may operate.

6.4.2. Processes

For the Independent Flight Architecture to function, several processes need to be created or modified. The major two processes hinge upon increasing the capabilities of the FAA DroneZone site and establishing a subscription service for GBDAA.

Architecture 1 uses the FAA DroneZone site for several processes, which requires the FAA the increase its level of automation related to sUAS. Receiving an authorization remains similar to the 2018 rollout of LAANC, which allows for near real-time approval of sUAS flight operations (assuming no special circumstances or requests). Waivers are also able to be submitted through DroneZone (currently a manual process) and increased automation enables approval/rejection within 24 hours. Since sUAS users register their devices through the DroneZone, all relevant contact information is stored here. Since no UTM network is part of Architecture 1, DroneZone uses contact information (email/text) to inform sUAS pilots of any notifications (e.g. weather conditions, TFRs, alerts, etc.). All of these processes require increased investment into the DroneZone site infrastructure, which currently serves relatively basic functions (registration and accident reporting).

Having a vendor provide GBDAA services requires establishing a process for DAA commands. A sUAS ground control station needs to connect via cellular/WiFi to the DAA sensor network. Once the DAA sensor network authenticates that the sUAS is registered and the remote identification is active, the DAA network provides DAA services. All DAA commands are communicated from the GBDAA radar sensor to the sUAS ground control station. The user then acts in accordance with the DAA command. This GBDAA service is subscription-based, allowing for other DAA vendors and methods as technology continues to progress.

6.4.3. Information

Information sharing in the Independent Flight Architecture is critical because there is no coordination between individual sUAS or manned aircrafts. As previously mentioned, the DAA network (through an FAA-approved vendor) issues commands to the user via ground control station. A sUAS continually transmits its remote identification information to GBDAA sensors, and this information is sent to the DroneZone. Because there is no UTM or other coordination mechanism, remote identification accuracy becomes more important. This transmissions to DAA sensors must be accurate and have high reliability. The general public has visibility, via

DroneZone, of sUAS operations in geographic areas. Law enforcement has access to additional remote identification information, eliminating the anonymity of sUAS pilots. The DroneZone also provides necessary notifications, updates, and alerts to active sUAS users via email/text.

6.4.4. Infrastructure

While the level of infrastructure required for the Independent Flight Architecture is less intense than the other two architectures, two requirements exist: reliable cellular networks and a ground-based DAA sensor network. This alternative architecture relies on transmitting data (remote identification and DAA commands) using primarily cellular networks, so this is feasible in built-up urban areas that have reliable cellular coverage. Should adequate cellular coverage not exist, major infrastructure improvements may be required for Architecture 1 to become viable. At least one FAA-approved vendor will undertake the second infrastructure requirement, which is establishing a GBDAA sensor network. The capital investment required to locate and install multiple DAA sensors throughout an urban area with 100% coverage spanning the Mode C Veil is significant. The vendor will recover these costs by establishing a subscription-based model. Without the GBDAA subscription, sUAS have limited avenues to perform BVLOS operations.

6.5. Architecture 2 – Coordinated Flight

Coordinated flight is a second alternative architecture that supports BVLOS sUAS operations in urban airspace. This architecture has increased structure and systems in place relative to the Independent Flight Architecture. Individual sUAS users maintain the responsibility for separation from all obstacles; however, for the *Coordinated Flight Architecture*, there is coordination between other unmanned aircraft. DAA is achieved via an airborne sensor on the unmanned vehicle to enable remote PIC to remain well clear of manned aircraft. UTM coordinates sUAS flights, so there is a coordination and scheduling aspect incorporated to sUAS operations. This architecture improves coordination and situational awareness and requires additional infrastructure. Figure 6-4 illustrates the concept for this architecture. A sUAS is able to operate upon receiving UTM approval. Table 6-3 describes the specific ARIES elements that compose the Coordinated Flight Architecture, which are explained in Sections 6.5.1 through 6.5.4.

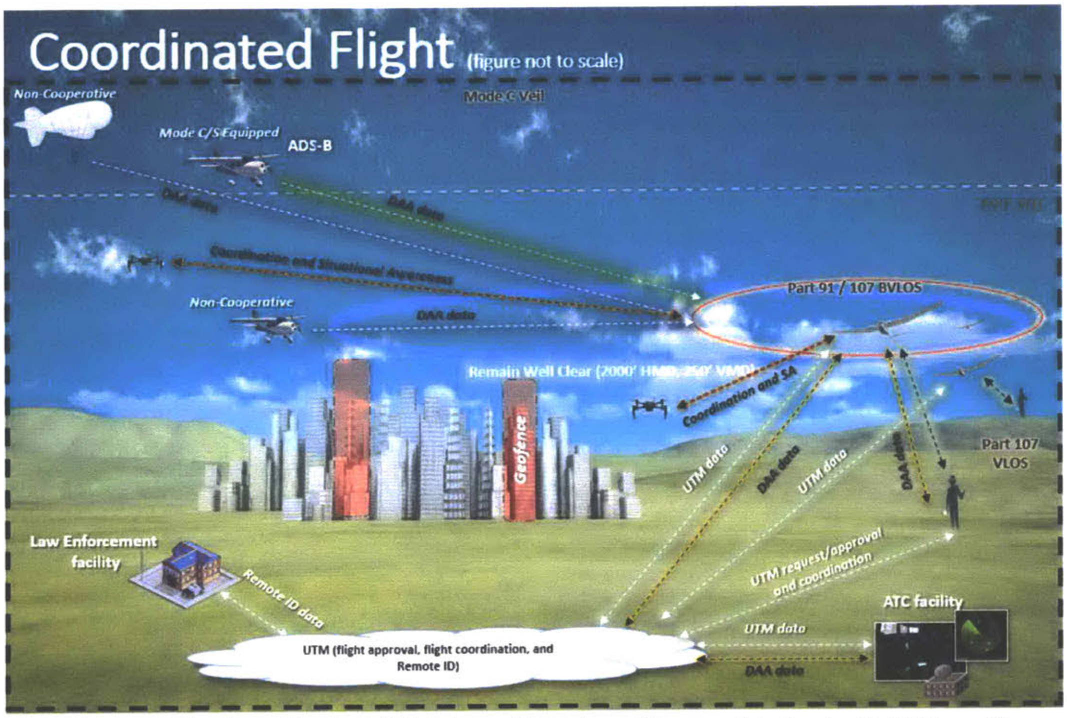

Figure 6-4: Coordinated Flight Architecture Concept (adapted) [114, p. 6]

Table 6-3: ARIES Elements for Coordinated Flight Architecture

Architecture 2 – Coordinated Flight	
Strategy	•Incremental integration •Segregation between sUAS and manned AC •Focus on noise impacts and societal acceptance
Policies	•Adopt sUAS well-clear recommendation •Maintain requirement for DAA obstacles •Require remote identification for all users
Organization	•Elevate UAS Integration Office to consolidate knowledge, expertise, and decision-making •Increased partnerships with industry to promote innovation
Knowledge	•Increased hiring of experts for UAS Integration Office from industry and academia •Performance-based test for sUAS BVLOS users with not fully autonomous systems •Development of MOPS for sUAS, DAA, and C2
Products/Services	•UTM to coordinate/schedule individual flights •DAA via airborne sensors using ACAS sXu logic (radar) •UTM provides spatial data and alerts •UTM provides recommended flight path to user •Remote ID through UTM •Limited geofencing
Processes	•USS approves flights (via UTM) •Deconfliction via airborne DAA and UTM (manned AC and sUAS) •Expand/repurpose UAS Facility Maps
Information	•UTM coordinates individual flights •UTM provides situational awareness, spatial data and alerts •DAA commands via airborne sensor •Notifications and UASFM updates via UTM •Remote ID accessible to LE and public via UTM
Infrastructure	•Transmission of data to UTM via cellular/WiFi (adequate service level required) •UTM network (managed by USS)

6.5.1. Products/Services

Architecture 2's products and services help to enable coordinated sUAS flight within urban airspace. Key services for this alternative architecture are: airborne-based detect and avoid, UTM to coordinate sUAS flights and exchange data, and limited geofencing to prevent unauthorized operations.

Architecture 2 relies upon an airborne-based detect and avoid system to enable BVLOS. An example of an airborne-based sensor was demonstrated in October 2018. Flight tests conducted by the Northeast UAS Airspace Integration Research Alliance (NUAIR) utilized a Fortem TrueView R20 radar system on-board a sUAS. The system fed the data from the radar system into ACAS sXu for collision avoidance. Tests were successful in detecting manned aircrafts, and there was also some success in detecting unmanned aircraft. The current requirement for compliance with 14 CFR 91.113 is to detect and avoid manned aircraft, which this airborne sensor system accomplishes [116]. The *Coordinated Flight Architecture* requires an FAA-approved airborne-mounted DAA avionics system for any sUAS that requests BVLOS operations. One major tradeoff from utilizing an airborne-based DAA system is the low size, weight, and power – cost (SWaP-C). With a limited payload capacity for sUAS, requiring an approved sensor and adequate power source significantly impacts the ability to conduct other missions.

To have coordinated flight, there is an unmanned aerial system traffic management system that provides approval, coordination, and scheduling services. Coordinated flight refers to the coordination that UTM provides between sUAS, manned aircraft are excluded. As discussed in Section 5.2.1, NASA is leading the research and development effort for UTM. UTM relies on a USS to establish a data exchange network that enables automated approval of flight requests and shares NAS information (e.g. TFRs, alerts, notifications) to individual sUAS users (see Figure 5-2). After submitting a flight plan, sUAS users receive an approved flight plan from UTM that considers other sUAS operations in the vicinity. The approved flight plan may adjust the proposed flight path or flight times to deconflict with other sUAS operations. This additional level of deconfliction decreases the likelihood of a mid-air collision between sUAS. The airborne-based DAA avionics system provides the remote PIC with commands to maneuver and avoid manned aircraft by using a radar sensor to detect intruders. With UTM in place, remote identification is possible without a ground sensor network. Upon receiving flight approval via UTM, the ground control station remains connected to UTM. The vehicle transmits the remote identification information back to the GCS, which feeds the information to UTM. UTM stores this data and allow the general public and law enforcement to view relevant information about sUAS operations to allow for transparency.

