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UNITED STATES AIR FORCE APPLICATIONS OF UNMANNED AERIAL SYSTEMS (UAS): A DELPHI STUDY TO EXAMINE CURRENT AND FUTURE UAS AUTONOMOUS MISSION CAPABILITIES

THESIS

Alberto Sigala, Captain, USAF

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DEPARTMENT OF THE AIR FORCE

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AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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UNITED STATES AIR FORCE APPLICATIONS OF UNMANNED AERIAL SYSTEMS (UAS): A DELPHI STUDY TO EXAMINE CURRENT AND FUTURE UAS AUTONOMOUS MISSION CAPABILITIES

THESIS

Presented to the Faculty

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering and Management

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Abstract

Over the past two decades, the Department of Defense (DoD) has experienced a growing demand and reliance upon Unmanned Aerial Systems (UAS) to perform a broad spectrum of military applications to include Intelligence, Surveillance and Reconnaissance and Strike and Attack missions among many others. As UAS technology matures and capabilities expand, especially with regard to the ability to execute operations with increased autonomy, acquisition professionals and operational decision makers must determine how best to incorporate advanced capabilities into existing and emerging mission areas. Toward this end, the DoD has published multiple *Unmanned Systems Integrated Roadmaps* (USIRs) with the purpose of establishing a "technological vision for the next 25 years." Additionally, each military branch has published similar roadmaps highlighting the evolving role of autonomous systems (U.S. Army, 2010), (USMC, 2015), (USAF AF/A2CU, 2016), (USIR, 2011). However, these roadmaps do not provide practical applications for how autonomy could or should be incorporated into UAS platforms designed to fulfill future DoD mission areas. Therefore, this research builds on the concept of the aforementioned publications with the perspective of describing UAS capabilities within the context of autonomy as they may be implemented in future USAF military missions.

This research study employed the Delphi method to forecast future UAS mission areas over the next 20 years, especially with regard to increasing capabilities for UASs to perform such missions autonomously. The Delphi technique has been applied in many similar fields, but has specifically had notable success in forecasting how technology development might affect military operations (Linstone & Turoff, 2002). The Delphi technique used subject matter experts (SME) sourced from the USAF communities' professionals performing day-to-day operations,

acquisitions, and research of UAS technologies. The study used two rounds of questions to provide insight into which future capabilities the UAS community views as most important and likely to be incorporated into military mission areas as well as how different UAS communities view the challenges and opportunities autonomy presents for military missions.

"Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after the changes occur."

~ Giulio Douhet

This thesis is dedicated to my wife and children who inspire me every day.

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This thesis would not be possible without the guidance, instruction and support of the Air Force Institute of Technology faculty and staff. I would like to thank my advisor, Dr. Brent Langhals, for his guidance and direction through the thesis process. I would also like to thank the members of the Big Data team for their encouragement and support.

Alberto Sigala

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UNITED STATES AIR FORCE APPLICATIONS OF UNMANNED AERIAL SYSTEMS (UAS): A DELPHI STUDY TO EXAMINE CURRENT AND FUTURE UAS AUTONOMOUS MISSION CAPABILITIES

I. Introduction

A majority of military unmanned aerial systems (UAS) are currently remotely or tele-operated by pilots on the ground in a human-in-the-loop (HITL) construct or with a pilot at the controls with little autonomous functionality. However, the Department of Defense (DoD) and other 25-year roadmaps envision increased levels of autonomous UAS capabilities with advances in technology and predict an increased reliance on UAS in military missions. The roadmaps, along with near-peer competitor pressure, globally available technology, and the commercial industry advancing autonomous technology motivate an investigation into how autonomy in UAS may expand within the military mission application space.

A variety of publications (articles, journals, papers, websites, etc.) can be found in the research community toward advancing autonomous UAS capabilities (Ditzler, Hariri, & Akoglu, 2017; Straub, 2016; Van Hien, Van He, & Diem, 2018; Zema, Natalizio, Ruggeri, Poss, & Molinaro, 2016). Enabling autonomous system capabilities in UAS and other unmanned systems cover a range of interrelated efforts addressing software complexity issues, creating common autonomous system architectures, data-centric solution efforts, developmental and operational test and evaluation (ODT&E) certification processes, and human-system collaboration and man-machine-unmanned teaming (MUM-T), etc. Other key development areas, such as artificial intelligence (AI), machine learning (ML) and 'smart' sensors, also play a vital role in realizing an array of advanced autonomous UAS capabilities. While many of these areas are still developing, technology forecasting techniques are one tool to help military leaders reassess the potential direction of future capabilities, enabling decision makers to adapt requirements and close capability gaps as warfighters seek to employ more autonomous UAS in complex and uncertain environments.

Better Business Practices 3.0 (BBP3.0), Joint Capabilities Integration and Development Systems (JCIDS) and other key acquisition supporting processes, such as the Software Development Life Cycle (SDLC), emphasize the need for including stakeholder inputs early in the planning process for describing objectives, capabilities, and user needs. This research identifies stakeholder inputs from key UAS specialty fields. UAS stakeholders come from members in program offices, academia, the pilot community, policy makers, industry, etc. Their perspective on future autonomous UAS mission areas and challenges may help planners and developers anticipate where investments should be made, where systemic barriers may exist, and how to better realize the benefits of autonomy in UAS. Ultimately, when decision makers have an idea about the direction UAS missions and autonomy are likely heading (based on stakeholder inputs) planners can better describe CONOPS, specify user needs, and translate user inputs into system requirements while also helping to reduce technical and safety risk. The earlier this is done, the stronger of a foundation future programs will have and the more cost effective UAS systems will be in the long run.

The implications of properly describing, defining, assessing, and projecting autonomy are far reaching. It is difficult to predict how advances in all of the associated areas of autonomous enabling technology will impact the role of UAS in military settings, but gaining an appreciation of how key stakeholders understand and view challenges for current and future applications of UAS can help us better plan and understand how increased autonomous capabilities may be used in the near future.