The Coordinated Flight Architecture has a decreased need for extensive geofencing since UTM provides an approved flight plan. Assuming sUAS users follow the approved flight paths, any geofencing becomes redundant and may only be necessary for high-priority locations (e.g. military bases, airports). Unlike the *Independent Flight Architecture*, deviations from flight plans are easier to identify because UTM has real-time feedback about the sUAS operations in low-altitude airspace. Repeated deviations can be attributed to the registered remote pilot and appropriate actions taken.

6.5.2. Processes

Architecture 2 (Coordinated Flight) has two processes that differentiate it from Architecture 1 (Independent Flight). The first process relates to receiving flight request approval, and the second encompasses the deconfliction of vehicles within the NAS.

Flight approval under Architecture 2 is more complex than in the first alternative architecture. The USS approves all proposed flight plans that are submitted through UTM, but this approval seeks to optimize the pending flight plan by considering several factors. The primary factor considered is ongoing or already-approved flight plans. To prevent mid-air conflicts (between sUAS) UTM may either adjust the flight path or the requested flight schedule time for the proposed flight plan. This process may change in the situation where a proposed flight plan has high priority (e.g. law enforcement sUAS). UTM then would immediately notify sUAS users in the affected airspace to divert/cease operations to allow the high priority flight to operation unimpeded.

Deconfliction between sUAS and other aircraft is a process that differs in the Coordinated Flight Architecture. While achieving DAA with manned aircraft is a requirement, UTM also provides the additional benefit of deconfliction with other unmanned aerial vehicles. While unable to have transponders that communicate directly between UAVs because of current spectrum limitations, the UTM approval process provides a level of deconfliction between sUAS. When approving flight plans, UTM not only ensures that sUAS operate within established NAS constraints, but also that multiple sUAS operations do not conflict with each other. This additional process adds an additional safety check into the enterprise.

6.5.3. Information

The information-sharing within Architecture 2 is primarily accomplished with the UTM network. UTM receives the individual flight requests and coordinates those flights. UTM also provides the sUAS users with situational awareness about other sUAS operations in the same airspace, as well as any notifications or alerts. DAA commands remain a separate system from UTM, and the airborne DAA sensor sends commands to the user via the ground control station. Updates to UAS Facility Maps or any other sUAS relevant planning resource are also done through UTM. Remote identification information is sent from the device to the ground control station, which is always connected to UTM. The general public and law enforcement have access to UTM to monitor remote identification information, with law enforcement being able to identify specific users. This remote identification information eliminates anonymity and makes sUAS users more accountable for their actions.

6.5.4. Infrastructure

The two infrastructure requirements for the Coordinated Flight Architecture are reliable cellular networks and a robust UTM network. The UTM network consists of the USS and a central data processing capability. Similar to Architecture 1, transmitting data is primarily accomplished through cellular networks, so coverage and reliability must be extremely high. For the urban airspace these architectures are considering, the cellular coverage is likely acceptable to enable data transfers between the UAV, ground control station, and UTM network. This UTM network is critical to this alternative architecture functioning as intended, as it allows for flight coordination, remote identification, and information sharing for many parties. An FAA-approved USS develops and manages this network, and the costs required to design, test, secure, and manage UTM are significant. The vendor will determine the best method to recover these costs, potentially through a paid subscription service or upfront fee during sUAS remote identification registration.

6.6. Architecture 3 – Flight Corridors

The third alternative architecture supporting BVLOS sUAS operations in urban airspace is named the *Flight Corridors Architecture*. This architecture incorporates aspects of both previous architectures: DAA is achieved via GBDAA and there is coordination among sUAS via UTM. UTM establishes flight corridors (see Figure 6-5) that provide clear and limited areas of operation (vertically and horizontally) that sUAS may operate. The flight corridors concept provides transit lanes that support movement of packages or other point to point missions. However, it inhibits the ability to conduct tasks that require increased flexibility, such as conducting inspections and aerial photography. These use cases would require additional time to submit flight requests, allowing UTM to adjust flight corridor usage to allow the missions to occur. Emergency services are the exception, and would take priority over all other sUAS operations. Architecture 3 requires the most planning to design and implement as it has a robust UTM network with increased capabilities compared to Architecture 2. UTM provides coordination and scheduling among sUAS, as well as specific "corridor reservations." Table 6-4 describes the Flight Corridors Architecture by each ARIES element, which are detailed in Sections 6.6.1 to 6.6.4.

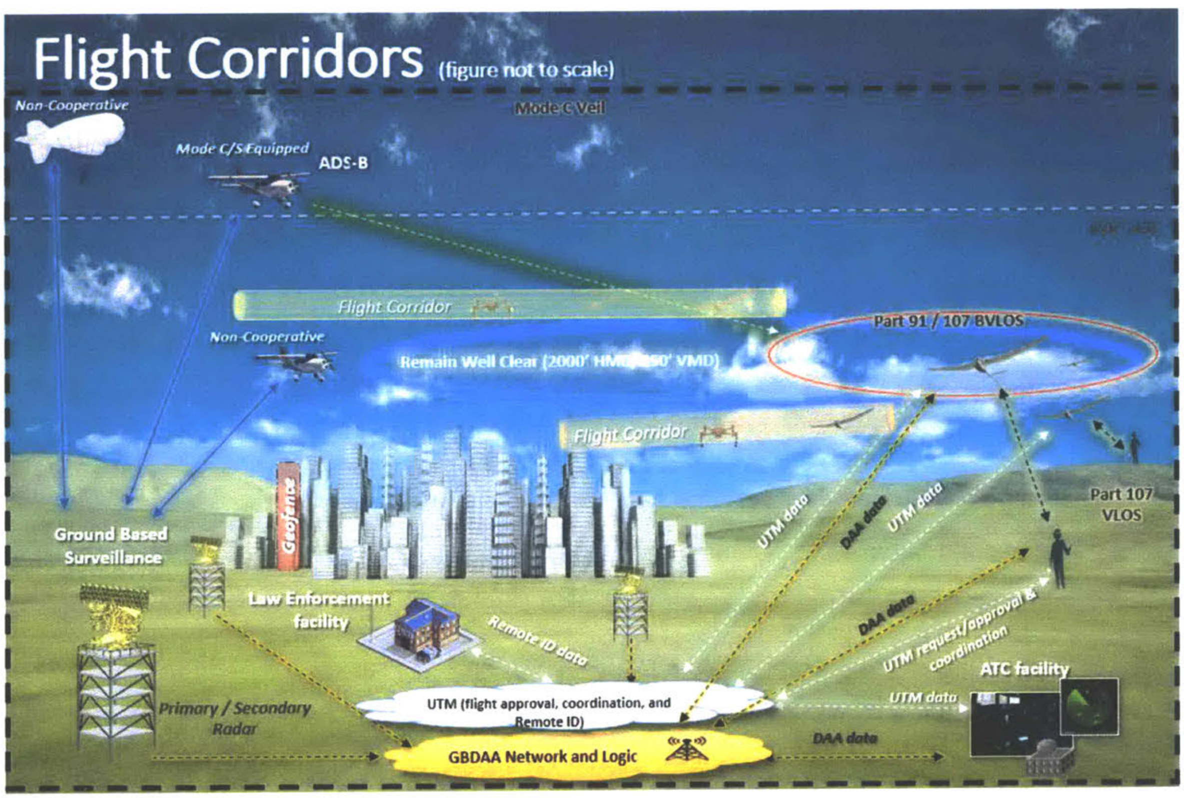

Figure 6-5: Flight Corridors Architecture Concept (adapted) [114, p. 6]

Table 6-4: ARIES Elements for Flight Corridors Architecture

	Architecture 3 – Flight Corridors
Strategy	•Incremental integration •Segregation between sUAS and manned AC •Focus on noise impacts and societal acceptance
Policies	•Adopt sUAS well-clear recommendation •Maintain requirement for DAA obstacles •Require remote identification for all users
Organization	•Elevate UAS Integration Office to consolidate knowledge, expertise, and decision-making •Increased partnerships with industry to promote innovation
Knowledge	•Increased hiring of experts for UAS Integration Office from industry and academia •Performance-based test for sUAS BVLOS users with not fully autonomous systems •Development of MOPS for sUAS, DAA, and C2
Products/Services	•UTM to coordinate/schedule corridor use •DAA via Ground-Based DAA network (subscription) •UTM provides corridor performance requirements •UTM provides "corridor reservation" to user •Remote ID through UTM •Very limited geofencing
Processes	•UTM to coordinate/schedule corridor use •USS approves flights (via UTM) •Deconfliction via GBDAA, corridors, and UTM (manned AC and sUAS) •Minimal necessity for UAS Facility Maps
Information	•UTM coordinates use of flight corridors •DAA commands issued to user via UTM network •Notifications via UTM •Remote ID accessible to LE and public via UTM
Infrastructure	•Transmission of data to UTM via cellular/WiFi (adequate service level required) •UTM network (managed by USS) •Ground-Based DAA sensor network required

6.6.1. Products/Services

The Flight Corridors Architecture's products and services support a structured approach to sUAS operations in urban airspace. The services provided are similar to the other proposed architectures: detect and avoid with manned aircraft, remote identification, sUAS coordination, and data exchange. These services are delivered using different products that contribute to generating different externalities when evaluated against Architectures 1 and 2.

Architecture 3 uses a ground-based DAA system to meet the detect and avoid requirement and comply with 14 CFR 91.113. As discussed in the Independent Flight Architecture, the LSTAR® sensor represents one possible GBDAA non-cooperative sensor that can be paired with ACAS sXu logic to surveil, track, determine threat logic, and alert the remote pilot. This solution has already been certified by the FAA in accordance with DO-178 and can be installed to optimize coverage in an urban area. Because of the process that the Flight Corridor Architecture follows for sUAS operations (fixed corridors), a decreased number of sensors may be required to have adequate DAA [115]. As with Architecture 1 and 2, ACAS sXu logic uses the sensor data to provide sUAS users with commands about required maneuvers upon detection of manned aircraft, and ADS-B In information provides transponder information for cooperative manned aircraft.