1.1 Background

The Air Force has evolved from using UAS during the Vietnam era as target drones for training interceptor pilots, to fitting them with cameras for use as reconnaissance tools; from acting as a decoy for manned aircraft with jamming technologies to protect against surface-to-air missiles, to the eventual first UAS combat engagement in Afghanistan with a Predator Hellfire missile in 2001 (Arkin, 2009). Since the early 2000s, UAS have evolved to become a key warfare asset not only for U.S. Forces, but for global allies and adversaries as well. Once driven and dominated by the DoD, the field of UAS technology has seen a surge in commercial and global competitor driven markets. This increased development activity brings the DoD closer to more advanced implementations of autonomous UAS, such as manned aircraft teaming with near-full autonomous UAS, perhaps in contested environments, or swarms of UAS supporting ground troops with precision close air support (CAS). The possibilities are as endless as one can imagine. Reaching the right balance of autonomous UAS capabilities requires dedicating resources in an increasingly constrained budgetary and manning environment.

This research will look at autonomy as it applies to military UAS and will attempt to identify where research and acquisition efforts should be directed for future development. While other roadmaps and flight plans focus on aggressive 25-year visions, this study takes a closer look at how stakeholder's expectations about autonomy in UAS may play a role in predicting future mission capabilities for a 20-year timeframe.

1.2 Motivation

Over the last two decades, developments in UAS technology have enhanced warfighter capabilities and have become an integral part in joint military operations (Norton, 2016). Developments in every aspect of UAS technology continue at a rapid pace, fueled by competition in defense, commercial, and global markets. From a global perspective, countries who have acquired armed UAS has grown from two countries (the US and UK) in 2008, to at least twenty-eight in 2018; ten countries have reportedly used them in combat ("Who Has What: Countries with Armed Drones," 2018). Outside the DoD, the UAS sector growth is predicted to continue to rise and was described as "the most dynamic growth sector of the world aerospace industry this decade." (Finnegan, 2016) US military research and development (R&D) is estimated to account for roughly 64% of total worldwide spending (not accounting for classified UAS development) over the next decade (Finnegan, 2016).

As figure 1.1 depicts, an increase in funding toward unmanned systems by branch as well as overall DoD funding toward unmanned systems and robotics acquisitions and research, development, testing and evaluation (RDT&E) has increased since at least 2017. The right hand side of the figure clearly indicates UAS as the largest funded portion of the unmanned systems budget. Another military UAS forecast estimates that by FY27, the procurement and RDT&E budget for UAS will increase to $13 billion from $9.6 billion (FY18) (Finnegan, 2016). As funding for platform procurement winds down, increased funding will go toward developing key technology areas to enable future mission capabilities. The specific targeted areas of research will be largely dependent on what adversary capabilities are as well as user needs as defined by key stakeholders in the UAS community.

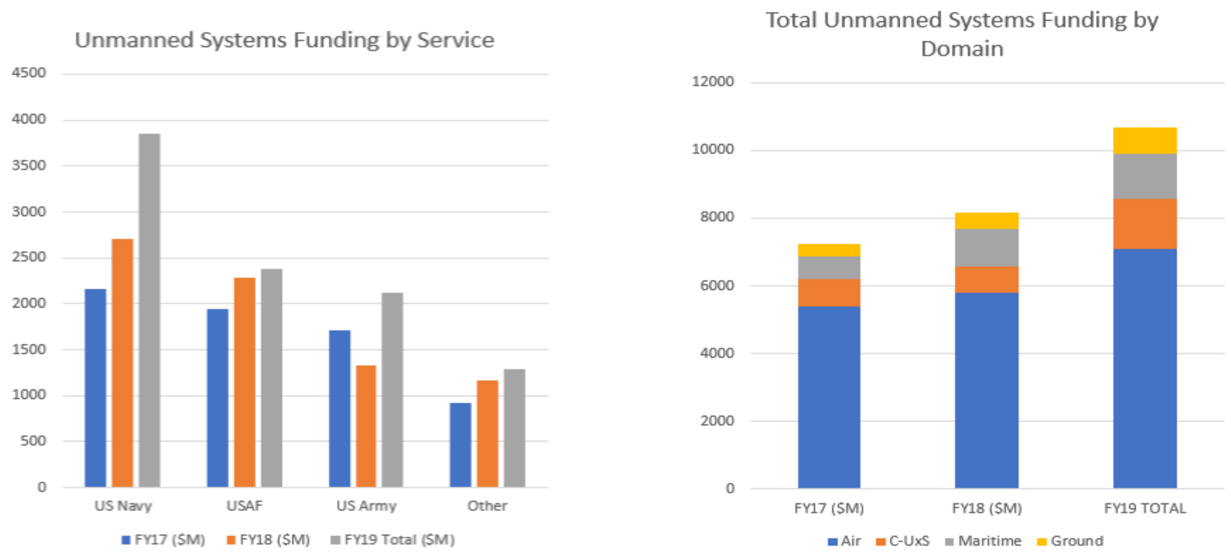


Figure 1. 1 Estimated FY2019 DoD Budget for Unmanned Systems Acquisitions & RDT&E

(Klein, 2018)

Figure 1.2, taken from the 2017-2042 USIR, indicates a broad range of organizations currently using UAS. The expanding role of UAS is evident as is the number of programs to handle the growing expectations for UAS support. Increased autonomy and increased interoperability have been and continue to be common goals among the individual branches, but more so in the Joint environment. The emphasis on autonomy further underpins the motivation for exploring the stakeholder perspective on how far autonomy will grow in terms of current and future mission capabilities.