An unmanned aerial system traffic management system provides approval, coordination, and scheduling services for flights within defined flight corridors. FAA-approved vendors build and maintain a data exchange network for flight request approval and information sharing. Among the information shared is remote identification information, notifications, and alerts. Unlike the Coordinated Flight Architecture, the Flight Corridors Architecture prescribes routes based on established flight corridors. An sUAS user enters and exits low-altitude airspace at designated entry/exit points. When submitting a flight plan, UTM considers the purpose of the flight (e.g. package delivery, aerial photography, inspection, etc.) and the performance capabilities of the requesting unmanned vehicle. UTM then assigns an appropriate flight corridor, a "corridor reservation," that has a defined airspeed and path (altitude and horizontal pathway). This flight corridor assignment occurs concurrently with the defined UTM flight approval defined in Architecture 2. Flight corridors have set requirements for operations; some corridors permit slow, manual, sUAS flight, while others are designed for faster, autonomous flight. UTM and the flight corridors provide deconfliction and coordination among sUAS to provide structure and decrease the probability of mid-air collisions between sUAS.

The Flight Corridor Architecture has the lowest requirement for geofencing. UTM provides an approved flight plan, and flight corridors require sUAS to operate in designated locations only. Discounting malicious users, sUAS should operate in defined corridors. While geofences around critical locations may be necessary for redundant security measures, UTM easily identifies when users deviate from a flight path and that user will face the appropriate penalty. UASFM also become less significant, as sUAS users now submit flight plans that consider defined corridors rather than varying maximum altitudes throughout an urban area.

6.6.2. Processes

Similar to the Coordinated Flight Architecture, the Flight Corridors Architecture has two critical processes. The first process is corridor reservation and flight approval, and the second is aircraft deconfliction.

The Flight Corridors Architecture is more prescriptive than first two alternative architectures. Prior to the approval of a flight request, UTM considers the mission intent and unmanned aircraft performance capabilities. This generates an assignment to a flight corridor that best matches the flight request. The sUAS user receives a "corridor reservation" that authorizes him/her to operate the aircraft at a specific speed within clearly defined boundaries (location, altitude, time duration). UTM continuously accounts for all approved sUAS within each corridor and manages the traffic density within each corridor to prevent conflicts and mid-air collisions. In the event of a high-priority flight (e.g. medical evacuation), UTM would notify all active sUAS users and have vehicles divert or cease operations to allow for uninhibited operation.

The deconfliction process is similar to the process in the Coordinated Flight Architecture. UTM provides reservations and coordination between sUAS users so as to provide additional safety compared to the Independent Flight Architecture. The specificity of reservations, with specific time, speed, and corridor assignments, is complex to manage and may introduce limitations to sUAS operations (e.g. locations may not be accessible via sUAS). The potential benefits are significant, as flight corridors may be established directly above roadways or buildings, where the effects of a mid-air collision or noise pollution will have limited impact on ground personnel.

6.6.3. Information

Like Architecture 2, information relies on the USS-managed UTM network. sUAS users submit flight requests through UTM, and UTM assigns suitable corridors to each request. Flight approvals and notifications occur through UTM, and UTM provides users with situational awareness about others within their corridor. DAA operates independently of UTM, and the GBDAA sensor network provides DAA commands to users via ground control stations. The UTM network allows for the general public to access and monitor remote identification information, and law enforcement can identify specific users to hold sUAS users accountable.

6.6.4. Infrastructure

The Flight Corridors Architecture has a more substantial architecture requirement compared with the two alternative architectures previously discussed. Similar to the Independent Flight Architecture, a GBDAA system needs to be established. An FAA-approved USS will design, install, and maintain the GBDAA, and the resources required are significant. Like the first two architectures, the Flight Corridors Architecture transmits data via cellular network, so reliable coverage is necessary. If not present, major infrastructure upgrades may be necessary.

Also required for the Flight Corridors Architecture is establishing a UTM network. UTM is the conduit for all information sharing except for DAA commands. Corridor reservations, flight coordination, remote identification, and information sharing all rely on UTM to quickly and accurately accomplish defined tasks. The FAA-approved vendor who develops and maintains UTM needs to ensure critical functions have redundancy and the many possible contingencies have been planned for. Establishing a UTM network that can accomplish the requirements for the Flight Corridors Architecture also requires significant efforts from the USS.

6.7. Alternative Architecture Comparison

Having developed three distinct alternative architectures, this section highlights the characteristics that differentiate them. The intent is to briefly describe major factors that are noteworthy and influential for the evaluation of the architectures. APPENDIX B depicts each architecture in terms of the ARIES elements and serves as a basis to identify changes across the architectures. Rather than compare and contrast individual differences, architectures are described holistically to consider emergent properties.

Architecture 1 (Independent Flight Architecture) has the greatest independence for sUAS operations. After receiving flight request approval, a sUAS user may operate with a high degree of flexibility since there is no explicit coordination among sUAS requests. GBDAA sensors provide alerts to the user in the event a manned aircraft in the proximate airspace, but the user has limited concern about other sUAS operating around his/her aircraft. Users also have limited situational awareness about sUAS operations in the same airspace as their vehicles, and there is the potential for a mid-air collision between sUAS. This possibility of sUAS collisions increases dramatically as the density of sUAS increases because there is no coordination or management of sUAS operations [117, p. 8]. The GBDAA sensor network must be extensive because with independent flight, sUAS users may request to operate anywhere within the Mode C Veil. Obstacles in urban environments require more sensors to be strategically placed to ensure DAA coverage. With independent flight, the societal impact of noise pollution is not addressed beyond requiring higher flight altitudes (limited to 400’ AGL) or manufacturers developing quieter vehicles. Remote identification mitigates some privacy issues, but with limited transparency via

FAA DroneZone, the general public may still fail to fully support sUAS operations. While the architecture requires limited changes to the current enterprise (no coordination/UTM structure, no interaction with manned aircraft) and is relatively straightforward to implement, pending the development of remote identification standards and establishment of a GBDAA network.

Architecture 2 (Coordinated Flight Architecture) provides increased structure and safety for sUAS operations while still providing a degree of independence. An sUAS user submits his/her intended flight path, and UTM considers other operations in or along that desired route. All unmanned aircrafts operating BVLOS have FAA-approved airborne DAA sensors, which allow for increased flexibility in path selection. UTM does not need to account for where GBDAA sensors are positioned when approving flight paths, as all vehicles must have an airborne sensor. The range of airborne sensors needs to increase (from approximately two miles to six miles) to detect high-speed manned aircraft in time to provide commands to the remote PIC. Like Architecture 1, the Coordinated Flight Architecture accounts for manned aircraft via ACAS sXu logic using DAA sensors. However, Architecture 2 also incorporates UTM to coordinate and schedule sUAS flights. UTM procedural separation decreases the potential of mid-air collision between sUAS. Having a UTM network and related products allows for increased transparency and ease of information sharing. Remote identification displays and historical information can be accessed via the public UTM database, and law enforcement has an enhanced version to identify violations. This architecture's scalability is most limited most by the low-altitude airspace constraint of 400' AGL, but that limitation may shift with time and improved technologies. The main reason for the 400' AGL limit is to segregate sUAS from manned aircraft, but the FAA's long-term strategy is to have full integration of UAS and manned aircraft [69]. With the Coordinated Flight Architecture, social acceptability increases. UTM can account for residential areas and public spaces, and, depending on the intent of a flight request, may recommend a flight path that avoids flying over these areas with higher sensitivity to sUAS. This capability decreases both noise pollution and privacy concerns for the general public and increases the willingness to accept sUAS. While Architecture 2 requires a UTM network and USS to establish and maintain the network, impacts on current manned aircraft operations are minimal. All sUAS must remain well-clear of manned aircraft, with sUAS having the responsibility to DAA and resolve any conflicts. Implementability is possible over a five-year time horizon as UTM is being tested and matured, and individual sUAS users become responsible for equipping their vehicles with airborne DAA systems.

Architecture 3 (Flight Corridors Architecture) has many similarities to the Coordinated Flight Architecture and has further structures in place to establish flight corridors for sUAS operations. The Flight Corridors Architecture has increased safety compared to Architecture 1 and 2. The GBDAA sensor network provides a similar capability as Architecture 1 to detect and avoid manned aircraft, and UTM provides procedural separation with other sUAS via scheduling and reservations. Both of these systems contribute to a decreased likelihood of a mid-air collision. By having designated flight corridors synced with roadways and structures, the impact of a mid-air collision is lower, as a recent MITRE study demonstrated that sUAS strikes to people are lethal when humans have no shelter [96, p. 16]. Similar to Architecture 2, this architecture relies on UTM to provide a high level of transparency. The general public may find it even more transparent because the concept of "sUAS roadways" is analogous to terrestrial roadways. Architecture 3 has limits on its scalability, as increasing the number of corridors rapidly increases the number of interactions and possible conflicts between sUAS. The total number of flight corridors must remain relatively low to remain effective. Path selection is most restrictive for this architecture, as the designated flight corridors are assigned based on mission intent and vehicle capability. It is likely that some flight requests are denied or never submitted because they fail to meet the corridor requirements (route or performance capabilities). For many commercial and public users, this may frustrate users and decrease the social acceptability. As with Architectures 1 and 2, the impactability on the NAS for manned aircraft is low, as segregation between manned and unmanned remains in place, and GBDAA sensors ensure sUAS resolve conflicts with manned aircraft and ATC and pilots do not receive any unwanted additional information. The implementability of Architecture 3 is challenging, as it requires major infrastructure both for a UTM network and the installation of a GBDAA sensor network throughout the Mode C Veil. The time and costs associated with both tasks are significant.

6.8. Alternative Architecture Evaluation

After comparing the three alternative architectures that support sUAS operations in urban airspace, the author evaluated the concepts using a Pugh matrix. Considering the fidelity of the architectures and the qualitative nature, the Pugh matrix seemed more appropriate than using a weighted decision matrix or tradespace for evaluation. This tool allows for the alternatives to be evaluated holistically against established criteria (see Section 5.6). A Pugh matrix relies on evaluating alternatives to a reference architecture. For sUAS BVLOS operations in the Mode C Veil, Architecture 1 (Independent Flight Architecture) is the reference architecture with which the other two alternatives are compared. Architecture 1 is chosen as the reference architecture because it is the future architecture that most resembles the current NAS architecture for sUAS operations. Pugh matrices provide some clear benefits in that they allow for the assessment of a holistic architecture with limited quantitative data. However, a Pugh matrix assessment has a significant level subjectivity incorporated into its scoring methodology. The author recognizes this shortcoming of the method employed but feels that the Pugh matrix provides a useful way to capture externalities that may otherwise be overlooked. A second shortcoming is that the Pugh matrix does not assign weights to the evaluation criteria [4, p. 108]. The author acknowledges and intends for the evaluation to serve as a basis for discussion that can further refined with stakeholder input in future work.

Having compared the alternative architectures in Section 6.7, the results are summarized in Table 6-5. While Architectures 2 and 3 receive similar scores in several evaluation criteria, a few key differences emerge. The Coordinated Flight Architecture is most scalable because it coordinates flights throughout low-altitude airspace without being overly structured and limiting the airspace utilized (as in the Flight Corridors Architecture). Initial simulations have shown that a level of coordination is necessary for UAS operations to increase in scale [117]. Under the Independent Flight Architecture, UAS operations would rapidly approach the traffic density thresholds for acceptable safety levels, limiting this architecture's scalability. Implementability is another criterion where the Coordinated Flight Architecture outperforms the other two alternatives. Architectures 1 and 3 require installing a GBDAA sensor network, which consumes substantial resources. Architecture 3 additionally requires the development and implementation of a UTM network. The pairing of both of these tasks make a five-year time horizon very challenging for the Flight Corridors Architecture.

Table 6-5: Evaluation Matrix for Alternative Architectures

	Architecture 1 – Independent Flight	Architecture 2 – Coordinated Flight	Architecture 3 – Flight Corridors
Safety	0	+1	+1
Robustness	0	0	0
Transparency	0	+1	+1
Scalability	0	+1	0
Social Acceptability	0	+1	+1
Impactability	0	0	0
Implementability	0	+1	-1
Total +1 vs. Architecture 1	0	+5	+4
Total -1 vs. Architecture 1	0	0	-1
Total 0 vs. Architecture 1	0	2	3

Performing this analysis led to a few interesting insights based on evaluation criteria. Robustness was selected to measure the ability to withstand disruptions to the enterprise. Three main disruptions would be the reliability of cellular services to transmit data, cybersecurity vulnerabilities, and the behaviors of malicious actors. Cellular services are a constant across all architectures as the primary means to transfer data, so the robustness does not vary. It is difficult to predict how cyber threats may manifest themselves across these alternatives. Rather than speculate on how robust an architecture may be (when considering cybersecurity), all future architectures must fully incorporate cyber security measures. For example, networks should be segmented with access restricted to personnel who require access, and patches and updates should be automatically installed to address identified vulnerabilities [118, pp. 1-3]. In this limited analysis, malicious actors are discounted; future work may consider this disruption, as counter UAS is a research area unto itself. Impactability showed no demonstrable changes across architectures. This is mainly because of the tacit requirement to minimize impacts to manned aviation and ATC. NATCA and ALPA have significant influence with Congress and the FAA.

Any major changes to the duties of ATC or commercial pilots would initiate legal disputes and further slow the integration of unmanned aircraft. As such, all architectures minimize the impact to ATC and manned aviation operations, yielding no difference for impactability across the alternatives.

6.9. Example Operational Concept within Coordinated Flight Architecture

Having evaluated several alternatives for sUAS operation under the Mode C Veil, the logical next step is to describe how a potential use case operates within the recommended architecture. The following seven steps represent how an above-ground railway inspection occurs from the user perspective. While many possible use cases exist (see Section 5.3.3), railway inspections are selected because they clearly benefit from sUAS BVLOS operations and the requirements are straightforward. As mentioned, BNSF Railway is part of the FAA's Pathfinder Program and has received waivers for BVLOS operations for railway inspections. While these inspections have occurred in rural areas with low aircraft density, the natural extension is for railway inspections to occur in both controlled and uncontrolled airspaces. This operational concept includes two steps (Step 1 and 2) that need only occur once per sUAS. They are included to help describe the procedures required for an sUAS railway inspection, even prior to the initial submission of a flight request.

Step 1: Obtain pilot and sUAS certification for airworthiness

Before beginning a flight operation, the sUAS user must obtain certifications, both as a pilot and for the sUAS. The user must complete a written exam to receive the FAA's sUAS Part 107 Remote Pilot Certificate. Additionally, to conduct BVLOS, the user must pass a performance test demonstrating his/her abilities to operate the sUAS in multiple scenarios (degraded communication link, severe weather, emergency incident). Upon successful completion of the performance test, the user obtains a BVLOS rating for his/her Remote Pilot Certificate.

In additional to the user being certified to conduct BVLOS operations, the sUAS must be certified. If the sUAS manufacturer constructs the device to meet all FAA requirements for BVLOS, then the FAA may directly approve that system for BVLOS. The FAA may also approve sub-systems to meet requirements (DAA, remote ID), and if an approved unmanned vehicle is properly equipped with approved sub-systems, the entire sUAS is certified to operate BVLOS.

Step 2: Register sUAS

After acquiring the necessary certifications (pilot and unmanned vehicle), the user will register the sUAS through UTM. Through UTM, the remote pilot registers the sUAS with all required information about both the pilot, the unmanned aircraft device, and sub-systems (if applicable). This registration process gives the user direct feedback to confirm that he/she is authorized to conduct BVLOS operations. If there is a missing requirement (BVLOS rating, approved DAA system, etc.), the registration process will identify it. The sUAS may still be able to conduct limited operations, such as VLOS in uncontrolled airspace. The sUAS is provided a registration number that it transmits to UTM while in operation. This step concludes when remote identification is fully functioning so that all remote identification information is transmitted to UTM during vehicle operation.

Step 3: Submit flight request

Having registered the sUAS, the user now submits a flight request in UTM. The submission includes key information to allow UTM to consider risk level and approve/reject the request. The user submits: sUAS remote identifier, mission intent, vehicle weight, start and stop times, route with waypoints, altitude, and airspeed. The user also submits alternate landing points and routes in the event of degraded operations or emergency situations. The user can submit either through a mobile application or through the UTM site. This mission intent is to conduct railway inspections; however, UTM approval assumes that the payload on the sUAS is capable of this task. UTM does not consider whether the individual unmanned aircraft has adequate capability to capture imagery in its mission assessment, its focus is on risk level and coordination with existing sUAS operations.

Step 4: Obtain flight request approval

Upon receipt of a flight request, the USS authenticates the sUAS registration and remote identification. The USS verifies that the flight request does not violate any constraints (feasibility based on performance characteristics, manned air traffic plans, TFRs, weather constraints, existing sUAS approved missions, total air traffic density in airspace). Considering these variables, UTM assigns a risk rating. If the risk rating is under the established threshold, then the flight may be approved; else, it will be rejected pending adjustment. UTM may recommend alternate routes based on mission urgency, zoning type (residential vs. commercial), and air traffic density. For this railway inspection flight operation, alternate routes are not practical for mission completion, but for package delivery, a circuitous route may slightly increase time but eliminate potential mid-air conflicts [117, p. 4]. The user receives, through UTM, an approval decision on the flight request. If approved, the user may prepare for sUAS railway inspection operations.

Step 5: Conduct pre-flight system tests (UTM connection and DAA sensor)

Once the flight request is approved, the user tests all critical systems. Critical tests include: communication link, airborne DAA sensor, remote identification transmission, and airworthiness of the unmanned aircraft. All tests are run through an application accessible through the GCS, which sends results to UTM. The user is responsible for ensuring all specialty equipment (cameras, data storage, etc.) are functional so that the railway inspection is fruitful. Assuming all tests are positive, UTM gives a confirmation notice to the remote pilot to begin the flight mission at the approved start time and location.

Step 6(a): Conduct approved flight mission (primary)

The user is now clear to execute the approved flight mission. The remote pilot follows his/her approved flight request, making sure to conform to the stated start/stop times and locations, altitude, waypoints, and airspeeds. Throughout the unmanned vehicle flight, the remote pilot continually monitors the GCS for DAA alerts and maintains well clear from any manned aircraft. The remote pilot monitors UTM for situational awareness of other sUAS operations in his/her vehicle's vicinity. UTM provides the user information about the area of operations, such as dynamic constraints. During flight, new TFRs or high-priority operations are communicated to pilot through UTM. Based on the situation, UTM may recommend a reroute of the mission or early termination [80, p. 13]. Depending on the sUAS data storage sub-system, data can be sent back to GCS for in-depth analysis by sUAS operator (or third-party railway inspection firm).

Step 6(b): Operate in degraded status (contingency)

In the event of degraded operations, such as loss of communication link, the immediate response for the unmanned vehicle is to continue programmed flight operation for a short duration until connection is re-established. This time scale is based on the well-clear definition for sUAS, where a mid-air collision is very unlikely to occur within a short time period given initial well-clear status. Large-scale outages (caused by severe weather or malicious actors) may affect cellular coverage, GPS, and airborne DAA sensors [80, p. 9]. If the user regains positive communication with the unmanned aircraft, the user should check UTM for notices on communication outages in the area of operations and follow UTM guidance. If the user does not regain communication with the unmanned aircraft, the sUAS resorts to the pre-set recovery paths and landing points designated in the approved flight request.

Step 6(c): Actions upon incident (emergency)

Emergency operations are reserved for flights by medical or law enforcement vehicles flying at low altitudes (manned or unmanned). In this case, UTM immediately sends a high-priority notice to all active sUAS pilots along/near the intended emergency vehicle route. Remote pilots immediately cease operations and follow the recommended course of action from UTM. The most likely courses are of are: adopt alternate flight path or land at nearest designated point. If it is not possible to land or alter the flight path because of operating conditions, the remote pilot sends a message through UTM. UTM will appropriately alert emergency vehicle(s) that an unmanned vehicle is still in the air to avoid any conflicts or security concerns [89, p. 20].

Step 7: Execute safe landing/complete mission

After completing the flight mission (or terminating early because of contingency/emergency situations) the remote pilot lands the unmanned aircraft. He/she touches down at an established landing point and collects the vehicle. At this point, the remote pilot ends the mission in UTM and logs any mission-specific notes and comments.

6.10. Expert Feedback on Coordinated Flight Architecture

Having developed several architectures and provided a recommendation and an example operational concept, the author sought to validate the work using interviews with subject matter experts. After obtaining approval from the MIT COUHES, he recruited several individuals from MIT Lincoln Laboratory and MIT Department of Aeronautics and Astronautics who have expertise in the aviation industry and aviation surveillance systems. After reviewing the recommended architecture and example operational concept, the author interviewed the SMEs to obtain feedback on the feasibility and major concerns with the proposal. The results of six interviews, each lasting approximately 45 minutes, are summarized. Per the COUHES-approved protocol, all subject information is anonymized.