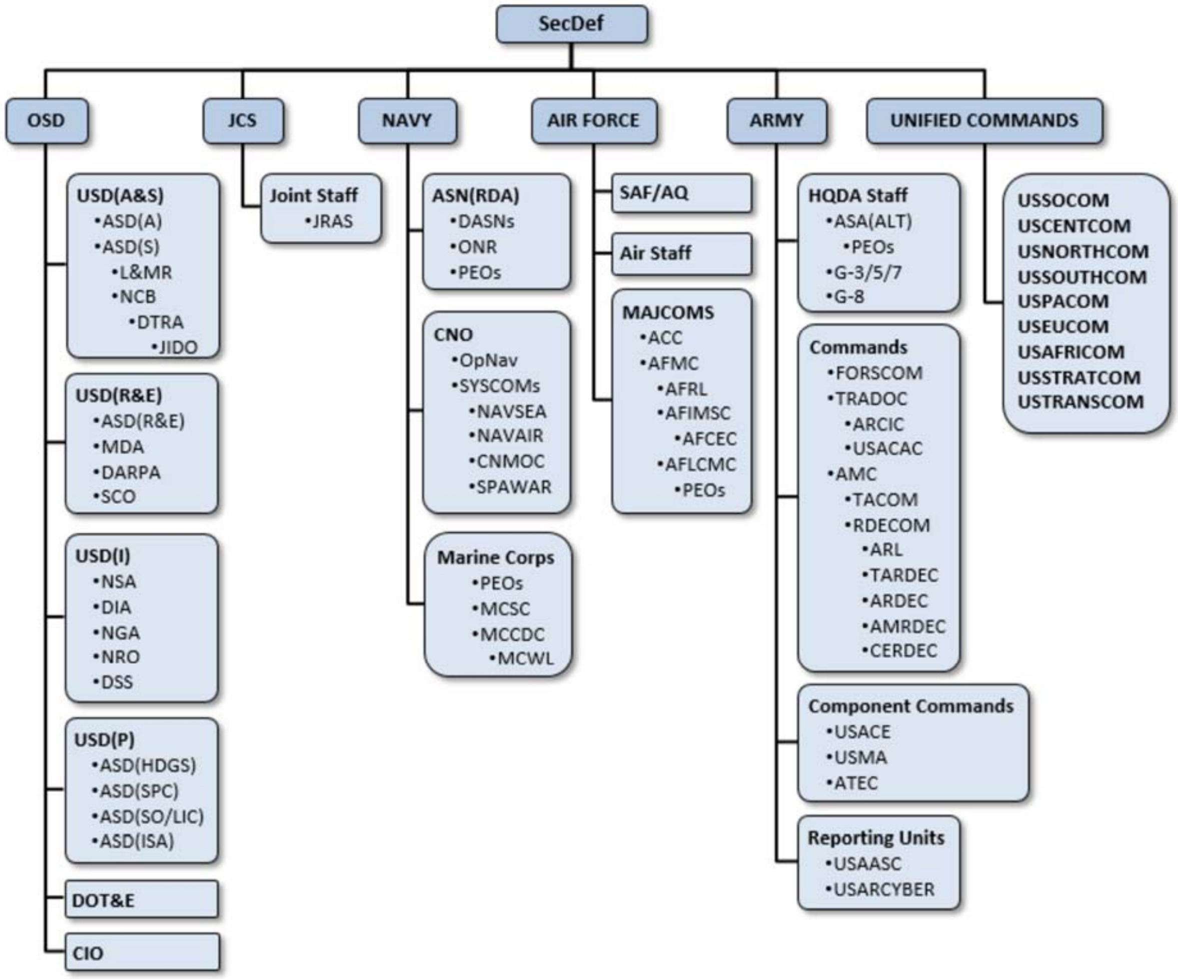


Figure 1. 2 DoD Organizations that Involve Unmanned Systems (DoD USIR 2017-2042, 2016)

While this research focuses primarily on USAF stakeholders, current and future mission capabilities often support the joint environment. Across the Armed Forces, missions are sometimes described in terms of supporting or enabling Joint doctrine functions: “related capabilities and activities grouped together to help Joint Force Commanders (JFCs) integrate, synchronize, and direct joint operations.” (US Department of Defense, 2011) These functions are command and control (C2), intelligence, fires, movement and maneuver, protection, and sustainment. Below,

Table 4.1, Common UAS Applications, covers the range of specific functions across the military in general and then by specific branch of service. The range of missions listed below is not comprehensive, but broad enough to give the reader an idea of the payload, sensors, and software combinations possible for a variety of mission needs. Add to this the various UAS platform options capable of carrying out a given mission and the complexity of describing each mission in terms of autonomy becomes more difficult.

It is evident that the rapid growth UAS capabilities has nearly unlimited potential, but the rapid growth also requires frequent assessments in order to anticipate and better dedicate resources based on the warfighter's needs. It should also be clear that the gap between the U.S. and our adversaries is not secure in an era where complex advanced systems will become widely and more readily available. Although funding appears to be available for technology and program development, resources must be managed responsibly and according to user needs. The breadth and diversity of technology and systems involved in forecasting UAS autonomous potential seems daunting to say the least. Approaching the subject from a broad perspective with input from experts who plan, implement, research, and develop UAS undoubtedly lends useful insights to the direction of potential future applications for UAS with increased autonomous capabilities.

Table 1. 1 Common UAS Applications

General Military UAS Application
• Intelligence, Surveillance and Reconnaissance (ISR) • Reconnaissance Surveillance and Target Acquisition (RSTA) • Surveillance using Synthetic Aperture Radar (SAR) • Deception Operations • Maritime Operations (Naval Fire Support, Over-the-Horizon Targeting, Ship Classification) • Electronic Warfare (EW) and SIGINT (SIGnals INTelligence) • Meteorology Missions • Route and Landing Reconnaissance Support • Adjustment of Indirect Fire and Close Air Support (CAS) • Battle Damage Assessment (BDA) • Radio and Data Relay • Nuclear Cloud Surveillance

Application by Type of Mission	Application by Military Branch
• Special Operations - Insert Route Reconnaissance - Landing Zone Imagery - Target Imagery - Force Protection - Confirmation/Denial • Point Reconnaissance - Road Intersection - Assembly Area - Attack Positions - Communication and/or Headquarter Sites - Airfields - Railroad Switch Points • Cued Surveillance - Road/Rail Network - Topography Support - Crew Served Weapons - Troop Movements - Survey Friendly Sites - Search and Rescue • Target Acquisition - Target Location - GPS Grid Coordinates Provision - Sensor to Shooter Link - Air Support Control - Indirect Fire Control - Track Cued Targets - Battle Damage Assessment • Weapons Delivery	**Navy** • Shadowing Enemy Fleets • Decoying Missiles by the Emission of Artificial Signatures • Electronic Intelligence • Relaying Radio Signals • Protection of Ports from Offshore Attack • Placement and Monitoring of Sonar Buoys **Army** • Reconnaissance • Surveillance of Enemy Activity • Monitoring of Nuclear, Biological or Chemical (NBC) Contamination • Electronic Intelligence • Target Designation and Monitoring • Location and Destruction of Land Mines **Air Force** • Long-Range, High-Altitude Surveillance • Radar System Jamming and Destruction • Electronic Intelligence • Airfield/Base Security • Airfield Damage Assessment • Elimination of Unexploded Bombs

1.3 Problem Statement

Although multiple roadmaps have been published by DoD entities about future UAS applications, there appears to be a lack of information about stakeholder's views, understanding, priorities and estimates about autonomy in future UAS missions and capabilities. As decision makers plan, strategize and make R&D investments in UAS technology to meet planned capabilities, it's important to understand the diverse perspective from stakeholder groups in the community. To understand stakeholder perspectives autonomy within the UAS context, this research employed a Delphi study. The Delphi technique uses subject matter experts (SMEs) to predict or estimate the probability of occurrence for various technological breakthroughs as well as probabilities about timeframes about such breakthroughs through an iterative questioning process while attempting to arrive at a consensus. The selected SMEs possessed UAS backgrounds from the remotely piloted aircraft (RPA) pilot community, acquisitions program offices, and academia. Even with the speculative nature of these types of forecasts, through the process of making predictions about future technologies, valuable information can be gathered to support funding and pursuing R&D when faced with competing programs and initiatives. This work looks at a 20-year forecast for the future of UAS missions with autonomous capabilities from the perspective of acquisition professionals, academia, and RPA pilot SMEs. Furthermore, it gives insight into how SMEs from each group perceive autonomy in current and future UAS missions as well associated challenges in meeting those UAS capabilities.

1.4 Research Objective

The first objective of this research is to apply a qualitative research method to gain insight about how current stakeholder’s interpretations of *autonomy* effects predictions about future UAS mission capabilities. Secondly, while the DoD plans for increased autonomous capabilities, how do stakeholder groups view challenges to reaching future autonomous capabilities.

1.5 Research Questions

The research questions investigated the above research objectives to help identify which missions may be most suitable for future autonomous UAS applications and what challenges should be considered to reaching the those missions. The questions asked will be in general as follow:

1. What missions does the USAF currently assig to UAS?
    a. What level of autonomy would SMEs (from specific backgrounds) assign current missions?
2. What mission could and/or should military UAS perform in 20 years?
    a. What level of autonomy would SMEs assign to future missions?
3. What data or information would be needed to perform missions identified in question 2.
4. How does the perception of autonomous capability influence which future mission capabilities to pursue?

1.6 Scope

This thesis focused on the opinions and expertise of SMEs in the area of unclassified, USAF UAS. The extent of this study did not explore details of software applications, specific components or detailed architectures. Neither was the coverage or descriptions of autonomy intended to apply to other military autonomous platforms such as so-called unmanned ground vehicles (UGV) or unmanned maritime vehicles (UMV). While the DoD would certainly benefit from the implications of interoperability, flexibility, and unmanned teaming for a common multi-unmanned system, the research herein was focused primarily on USAF UAS autonomy. One other scope component worth noting and repeating in this study is the number and range of participants that were able to contribute. Finally, this study is qualitative in nature, with no quantitative or statistical analysis provided.

1.7 Assumptions

For the purposes of this research, responses from each subgroup of SMEs are assumed to be representative of the larger community. Further studies could be conducted with a similar makeup of SMEs to verify this assumption was correct.

1.8 Limitations

While the Delphi study has been used successfully in the past to provide estimated probabilities of technological breakthroughs as well as time frames with probabilities for accomplishing tech driven capabilities, in the context and scope of this research, the method used a limited number of SMEs, rounds, and time frame not conducive to an emphasis on statistical results. Still, the results could serve as a starting point for a larger group of participants or for other quantitative work. Additionally, the estimates about levels of autonomy for future missions are intended to give insight into how SMEs view the direction of autonomous technology in UAS as opposed to concrete recommendations about which challenges or technologies to tackle.

1.9 Summary

This chapter presented an introduction to the growing research and development area of autonomy in UAS. It briefly discussed the value and practice of including key stakeholders for supporting decision makers and procurement decisions. In the motivation section, evidence for the growing use of UAS and autonomous technology was presented in terms of global ally and adversary procurement, increased DoD budgets and forecasts for future RDT&E in UAS, and the various DoD organizations who use UAS, as well as a brief overview of current missions. The problem statement and research objectives were introduced as broadly determining future UAS autonomous mission areas. The Delphi study was described as the 20-year forecast method used to address the research questions.

The remainder of the document is organized in the following order: Chapter 2, Literature Review, covers an overview of UAS types, autonomy terms, and UAS related technology necessary to have an informed discussion over future-potential autonomous UAS applications. Chapter 3 discusses the Delphi technique and logic for selecting it as the methodology for forecasting future capabilities. It also covers criteria for SME and outlines the process and approach for gathering relevant data from SMEs. Chapter 4, the Results and Analysis section provides a summary of the responses provided during the study and categorizes future mission areas as well as challenges by SME subgroups. Finally, in Chapter 5, a discussion and conclusions on the findings are provided in terms of characterization of SME groups, areas of consensus and recommendations for future UAS autonomous mission areas as well as recommendations for addressing identified challenges. Lastly, as part of Chapter 5, a section on the limitations of the Delphi study and future recommended areas for further research are made.