6.10.1. Summary of Positive Feedback for Coordinated Flight Architecture

Interviewees provided many supportive comments for the Coordinated Flight Architecture, generally approving of the elements and the overall architecture. From a strategy lens, experts noted that the architecture integrates several concepts and technologies that have been considered and successfully tested individually. This architecture was the first that experts have seen that addresses sUAS operations in low altitude airspace with such a holistic view (Subjects C and D). The strategy of incrementally introducing sUAS into the NAS is practical for implementation (Subject D and E). One interviewee elaborated on this incremental implementation, recommending a "crawl, walk, run" strategy in selected test cities with clear milestones before instituting nationwide (Subject E). The three to five-year implementation timeline is not impossible, pending any rulemaking changes needed (Subject B), and it is very feasible pending the FAA establishing clear performance requirements (Subject C). Another positive aspect from a strategic level is that the Coordinate Flight Architecture remains technology agnostic (no specific devices required), which allows for future upgrades and makes the concept easier to scale (Subject A).

From an organizational lens, there was limited feedback on the recommendation to elevate the UAS Integration Office and consolidate some knowledge and expertise at the FAA. One subject believes that putting increased emphasis on the UAS Integration Office may help alleviate some of the approval questions and distributed decision-making that currently affects the office (Subject B). Several interviewees stated that their work and research areas are technical and they have not had noteworthy observations about the organizational culture to make a fair comment (Subjects A, D, and E).

The policy recommendation for an sUAS well-clear definition received support from the SMEs, especially because it has already had some initial validation via modeling and simulation (Subjects A, B, D, and E). While the sUAS well-clear definition is suitable for the proposed scope of this thesis, it also is a robust definition that may be able to extend beyond 400' AGL (Subject A and B). If the Coordinated Flight Architecture was to incorporate corridors or routes for specific cases, the well-clear definition may require exceptions to decrease the 2000' horizontal separation (Subject E).

Employing UTM as a critical aspect of the recommended architecture was generally supported, as it provides a method for coordination and approval that does not require ATC interaction. UTM's role in providing a central database and approval authority is important for sUAS operations to be successful, and over time many aspects of UTM may become automated (Subject F). A UTM-like solution is necessary for cooperative surveillance and information sharing of sUAS, and UTM plays an important part in NAS safety. By providing projected locations for sUAS, UTM provides strategic separation to avoid sUAS to sUAS mid-air collisions (Subject A). While supportive of the UTM concept, one expert noted that UTM is a promising research area for access to the NAS for sUAS, although its implementation will require several years and significant investment (Subject D). By incorporating aspects of the Flight Corridor Architecture, sUAS operations may become more analogous to manned aircraft operations, and lessons learned from ATM may be applied to UTM. Route deviations and malicious actors may be easier to quickly identify (Subject E).

Several subjects highlighted remote identification and its role in allowing sUAS to enter the low altitude urban airspace, especially over people and BVLOS. It was recognized as an important concept that is supported by both industry and government to decrease the misuse of sUAS by remote pilots (Subjects A and F). Although the requirements for remote identification are not yet fully defined, it will likely support law enforcement efforts. The information from remote identification probably will not be linked to DAA efforts (Subject B).

The notion of implementing a performance test for remote pilots was met with some ambivalence, mainly because of the expected increase in automation levels for sUAS. One interviewee said that if a sUAS has a relatively low level of automation, then a performance test may be necessary, but it should be situation dependent (Subject D). Although acknowledging that sUAS automation will likely increase, another expert said a performance test is beneficial to implement, as there is limited downside and it will increase the trust in sUAS operations from the general public (Subject E). A related view was that the performance test should depend on the specific operations executed by the remote pilot (Subject F).

The emphasis that the Coordinated Flight Architecture placed on social acceptability was well received by the SMEs. Having a well-defined architecture that accounts for the safety, security, and privacy will increase confidence in sUAS operations. The general public will be mainly concerned with noise and privacy issues and remain naïve to safety until a major incident occurs (Subject D). Public perception will be mainly event-driven and tied to recent experiences; there will be a very negative reaction if there is an incident, especially death, caused by sUAS. Such an event will trigger increased scrutiny and regulation (Subject B and F). Privacy will be a concern, so the remote identification will help to alleviate the apprehension associated with sUAS (Subject E). Finally, the noise concerns will be a major public concern, but UTM helps to mitigate with the routing of sUAS (Subject C and E). So long as the general public is able to detect value from the addition of sUAS to the NAS, individuals will be far more will to accept the additional risks that emerge (Subject B and C).

6.10.2. Summary of Potential Issues with Coordinated Flight Architecture

The SMEs interviewed identified potential issues with the Coordinated Flight Architecture, focusing mainly on the very high reliability requirements for safety and communication link as well as the urgent need for system and performance requirements. These comments and honest feedback provide areas where the recommended architecture may be improved going forward and identify gaps and concerns that exist throughout the greater sUAS and aviation communities.

Safety was continually brought up by experts, with the major concern being the need to define an acceptable level of safety during sUAS operations (Subjects B, C, D, and F). Research and standards organizations are currently developing risk methodologies, but until the FAA adopts a clear standard, sUAS safety requirements remain an open question. Closely related is whether UTM and DAA systems will be able to achieve the acceptable level of safety, once defined (Subject D). Assuming a well-defined safety requirement is established, one subject has concerns about how scalable the Coordinated Flight Architecture will be while maintaining the acceptable safety level (Subject D). This concern may be addressed with simulations and further analysis. A final safety issue is related to public perception and the number of sUAS operations. The safety standard should yield a low frequency of collisions or incidents, not simply a low probability of occurrence. With a large enough number of sUAS operations, incidents may become relatively frequent and social acceptance may decline (Subject C).

Related to safety is the need for high reliability in the communications link for sUAS operations, which was a common theme across all experts. The urban canyon effect and major events within metropolitan areas may impact cellular services, causing latency issues (Subjects A and C). High reliability is mandatory, and further analysis is necessary (Subject B). Failure in the communication link is a significant risk, and redundancy is important (Subject C). If possible, cellular providers may need to prioritize UTM over consumer voice & data services, in an effort to guarantee reliability (Subject D). Implementing a 5G cellular network as a primary link with an additional system (possibly GPS) may help to provide redundancy (Subjects E and F).

Another universal issue that experts identified was the need for system and performance requirements. The rulemaking process is lengthy and may substantially impact the implementation timeline for sUAS (Subjects B and D). However, clearly defined regulations and certification processes are critical, as are identifying what organization or entity certifies sUAS (Subjects B, C, E, and F). The current lack of performance requirements may be causing some operators and companies to not contribute or innovate within the sUAS space because it is viewed as too risky of an investment (Subjects C and D). As previously mentioned, defining a risk methodology is ongoing, which relates to the process for sUAS airworthiness and certification. A major question exists of whether airworthiness and certification will depend on size, performance, or another characteristic (Subject B).

An airborne-based Detect and Avoid system elicited some negative feedback, mainly because of the tradeoff incurred by adding an additional sensor and power requirement to the unmanned vehicle. Requiring an airborne radar-like sensor introduces SWaP issues for very small UAS (<20 lb), which may decrease commercial viability of sUAS (Subject A and F). Allowing industry to develop a solution for DAA rather than dictating a way forward (Subject A), or allowing a hybrid solution may be more suitable (Subject F). Although the current requirement for DAA per 14 CFR 91.113 is to detect and avoid only manned aircraft, perhaps sUAS to sUAS DAA capability is also necessary to achieve an adequate safety level (Subject E). While the Coordinated Flight Architecture recommends having DAA be integrated with UTM, whether or not to make DAA independent from UTM is a major question across the UAS community (Subject C).

Although the strategy of incrementally expanding sUAS operations in the NAS was well received, one subject disagreed that the segregation of airspace was entirely feasible. He believes that airspace segregation between sUAS and manned aircraft may be difficult to achieve because of new entrants, mainly urban air mobility (UAM) and electric vertical takeoff and landing vehicles (eVTOL) (Subject E). One solution may be to allow hobbyists to operate below 400' AGL and commercial sUAS to operate above 400'AGL with increased safety and performance requirements (Subject E).

Although UTM is recognized as a promising element of a solution to increase sUAS operations, one SME has concerns with the transition from NASA to the FAA for implementation. The formal structure required for a USS to properly manage UTM requires a major capital investment, and the profitability of this endeavor for a USS is not apparent. Additionally, the assumption that all users are compliant and will await approval from UTM before operating sUAS may be unrealistic (Subject B).

6.11. Summary of Recommended Future Architecture

Having developed, compared, and evaluated several architectures, the author recommends the Coordinated Flight Architecture for near-term sUAS operations that extend beyond existing Part 107 regulations. Although requiring increased investment in UTM infrastructure to coordinate and schedule sUAS operations, the recommendation provides a high level of safety, security, and privacy to the general public. These factors are significant in the long-term adoption of sUAS in the NAS, and the architecture considers them from the initial design, rather than add them after operations have commenced. A major tradeoff (as highlighted by the SMEs) is the airborne DAA system, which increases the weight and power requirements to the small unmanned vehicle. However, this requirement avoids the alternative, which requires an additional capital investment of an extensive GBDAA system. There is not a clear consensus on a best DAA system (ground versus airborne), and a hybrid option may ultimately be the best solution. In all scenarios, ACAS sXu logic can provide track correlation, threat logic, and alerting through a standard interface to the remote pilot. Although experts provided much positive feedback about the recommended architecture, a few key concerns emerged for extending sUAS operations: the need for a reliable communications link, clearly defined system and performance requirements, and the ability to maintain a high level of safety. The author acknowledges these concerns and hopes that this work highlights these issues for further discussion and research.

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7. CHAPTER 7: CONCLUSION

As this chapter is the conclusion of this work, it serves to summarize the key findings in a succinct way. The author answers his four research questions based on his research and insights. However, a significant portion of this chapter is dedicated to addressing the limitations and future work required for sUAS operations to expand past the Part 107 rule in urban airspace. The author has developed a recommended architecture that may permit increased sUAS operations, but this recommendation remains far from implementable. It would be naïve and unsafe to move forward with the recommended Coordinated Flight Architecture without thorough testing and vetting from experts across the aviation and UAS industries. The author instead hopes this work serves as motivator and possible way forward for increased sUAS operations in low altitude urban environments.