II. Literature Review

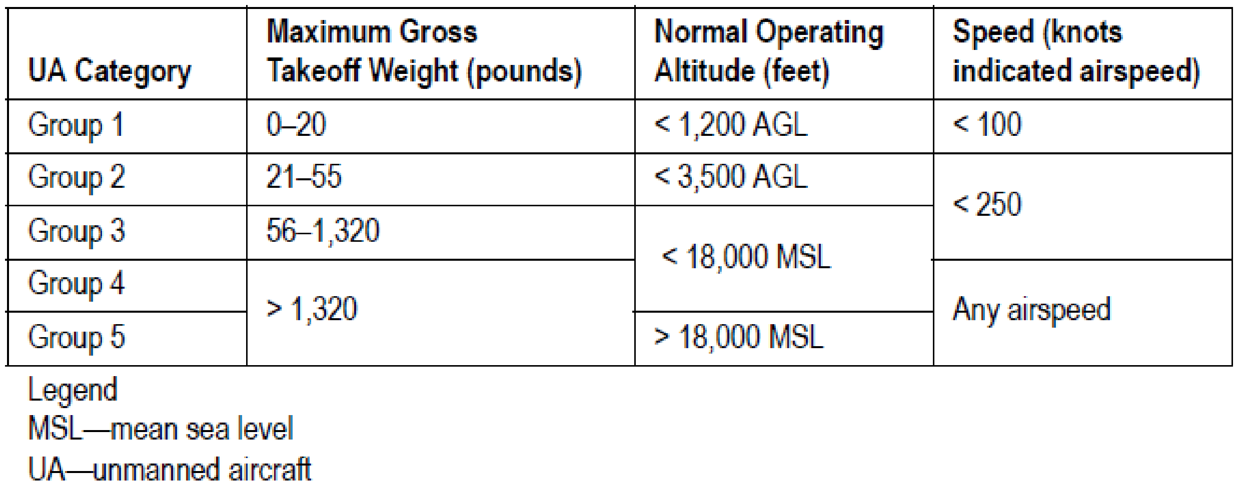
2.0 General Overview

An overview of key UAS concepts, terms, and technologies are necessary to have an informed discussion about future-potential autonomous UAS military applications. This section will define UAS and some common UAS terminology. Next, under the heading of Autonomous Systems, autonomy will be defined, and a central reference guide will be presented for describing autonomy. Following autonomy, other general, but important UAS factors such as sensors and communication and networking will be presented as considerations to the overall autonomous system domain. Typical uses of UAS are discussed beyond the traditional mission applications presented earlier in Chapter 1, such as combat UAS, human-machine teaming, and UAS swarms. With this foundation, potential future mission types may be better anticipated in a forecasting study (both real and hypothetical).

2.1 The General UAS

The topic of UAS technology is replete with hundreds of thousands of results appearing under various combinations of UAS, military, and autonomous systems when searched in a Scopus database. The history of UAS goes back as far as the history of military aircraft (Newcome, 2004). References to unmanned aircraft are made when discussing the first use of kites, hot air balloons used in the aerial bombardment of Venice in 1849 and the American Civil War, as well as many, albeit unsuccessful examples of their use in WWI and WWII (Watts et al., 2012). Today, UAS have come to encompass autonomous or remotely piloted aircraft, mimicking the maneuvers of a human-piloted aircraft, but without a pilot onboard. The military has evolved from simply recognizing the potential for UAS in supporting warfare efforts for traditional so called ”three-D” (i.e. dull, dirty, or dangerous) missions, to an ever increasing role in all military domains as can be noted in various DoD and individual military branch 25-year roadmaps (U.S. Army, 2010), ("U.S. DoD USIR 2013-2038," 2013). One key technology area that is increasing the military UAS application space is that of autonomy and increasing levels of autonomous capabilities. Visions of future capabilities are being discussed without fully defining or understanding what autonomous systems are, what the limitations are, or the associated complexities and costs of planning and integrating them into the military. Before discussing autonomy and future capabilities, a brief overview of the general UAS is necessary.

UAS aircraft are typically fixed-wing or rotary and can be remote controlled or can fly in some autonomous capacity based on pre-programmed flight plans or more complex, dynamic automation systems. A general UAS is comprised of the unmanned aircraft, C2 link/data link, the Ground Control Station (GCS), and the human element (Gupta, Ghonge, & Jawandhiya, 2013). The DoD categorizes UAS into five Groups as described in Figure 2.1 (where UAS is described as unmanned aircraft (UA)) based on weight, operating altitude, and airspeed. The Air Force defines Groups 1 through 3 in Figure 2.1 as small unmanned aircraft systems (sUAS) and Groups 4 and 5 as RPAs (DoD USIR 2017-2042, 2016). Group 5 includes UAS such as the USAF MQ-9 Reaper. The MQ-1 Predator falls under Group 4, while most sUAS, mostly RQ-11s fall under Group 1. These "groups" are based exclusively on characteristics of the aircraft itself without regard for the remainder of the system. Factors such as size, endurance levels, avionics and payload determine operating characteristics and mission capabilities.