7.1. Research Questions Addressed

This thesis used the ARIES Framework to develop an architecture for sUAS to operate in the Mode C Veil. Using the ARIES Process to methodically consider the various elements and stages allowed for the research questions posed in Section 1.4 to be addressed in this thesis, with summarized answers below.

OVERALL RESEARCH QUESTION: How can sUAS safely operate within the Mode C Veil considering constraints and externalities while employing mitigation techniques and existing/emerging operational concepts?

Having considered the NAS ecosystem (regulatory, political, economic, societal), key stakeholders, the current architecture for sUAS operations, and the envisioned future, the author developed three feasible architectures for sUAS operations in low-altitude airspace within the Mode C Veil. After evaluating the three architectures, the recommendation is the *Coordinated Flight Architecture.*

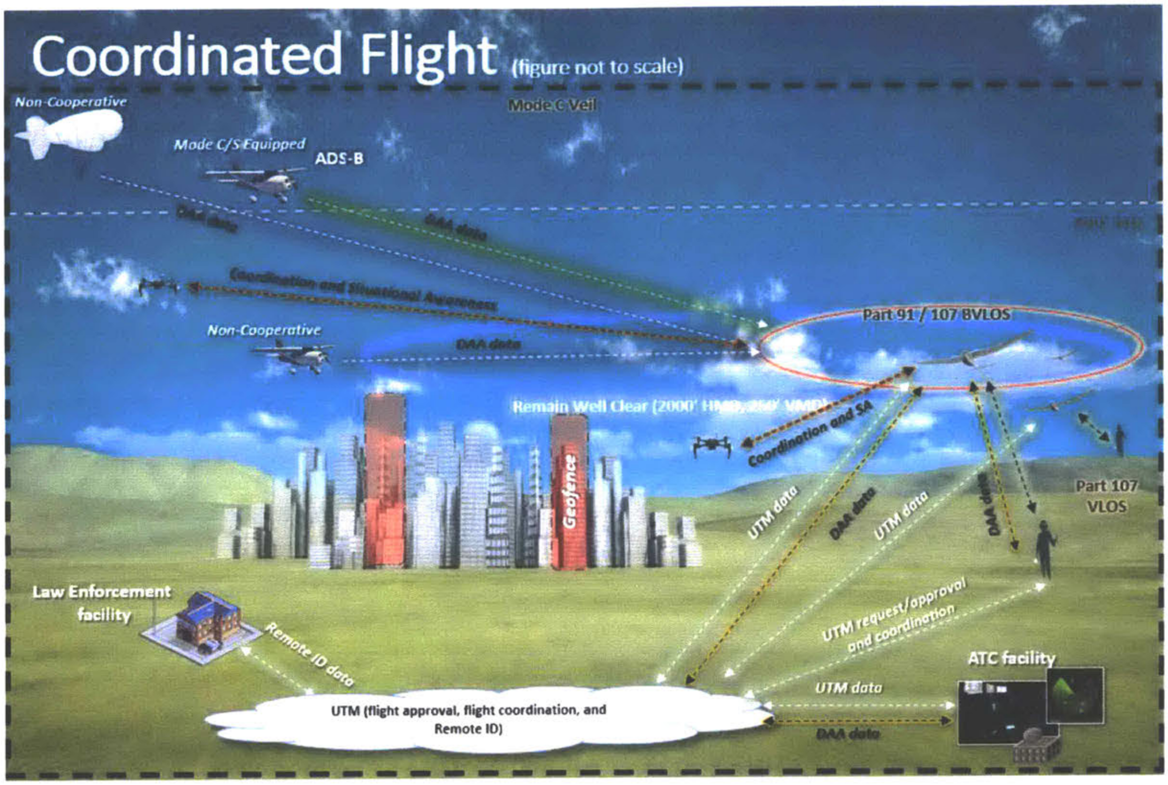

Figure 7-1: Coordinated Flight Architecture (adapted) [114, p. 6]

Coordinated flight supports BVLOS sUAS operations in urban airspace. Individual sUAS users maintain the responsibility for separation from all obstacles; however, for the *Coordinated Flight Architecture*, there is coordination between other unmanned aircraft. DAA is achieved via an airborne-based DAA system on the unmanned vehicle to enable remote PIC to remain well clear of manned aircraft. UTM coordinates sUAS flights, so there is a coordination and scheduling aspect incorporated to sUAS operations. This architecture provides improved coordination and situational awareness and requires additional infrastructure. Figure 7-1 Figure 6-4illustrates the concept for this architecture. A sUAS is able to operate upon receiving UTM approval. Table 7-1 describes the specific ARIES elements that compose the Coordinated Flight Architecture.

Table 7-1: Recommended sUAS Architecture

	Architecture 2 – Coordinated Flight
Strategy	•Incremental integration •Segregation between sUAS and manned AC •Focus on noise impacts and societal acceptance
Policies	•Adopt sUAS well-clear recommendation •Maintain requirement for DAA obstacles •Require remote identification for all users
Organization	•Elevate UAS Integration Office to consolidate knowledge, expertise, and decision-making •Increased partnerships with industry to promote innovation
Knowledge	•Increased hiring of experts for UAS Integration Office from industry and academia •Performance-based test for sUAS BVLOS users with not fully autonomous systems •Development of MOPS for sUAS, DAA, and C2
Products/Services	•UTM to coordinate/schedule individual flights •DAA via airborne sensors using ACAS sXu logic (radar) •UTM provides spatial data and alerts •UTM provides recommended flight path to user •Remote ID through UTM •Limited geofencing
Processes	•USS approves flights (via UTM) •Deconfliction via airborne DAA and UTM (manned AC and sUAS) •Expand/repurpose UAS Facility Maps
Information	•UTM coordinates individual flights •UTM provides situational awareness, spatial data and alerts •DAA commands via airborne sensor •Notifications and UASFM updates via UTM •Remote ID accessible to LE and public via UTM
Infrastructure	•Transmission of data to UTM via cellular/WiFi (adequate service level required) •UTM network (managed by USS)

Key services for this alternative architecture are: airborne-based detect and avoid, UTM to coordinate sUAS flights and exchange data, and limited geofencing to prevent unauthorized operations. The recommended architecture relies upon an airborne-based detect and avoid system to enable BVLOS. The current requirement for compliance with 14 CFR 91.113 is to detect and avoid manned aircraft, which this airborne sensor system accomplishes [116]. The Coordinated Flight Architecture requires an FAA-approved airborne DAA sensor for BVLOS operations.

To have coordinated flight, there is an unmanned aerial system traffic management system that provides approval, coordination, and scheduling services. UTM relies on a USS to establish a data exchange network that enables automated approval of flight requests and shares NAS information (e.g. TFRs, alerts, notifications) to individual sUAS users. After submitting a flight plan, sUAS users receive an approved flight plan from UTM that considers other sUAS operations in the vicinity. The approved flight plan may adjust the proposed flight path or flight times to deconflict with other sUAS operations. This additional level of deconfliction decreases the likelihood of a mid-air collision between sUAS. UTM approval also considers the type of property (residential, commercial, etc.) that the sUAS intends to fly over. To mitigate privacy issues and noise pollution, UTM may approve alternate flight paths that avoid more sensitive properties. With UTM in place, remote identification is possible without a ground sensor network. Upon receiving flight approval via UTM, the ground control station remains connected to UTM. The vehicle transmits the remote identification information back to the GCS, which feeds the information to UTM. UTM stores this data and allow the general public and law enforcement to view relevant information about sUAS operations for transparency and attribution.

Deconfliction between sUAS and other aircraft is a critical process in the Coordinated Flight Architecture. While achieving DAA with manned aircraft is a requirement, UTM also provides the additional benefit of deconfliction with other unmanned aerial vehicles. While unable to have transponders that communicate directly between UAVs because of current spectrum limitations, the UTM approval process provides a level of deconfliction between sUAS. When approving flight plans, UTM not only ensures that sUAS operate within established NAS constraints, but also that multiple sUAS operations do not conflict with each other. This additional process adds an additional layer of safety into the enterprise.

Information-sharing is primarily accomplished via the UTM network. UTM receives individual flight requests and coordinates those flights. UTM also provides the sUAS users with situational awareness about other sUAS operations in the same airspace, as well as any notifications or alerts. The general public and law enforcement have access to UTM to monitor remote identification information, with law enforcement being able to identify specific users. This remote identification information eliminates anonymity and makes sUAS users more accountable for their actions.

The two infrastructure requirements for the Coordinated Flight Architecture are reliable cellular networks and a robust UTM network. Transmitting data is primarily accomplished through cellular networks, so coverage and reliability must be high. For the urban airspace these architectures are considering, the cellular coverage is likely acceptable to enable data transfers between the UAV, ground control station, and UTM network. The UTM network is critical as it allows for flight coordination, remote identification, and information sharing.

CONSTRAINTS: What are the critical technological, operational, regulatory, and environmental factors that may constrain or prevent sUAS in Mode C Veil implementation in the United States?

Several existing constraints affect sUAS operations within the Mode C Veil at the present time. 14 CFR Part 107 is titled "Small Unmanned Aircraft Rule" and regulates sUAS certification and operations. The regulation allows for the increased use of commercial and public sUAS within the NAS, mainly in uncontrolled airspace (Class G). Part 107 directly addresses sUAS operational limitations, pilot certification and responsibilities, and aircraft certification requirements [1].

The operational limitations set forth by Part 107 are straightforward but restrictive for sUAS operations in the NAS. Many publications and organizations summarize the Part 107 rule, which permits daytime operation of sUAS in Class G airspace below 400 feet AGL while remaining within VLOS and not flying over people [58, pp. 4-4].