UA Category	Maximum Gross Takeoff Weight (pounds)	Normal Operating Altitude (feet)	Speed (knots indicated airspeed)
Group 1	0–20	< 1,200 AGL	< 100
Group 2	21–55	< 3,500 AGL	< 250
Group 3	56–1,320	< 18,000 MSL	
Group 4	> 1,320		Any airspeed
Group 5		> 18,000 MSL	

Legend
MSL—mean sea level
UA—unmanned aircraft

Figure 2. 1 Unmanned Aircraft Group Categories (USMC, 2015)

2.2 UAS Terms and Definitions

UAS, often interchangeably referred to as an Unmanned Aircraft Systems, is a "system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft" (Williams & Scharre, 1997). This definition while broad, encompasses the wide array of UAS categories or groups and is easily applied in a general sense to the overarching concept of the UAS. Small UAS is used only when referring to a specific subset of UAS; in general, the blanket use of "UAS" is used when referring to all UAS (UAS Pilots Code, 2018). For the Air Force, as mentioned previously, Groups 1-3 contain sUAS. This work however, does not distinguish between specific application of on particular group of UAS, rather, it aims to broadly cover how UAS may be used in the future. When considering the multidisciplinary field of UAS, many other terms and acronyms were found to have minimal to no distinguishable variances in definition. The most common military use for UAS are: UAV, drones, robot, and RPA or Remotely

Piloted Aircraft Systems (RPAS) (Williams & Scharre, 1997), (Cooke, Rowe, Bennett, & Joralmon, 2016), (Norton, 2016), (Gupta et al., 2013). In general, and for this research, wherever a distinguishable concept for the UAS must be made, Figure 2.2 should give the reader a point of reference for the UAS term's definition. The figure below lists a brief, but non-exhaustive range of terms found when referencing UAS during the literature review (Williams & Scharre, 1997), (Cooke et al., 2016), (Norton, 2016), (Gupta et al., 2013).

Term	**Acronym**	**Description**
Unmanned Aerial System	UAS	The entire system of systems that allows the aircraft to fly and perform its mission, including the GCS, telemetry, communication and navigation equipment, payloads.
Unmanned Aircraft System	UAS	
Uninhabited Air Vehicle	UAV	The air vehicle, sometimes referred to as an unmanned aircraft.
Unmanned Aerial Vehicle	UAV	
Unmanned Aircraft	UA	
Remotely Piloted Aircraft	RPA	UA controlled by a trained pilot; this term primarily used by the USAF to denote UA.
RPA Systems	RPAS	A term to indicate the complete UAS, including the pilot/human element.
Drones		Generic terms for any automated robot or machinery, but often used to refer to 'UAVs'
Unmanned Autonomous Robot		

Figure 2. 2 Commonly Used Terms for Referring to UAS

A "robot" refers to a machine capable of sensing its environment and reacting to it through independent decision making capabilities (Laster, 2014). This implies some interaction with its surroundings but does not require the machine to be mobile or intelligent. Drone is also a commonly used term for military UAS in addition to the broader use of the term in the commercial, civil, and hobby sectors. Definitions for drone vary widely, ranging from some by critics of the term claiming that drone can imply minimal effectiveness and control, to the "popular press" application of the term where it often implies (incorrectly) drones as being fully autonomous with intelligent decision-making capabilities (Cooke et al., 2016). A more specific definition of drone is “a machine that performs a preprogrammed task with or without human interaction. A true drone does not make independent decisions, although it may appear to do so to the outside observer.” (Laster, 2014) Typically, when this narrower description of drone is equipped with sensors, it enables remote operation or supervision by a distant operator.

Whereas robot is less used in the military and defense industry and drone tends to be used more frequently for referencing military UAS, the term RPA is becoming a term more specific to small, medium and large UAS. The USAF has recently adopted the term Remotely Piloted Aircraft, with *remotely piloted* replacing *unmanned* (Cooke et al., 2016). This change in terminology is due to a number of criticisms to other more commonly used terms, the predominately criticized term being UAV: 1) UAV is problematic since the majority of these systems are not ‘unmanned’ but instead remotely piloted or operated, and 2) UAVs are most commonly considered in the context of encompassing multiple people and supporting technologies, which together comprise a system.

To the previously made point, the RPA is part of an overall system. In many communities the use of the ‘S’ in RPAS appears to more appropriately encompass the entire RPAS (Cooke et al., 2016). The use of ‘piloted’ in RPA also works to address two issues related to the more general terms of UAS or UAV: 1) As UAS are further integrated and with more autonomy into military operations, using the word ‘unmanned’ may have the effect of dehumanizing the role of UAS which in turn may exacerbate trust, confidence, safety and political perceptions that can be problematic for decision makers (Wagner, 2014). 2) Increased manning demands for UAS have resulted in some cultural tensions among the military aviator community with regard to the title of pilot when referring to RPA versus manned aircraft; the change from UAV to RPA in the military may be an acknowledgement to RPA pilots for their contribution and role in bringing UAS capabilities to the warfighter (Cooke et al., 2016). This cultural tension has been cited as stemming from the shorter training period for RPA pilots to acquire pilot status and between what "deployment" entails for RPA versus manned aircraft pilots and the perceived or real associated mission pace (Cooke et al., 2016).

2.3 Functions of the UAS

Earlier, the UAS was presented in broad terms as being comprised of the unmanned aircraft, C2 link/data link, GCS, and the human element (Gupta et al., 2013). These elements enable to the aircraft to navigate, communicate, and accomplish controlled flight much the same as a manned aircraft, but with a suite of software and sensors that allow the UAS to operate without an onboard pilot. Embedded logic and rules within the autopilot typically include safety, compliance, self-monitoring system health, and contingency functionality. Beyond the components that comprise the UAS, the overall system is intended to fulfill various mission capabilities to support specific Joint functions. Joint doctrine articulates seven basic Joint functions as the "related capabilities and activities grouped together to help JFCs integrate, synchronize, and direct joint operations" (US Department of Defense, 2011). The functions for UAS support C2, information, intelligence, fires, movement and maneuver, protection, and sustainment.

2.4 Autonomous Systems

With respect to the UAS, autonomous capabilities encompass the technologies that enable unmanned flight and autonomous behavior in the absence of an onboard pilot (OASD(R&E), 2012). The 2012 DoD Defense Science Board (DSB) defines an autonomous system as one that is able to independently compose and adjudicate among a set of possible actions to accomplish goals based on its knowledge and understanding of the world and itself, and able to adapt to dynamic contexts in its environment (Defense Science Board, 2012). Alternatively, NATO recommends replacing the wide ranging definition of autonomous system with the more specific *system with autonomous functions* (Williams & Scharre, 1997).