Though not explicitly stated as constraints, a few principles drive the specific limitations set forth in the Part 107 rule. The principles of command and control and detect and avoid underlie the need to maintain VLOS with the sUAS during all operations. Command and control is the ability to maintain an active communication link between the control station, remote PIC, and the unmanned aircraft. The primary concern with current command and control technology relates to range and continued connectivity. To mitigate this issue, the sUAS must remain within VLOS. By requiring sUAS to remain within VLOS, the remote PIC is able to see-and-avoid any potential hazards. Since a precise definition for sUAS well-clear is still being developed, coupled with the lack of an approved SAA device/technology, the FAA requires VLOS with a ground observer to meet Part 91.113 requirements. This relates to the second principle that grounds the Part 107 rule: safety. The risk of injury to people, in aircraft or on ground, may increase by introducing sUAS into the NAS. To maintain the level of safety for the NAS, Part 107 allows sUAS to operate mainly in uncontrolled Class G airspace, and never over people. While safety may motivate Part 107, it also constrains how entities may employ sUAS for commercial and public purposes. The majority of use cases center around urban and suburban areas. These population centers can fall within some class of controlled airspace. While an authorization process exists, over 50% of FAA-approved authorizations are for Class D and E airspace. The FAA does not publish the percentage of denied requests for operations within Class B and C airspace, where demand from users and operators is likely much higher.

The ability to remotely identify unmanned vehicle is another major constraint. Remote identification eliminates the relative anonymity that current sUAS users have, which helps alleviate security and privacy concerns from the general public. However, this issue has caused significant consternation within the sUAS user community and civil liberty organizations. Allowing law enforcement to quickly identify the unmanned aircraft and its remote PIC increases accountability within the sUAS community and increases transparency to the public.

Certification standards also provide accountability by having standards organizations and the FAA define sUAS airworthiness. Without certification standards it is difficult for DAA systems to provide meaningful alerts or recommended maneuvers because an aircraft may not even be capable of performing the action. Similarly, without established specifications for remote identification, there is no way to standardize this feature for operators and users.

EXTERNATILITES: What externalities may emerge from the increased use of sUAS in the Mode C Veil, what potential impacts may they have on society, and how may they in turn influence sUAS operations?

The societal benefits from sUAS use in urban airspace are significant and additional use cases will emerge as sUAS become more commonplace. There are several benefits that extend beyond economic. One popular concept is the idea that sUAS will replace humans for tasks that fall into the "3 D's." Missions that are overly *dull, dirty,* or *dangerous* will be better accomplished with a sUAS controlled by a remote pilot. Many potential missions combine more than one of these characteristics. One such example is the dull task of collecting data for a land management firm, often done today using a manned helicopter. In an off-nominal scenario (e.g. environmental changes), this task becomes dangerous to the pilot. sUAS are suited for such tasks [108]. Safety benefits extend to many other tasks, from inspections of infrastructure to monitoring natural disasters. sUAS provide the benefit of having humans receive and process information without needing to be physically present.

Society also benefits from the efficiencies gained from sUAS use. Simulations have demonstrated that sUAS averaged 11 minutes faster per package than trucks (38 minutes compared to 27 minutes) and cost 45 cents less per package ($1.72 per package compared to $1.27 per package) [109, p. 11]. These cost and time efficiencies will become more valuable as urbanization and congestion continue to increase across the globe. Once BVLOS becomes a reality, sUAS will replace manned aircraft and satellites for many tasks. The lower altitude of sUAS operations will improve the resolution when collecting data. Implementing BVLOS sUAS for electric utilities inspections would be between four to twelve times more cost effective than manned helicopters (depending on several cost uncertainties), and this cost reduction does not factor in the safety benefits or improved quality of data [68]. Increased sUAS use will shift employment opportunities from performing the dull, dirty, and dangerous, to performing sUAS-related services, such as operations, maintenance, data analysis, and software development. While these efficiencies and benefits have not all been fully quantified (e.g. safety benefits for firms), they will be clear and transparent to the general public.

Societal costs are the negative externalities that emerge with the increase of a product or service. With the current architecture sUAS operations are relatively limited, so these sUAS negative externalities have little impact on the general public. However, expanded sUAS use may intensify the issues if a recommended future architecture does not adequately address them. The major social issues can be classified into four groups: safety, security, privacy, and noise pollution.

Safety is a major concern to the general public when considering sUAS use. Academic studies and the news media have many accounts of near mid-air collisions between manned aircraft and sUAS. Many sUAS users have limited tools providing situational awareness of aviation operations, leading to safety risks. Research about sUAS safety has demonstrated that for ground-based personnel, sUAS weighing more than two kilograms (4.4 lb) are most likely fatal without shelter or protection. "Population density is the single overwhelming driver of risk for sUAS flight over people," which underscores the need to have robust command and control links and shared information [96, p. 16]. By ensuring proper airworthiness standards, having robust communications systems, sharing relevant information, and having DAA systems, sUAS safety for the general public will be greatly enhanced.

Another societal cost is security degradation from sUAS integration. Malicious actors may intentionally employ sUAS as a weapon, either by directly controlling them, or by exploiting a security vulnerability. Steps to decrease the likelihood are available. Geofencing and restricted flight zones may be emplaced over critical facilities, and robust cybersecurity measures can minimize cyber exploitation. More advanced counter UAS measures and regulations will emerge to defend against malicious actors and limit any issues to the general public.

Protection of data and privacy is a third societal cost that emerges from increased sUAS use. The general public has concerns about both government and private entities misusing sUAS to collect data and invade their privacy. While no formal regulations exist protecting the public's privacy from intrusive sUAS users, sUAS users are educated and provided an industry-developed "Voluntary Best Practices for UAS Privacy, Transparency, and Accountability" document. While civil liberty unions will advocate for privacy, state and local law enforcement remain empowered to enforce privacy laws, even relating to sUAS abuse of privacy [26, p. 3]. If a transparent sUAS network allows law enforcement to observe operations, it may be able to identify sUAS users who violate individuals' privacy and take appropriate legal action.

Noise pollution is another externality that imposes a societal cost. sUAS in urban airspace will operate close to the public, especially for take-off and landing, and the noise pollution generated must be considered. The public has protested airline routes that produce excessive noise pollution over residential areas, causing airlines to re-route and impacting departure rates [95, p. 218]. Simulations have sought to model large-scale sUAS operations in urban areas, and preliminary results are that noise levels are relatively low (55 dB) when sUAS are operating between 150 and 250 ft AGL [112, p. 4]. While this noise level is comparable to light traffic in a suburban area, it does not account for public perception of the added noise pollution [113]. sUAS manufacturers may reduce the noise generated by the aircraft (technological solution). Alternatively, sUAS users may operate aircraft in operating modes that produce less noise (e.g. slower speeds), or emit noise in locations further from bystanders (operational solutions) [95, p. 219]. The willingness of the general public to accept noise pollution is closely tied to the level of benefit gained from sUAS.

MITIGATIONS: What technology or policy options are being considered in both the near and far-term to mitigate or resolve the constraints and negative externalities of sUAS in the Mode C Veil implementation?

Detect and avoid is a policy that relies on emerging technologies. While architectures may utilize different products/services and processes to achieve separation, all sUAS must detect and avoid other manned aircraft (both cooperative and non-cooperative). DAA requires more than evasive maneuvers to avoid a mid-air collision, and DAA solutions must evaluate flight paths for oncoming traffic, determine right-of-way, and maneuver to re-establish well-clear [32, pp. 21-22].

While the policy to detect and avoid is constant, alternate ways to achieve this requirement emerge in products/services and processes. The two major types of DAA systems are ground-based and airborne-based. Ground-based DAA utilizes a network of ground sensors that detect manned aircrafts, which enables the remote PIC to remain well-clear. In urban airspace with many obstacles (buildings, bridges, etc.) several GBDAA systems would need to be installed, but compliance with 14 CFR 91.113 (see and avoid) is feasible, even in degraded conditions (low-visibility/nighttime) [115]. Airborne DAA systems have been tested and shown to be successful; however, additional power and equipage requirements for a sUAS limit the vehicle's payload.

Another policy that seeks to mitigate the safety impacts of sUAS operations is defining well-clear. MIT Lincoln Laboratory has developed a robust well-clear recommendation for sUAS considering unmitigated collision risk. Maintaining well-clear allows sUAS to avoid having to take any collision avoidance action [30]. Interestingly, sUAS collision risk was not sensitive to different performance characteristics (cruise airspeed, max airspeed, climb/descend rate), allowing for a "hockey-puck" definition based only on horizontal and vertical separation criteria and not temporal criterion. The recommendation for sUAS is a horizontal separation of 2000' and vertical separation of 250' between a sUAS and any aircraft (manned or unmanned). Based on airspeed limitations of sUAS (slow vertical rate changes), even a low-performance sUAS can resolve an encounter and re-establish well-clear separation in sufficient time to avoid concern (less than 10 seconds) [30]. Based on the compelling simulation and modeling results and analysis, this sUAS well-clear definition applies to all alternative architectures.

Remote identification becomes more critical as sUAS operate BVLOS. The concerns of sUAS violating individual privacy and security significantly motivates the need for remote identification. The FAA may require manufacturers to emplace remote identifiers that must be activated before a new sUAS may operate. Remote identification instills an increased level of accountability for the sUAS user. Although useful to law enforcement, technology limitations make it infeasible to have a requirement that the remote identification system also identify the real-time location of the remote PIC. However, armed with the device registration and user information, law enforcement may be able to rapidly locate violators.

7.2. Limitations and Future Work

Looking at any enterprise in a holistic manner requires some level of abstraction as well as simplifying assumptions. The author attempted to justify these decisions throughout his analysis and identify areas that require further work. Similarly, several aspects of the research were limited to allow the author to further explore the entire enterprise and all ARIES elements, rather than focusing exclusively on a few select topic areas. Below are the main limitations for this work that represent potential future work to advance sUAS integration.

7.2.1. Develop an Implementation Plan

The final step for the ARIES Process is "Develop an Implementation Plan." This work does not address how the NAS enterprise should build a plan to institute the recommended architecture. This is done intentionally as the recommendation requires additional evaluation and detailed design before it is ready for implementation. Key stakeholders need to voice their concerns and willingness to support such an architecture for sUAS within the Mode C Veil. Several other areas of future work (listed below) must be completed before a meaningful implementation plan can be developed. Until a decision is made on the architecture for sUAS operations, implementation should remain on hold.