When we discuss a system as autonomous, it would be more accurate to discuss autonomy with respect to specific tasks or behaviors. In the next section, autonomy is discussed further, but for initially describing autonomous systems, it should be understood that autonomy is a capability (or a set of capabilities) that enables actions of a system to be automatic or within programed boundaries, “self-governing” (Defense Science Board, 2012). That is to say, an autonomous UAS may have autonomous landing capabilities, it may be able to autonomously perform air-to-air refueling, or it may be able to coordinate among other UAS in a swarm construct to determine which UAS is best suited to perform a particular task. When a system is described as being autonomous, it is not described as being fully autonomous with respect to all tasks. All autonomous systems a currently supervised by human operators at some level with limited software enabled capabilities, actions, or decisions delegated to the system (Defense Science Board, 2012). The particulars of autonomy in UAS is the subject of the next section. First, a DoD accepted definition of autonomous systems is presented in order to show that there are additional layers to describe autonomous systems.

The DoD-sponsored 2012 Autonomy Research Pilot Initiative (ARPI) defined autonomous systems as follows (OASD(R&E), 2012):

> Systems which have a set of intelligence-based capabilities that allow them to respond within a bounded domain to situations that were not preprogrammed or anticipated in the design (i.e., decision-based responses) for operations in unstructured, dynamic, uncertain, and adversarial environments. Autonomous systems have a degree of self-governance and self-directed behavior and must be adaptive to and/or learn from an ever-changing environment (with the human's proxy for decisions).

This definition of an autonomous system is general enough to apply to the case of an UAS, but it does not describe the system in any detail with regard to levels of complexity, environment, or human interaction. To refine the general definitions of autonomy within autonomous systems, we direct our attention to DoD directives, DoD roadmaps, and a NIST framework for describing contextually based autonomous systems.

2.5 Autonomy Defined

Further examination of the ARPI definition will help the reader navigate the varying degrees and categories used to describe autonomous systems. Use of the term autonomy found during this literature review revealed the multi-disciplinary and sometimes muddled application of the definition for describing autonomous capabilities. For instance, Bruemer uses the term dynamic autonomy while Barynov and Hexmoor use preference autonomy, choice autonomy and decision autonomy (Huang, 2007). Comprehensive works on autonomy point to the problem of there being no universally agreed upon definition of "autonomy" (Ilachinski, 2017). The problem of describing autonomy extends to attempting to assign levels of autonomy as well. The DSB Task Force Report: The Role of Autonomy in DoD Systems recommends replacing levels of autonomy with an autonomous systems reference framework (Defense Science Board, 2012). However, there continues to be efforts to describe autonomy in both contexts of a framework and general levels. For this work, levels are used to gauge the expected increase in autonomous capability rather than define autonomy at a granular level.

Conventionally, autonomy levels have been considered to be inversely proportional to the degree which human interaction is necessary; this degree is often described in terms of Human Independence (HI) (Huang et al., 2007). A framework for describing autonomy from the National Institute of Standards and Technology (NIST) adds two additional factors: complexity of mission the UAS is capable of performing and the difficulty of environment in which the UAS performs its mission (Huang, 2007). NATO has also adopted this framework and describes autonomous systems development in terms of three key attributes (Williams & Scharre, 1997):

1) Human-machine command-and-control (C2) relationship

2) Sophistication of the machine’s decision making

3) Type of decision or function being automated

Two common models for NIST's Autonomy Levels for Unmanned Systems (AFLUS) are depicted in Figure 2.3. ALFUS Framework is sometimes referred to as the Contextual Autonomous Capability Model.

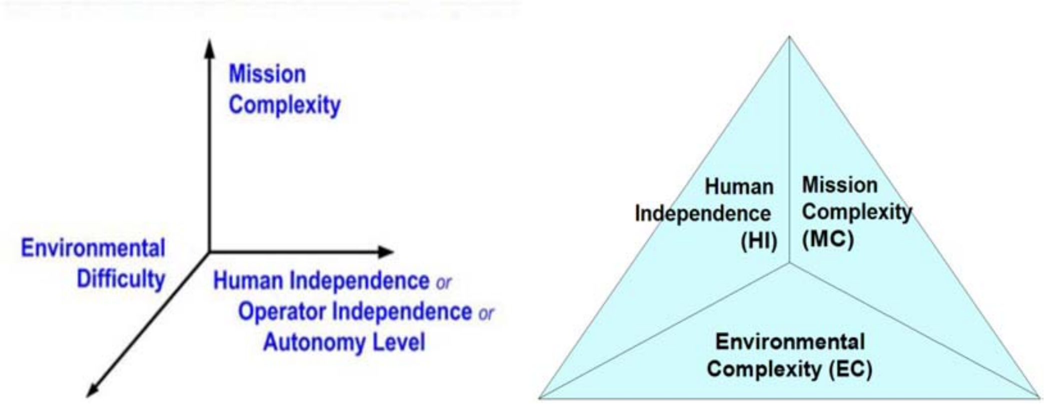


Figure 2. 3 AFLUS Contextual Autonomous Capability Model (Huang, 2007)

NIST's AFLUS levels are described in terms of the requirements on human interactions, the types of tasks, the teaming of the unmanned system and the humans, and the operating environment. They present a set of definitions and a model with which the autonomous capability of a system can be described. With the model and definitions described, NIST proposes practitioners can analyze capabilities of civilian and military autonomous system requirements and evaluate their performance (Huang, 2007). NIST claims that the framework (or model) is relevant as a tool to help form and articulate requirements, testing, and plans.