7.2.2. Considerations for Malicious Users

This work discounts how malicious users may affect the NAS with sUAS. Two major types of malicious users exist: those who seek to knowingly violate sUAS regulations to commit crimes or harm people and/or property, and those who seek to infiltrate the UTM network or user database to disrupt operations or illegally obtain data. Approaches to uphold the integrity and confidentiality of UAS and related data while limiting the availability are continuing to evolve [107]. Cyber security needs to remain a high priority as attacks can manifest themselves in both the physical and informational domains. Future work may incorporate the rapidly growing field of counter UAS, which has clear technology and policy impacts. Counter UAS may also be incorporated into future modeling and simulation efforts, rather than assume all sUAS users will attempt to follow established guidelines and procedures.

7.2.3. Simulation and Modeling Analysis

The author compared alternative architectures mainly based on existing literature and expert opinion. However, additional quantitative work would help to strengthen the justification for a specific architecture to become the final recommendation. Robust simulation and modeling of the NAS is critical to analyze the validity of concepts and identify additional gaps. This requires significant effort because of the wide variety of sUAS types and performance capabilities. Simulations would need to assign the many diverse use cases to sUAS to capture how the vehicles would operate. Simulations inherently rely on assumptions, so deciding what may be assumed for sUAS user abilities, communication reliability, etc. is difficult because existing data for BVLOS and sUAS operations in urban airspace is relatively limited. The benefits from modeling and simulating sUAS operations would be invaluable to final decision-making.

7.2.4. Evaluation Criteria Weighting

During the evaluation of alternative architectures, the author employed a Pugh matrix that assigns equal weights to the seven evaluation criteria (safety, robustness, transparency, scalability, social acceptability, impactability, and implementability). To increase the fidelity of the evaluation process, the criteria may be weighted to indicate importance to the key stakeholders. For example, safety would likely be weighted more than transparency. In order to incorporate weighting into the evaluation process, additional input would need to be elicited from stakeholders. Invariably, some weights will conflict and a solution will have to account for differing views on evaluation criteria. Having greater input from stakeholders, especially in architecture development and evaluation would improve the final recommended architecture and increase their buy-in.

7.2.5. Financial Impacts and Analysis

Financial impacts and analysis are based on expert projections and represent the growth of sUAS within the NAS. These estimates do not incorporate how a specific sUAS architecture would affect financial benefits and costs. It is possible that UTM could limit the total number of sUAS permitted to operate at a specific point in time to ensure the safety of ground personnel or to avoid mid-air collisions. These types of scenarios are not included in the financial projections that are currently published by many organizations. Such limitations may decrease the financial benefits to commercial operators. Financial models and projections need to incorporate how sUAS will be allowed to operate to realistically capture financial benefits. This may influence the final decision for a sUAS architecture.

7.2.6. Standards Development

Although there is a clear need for standards for unmanned aircraft, sub-systems, and pilots, the author did not propose any such standards. Many organizations (led by NIST) are currently developing MOPS for unmanned aircraft, DAA systems, and command and control systems. This work is highly technical and relies on significant research and testing; however, there is urgency to have established standards in place before sUAS may expand their operations. Regardless of the alternative architecture selected, having established performance standards is essential to providing guidelines and structure to the rapidly expanding sUAS community. MOPS provide established targets for manufacturers to meet as well as inform future testing and simulation work with clear baselines. The FAA, NASA, and many standards organizations and academic institutions are working to develop MOPS, which better defines the sUAS future.

7.3. Final Thoughts

Looking to the future, sUAS may provide significant benefits for public use, commercial operations, and the general public. Before society can realize many of these benefits, changes are necessary in the current NAS architecture to accommodate and integrate sUAS. This work highlighted several clear needs that enable sUAS to operate in the Mode C Veil safely. Any future architecture requires a DAA system, remote identification capability, robust command and control links, and standards for the sUAS system. Developing feasible alternatives for sUAS operations must address these issues to enable widespread BVLOS and extend beyond the current Part 107 sUAS rule.

The ARIES Framework emphasized that any recommendation for sUAS integration requires changes in many domains and that this problem set should be considered through several distinct lenses. While a solution may exist for a specific issue, the ramifications of that decision must be considered for the various stakeholders and across different elements. An interesting observation was that regardless of the alternative architecture considered, a few elements remained consistent. The FAA's strategy of incrementally integrating sUAS into the NAS allows for more immediate increased sUAS operations when compared with awaiting future technologies, processes, and policies to be fully in place. This strategy provides incentive to industry to develop innovative solutions while maintaining safe operations. Organizationally, the FAA should consider elevating the importance and level of the UAS Integration Office. With UAS positioned to increase in both number and capability moving forward, the UAS Integration Office should consolidate the FAA's knowledge, expertise, and decision-making for all UAS-related issues to increase the pace of decision-making and improve communication. Finally, expert knowledge to develop clear standards is essential to providing structure to the rapidly expanding sUAS community and supports both ongoing testing and future operations.

The externalities that emerge from increased sUAS operation and expansion must be fully incorporated in the future architecture design; they cannot merely be acknowledged post hoc. Gaining social acceptance for sUAS operations at low altitudes is challenging because of concerns regarding safety, security, privacy, transparency, and noise pollution; however, gaining public support is essential for long-term success. A recommended architecture needs to adequately address these concerns prior to implementation, as the initial way forward will have an outsized effect on how the NAS integrates sUAS in the future.

APPENDIX A – COUHES APPROVAL

MIT Committee On the Use of Humans as Experimental Subjects

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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To:	Raymond Vetter
From:	Leigh Firn, Chair COUHES
Date:	09/20/2018
Committee Action:	**Exemption Granted**
Committee Action Date:	09/20/2018
COUHES Protocol #:	1809521105
Study Title:	sUAS Integration into the Mode C Veil Using a Systems Approach

The above-referenced protocol is considered exempt after review by the Committee on the Use of Humans as Experimental Subjects pursuant to Federal regulations, 45 CFR Part 46.101(b)(2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

If the research involves collaboration with another institution, then the research cannot commence until COUHES receives written notification of approval from the collaborating institution's IRB.

Unless informed consent is waived by the IRB, use only the most recent, IRB approved and stamped copies of the consent form(s).

Adverse Events: Any serious or unexpected adverse event must be reported to COUHES within 48 hours. All other adverse events should be reported in writing within 10 working days.

Amendments: Any changes to the protocol, including changes in experimental design, equipment, personnel or funding, must be approved by COUHES before they can be initiated, except when necessary to eliminate apparent immediate hazards to the subject.

Human subjects training is required for all study personnel and must be updated every 3 years.

You must maintain a research file for at least 3 years after completion of the study. This file should include all correspondence with COUHES, original signed consent forms, and study data.

APPENDIX B – ALTERNATIVE GENERATION TABLE

	Architecture 1 – Independent Flight	Architecture 2 – Coordinated Flight	Architecture 3 – Flight Corridors
Strategy	• Incremental integration • Segregation between sUAS and manned AC • Focus on noise impact/societal acceptance	• Incremental integration • Segregation between sUAS and manned AC • Focus on noise impact/societal acceptance	• Incremental integration • Segregation between sUAS and manned AC • Focus on noise impact/societal acceptance
Policy	• Adopt sUAS well-clear recommendation • Maintain requirement for DAA obstacles • Require remote identification for all users	• Adopt sUAS well-clear recommendation • Maintain requirement for DAA obstacles • Require remote identification for all users	• Adopt sUAS well-clear recommendation • Maintain requirement for DAA obstacles • Require remote identification for all users
Organization	• Elevate UAS Integration Office to consolidate knowledge, expertise, and decision-making • Increased partnerships with industry to promote innovation	• Elevate UAS Integration Office to consolidate knowledge, expertise, and decision-making • Increased partnerships with industry to promote innovation	• Elevate UAS Integration Office to consolidate knowledge, expertise, and decision-making • Increased partnerships with industry to promote innovation
Knowledge	• Increased hiring of experts for UAS Integration Office from industry and academia • Performance-based test for sUAS BVLOS users with not fully autonomous systems • Development of MOPS for sUAS, DAA and C2	• Increased hiring of experts for UAS Integration Office from industry and academia • Performance-based test for sUAS BVLOS users with not fully autonomous systems • Development of MOPS for sUAS, DAA and C2	• Increased hiring of experts for UAS Integration Office from industry and academia • Performance-based test for sUAS BVLOS users with not fully autonomous systems • Development of MOPS for sUAS, DAA and C2
Products/Services	• DAA via Ground-Based DAA sensor network • Remote ID registration through FAA DroneZone (transmit via cellular & Bluetooth/WiFi) • Extensive geofencing	• UTM to coordinate/schedule individual flights • DAA via airborne sensors using ACAS sXu logic (radar) • UTM provides spatial data and alerts • UTM provides recommended flight path to user • Remote ID through UTM • Limited geofencing	• UTM to coordinate/schedule corridor use • DAA via Ground-Based DAA network (subscription) • UTM provides corridor performance requirements • UTM provides "corridor reservation" to user • Remote ID through UTM • Very limited geofencing
Processes	• Authorization through DroneZone • Waivers through DroneZone < 24 hrs • DAA commands issued to user via DAA network • All notifications through DroneZone to user (email/text) • Expand/repurpose UAS Facility Maps	• USS approves flights (via UTM) • Deconfliction via airborne DAA and UTM (manned AC and sUAS) • Expand/repurpose UAS Facility Maps	• UTM to coordinate/schedule corridor use • USS approves flights (via UTM) • Deconfliction via GBDAA, corridors, and UTM (manned AC and sUAS) • Minimal necessity for UAS Facility Maps
Information	• No coordination between aircraft (before/during flight) • DAA commands issued to user via DAA network • sUAS continually transmits remote ID to GBDAA sensors • All notifications through DroneZone to user • Remote ID accessible to LE	• UTM coordinates individual flights • UTM provides situational awareness, spatial data and alerts • DAA commands via airborne sensor • Notifications and UASFM updates via UTM • Remote ID accessible to LE and public via UTM	• UTM coordinates use of flight corridors • DAA commands issued to user via UTM network • Notifications via UTM • Remote ID accessible to LE and public via UTM
Infrastructure	• Transmission of data via cellular/WiFi (adequate service level required) • Ground-Based DAA sensor and data network required	• Transmission of data to UTM via cellular/WiFi (adequate service level required) • UTM network (managed by USS)	• Transmission of data to UTM via cellular/WiFi (adequate service level required) • UTM network (managed by USS) • Ground-Based DAA sensor network required

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