The NIST ALFUS further presents a capability model illustration depicting the varying degree of autonomy as seen below in Figure 2.4:

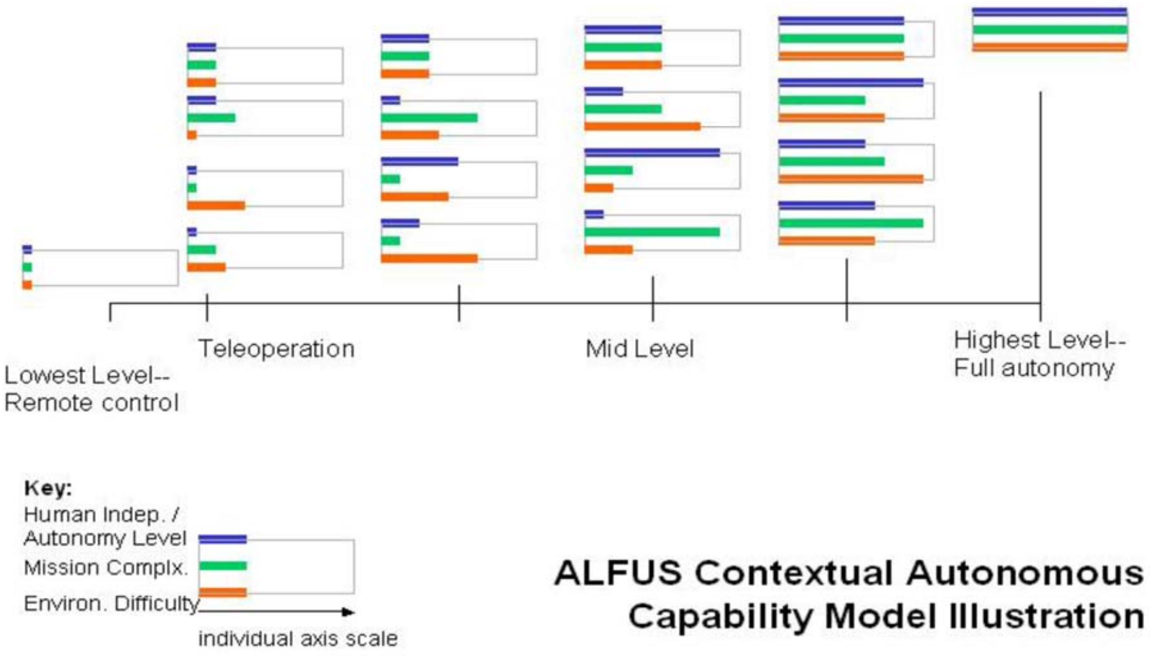


Figure 2. 4 ALFUS Contextual Autonomous Capability Model Illustration

The *DoD Directive 3000.09, Autonomy in Weapon Systems*, defines autonomy in three categories by taking into account the degree to which a human is involved in the performance of an autonomous system. The Directive establishes DoD policy and assigns responsibility for the development and use of autonomous and semi-autonomous functions in weapon systems, including manned and unmanned platforms (DoDD 3000.09, 2012). The three categories of autonomy described for such weapon systems are: semi-autonomous, human-supervised, and autonomous. The semi-autonomous weapon system is one that "once activated, is intended to only engage individual targets or specific target groups that have been selected by a human operator." This semi-autonomous description is what is often termed *human in the loop* (HITL); where the machine performs a function for a period of time, then waits for human input before continuing. The human-supervised, or *human on the loop* (HOTL) construct involves machines that can perform a function on their own, but have a human in a supervisory role, who can intervene if the machine fails or malfunctions. The human-supervised autonomous weapon system is "designed to provide human operators with the ability to intervene and terminate engagements." When the machine can perform a function on its own and humans are unable to intervene, the category of autonomous system is referred to as *autonomous*, or *human out of the loop* (Williams & Scharre, 1997). The autonomous weapon system is one that "once activated, can select and engage targets without further intervention by a human operator." The directive states that semi-autonomous weapon systems may be used to apply lethal or non-lethal, kinetic or non-kinetic force, but goes on to say that the system must be designed to not autonomously select and engage targets that have not been previously selected by an authorized human operator in the event of degraded or loss of communications. It also gives leeway to apply autonomous or semi-autonomous weapon systems in ways that fall outside of the policy if approval from appropriate authorities are obtained.

A summary of the DoDD 3000.09 three categories is as follows:

a. *Semi-Autonomous* or "Human in the Loop" (HITL)

> A weapon system that, once activated is intended to only engage individual targets or specific target groups that have been selected by a human operator, provided that human control is retained over the decision to select individual targets and specific target groups for engagement.

b. *Human-Supervised* or "Human on the Loop" (HOTL)

> An autonomous weapon system that is designed to provide human operators with the ability to intervene and terminate engagements, including in the event of a weapon system failure, before unacceptable levels of damage occur.

c. *Autonomous* or "Human out of the Loop"

> A weapon system that, once activated, can select and engage targets without further intervention by a human operator.

Finally, one of the original UAS roadmaps presented predicted future levels of autonomy as described through ten levels of Autonomous Control (OSD UAS Roadmap, 2005):

i. Remotely Guided
ii. Real-Time Health/Diagnosis
iii. Adapt to Failures & Flight Conditions
iv. Onboard Route Re-Plan
v. Group Co-Ordination
vi. Group Tactical Re-Plan
vii. Group Tactical Goals
viii. Distributed Control
ix. Group Strategic Goals
x. Fully Autonomous

These three points of view are useful for discussing autonomy when describing military UAS. Figure 2.5, Foundational Sources for Discussion of Autonomy, presents the central sources for discussing UAS autonomy for this research. The Autonomy in Weapon Systems, DoD Directive 3000.09, references the UAS as a weapon system and focuses on the level of human interaction with the system. The DoD Unmanned Systems Integration Roadmap describes ten progressive levels of autonomy. The NIST ALFUS model adds an accounting for mission complexity and environmental difficulty and further allows for a comparison between autonomous systems.

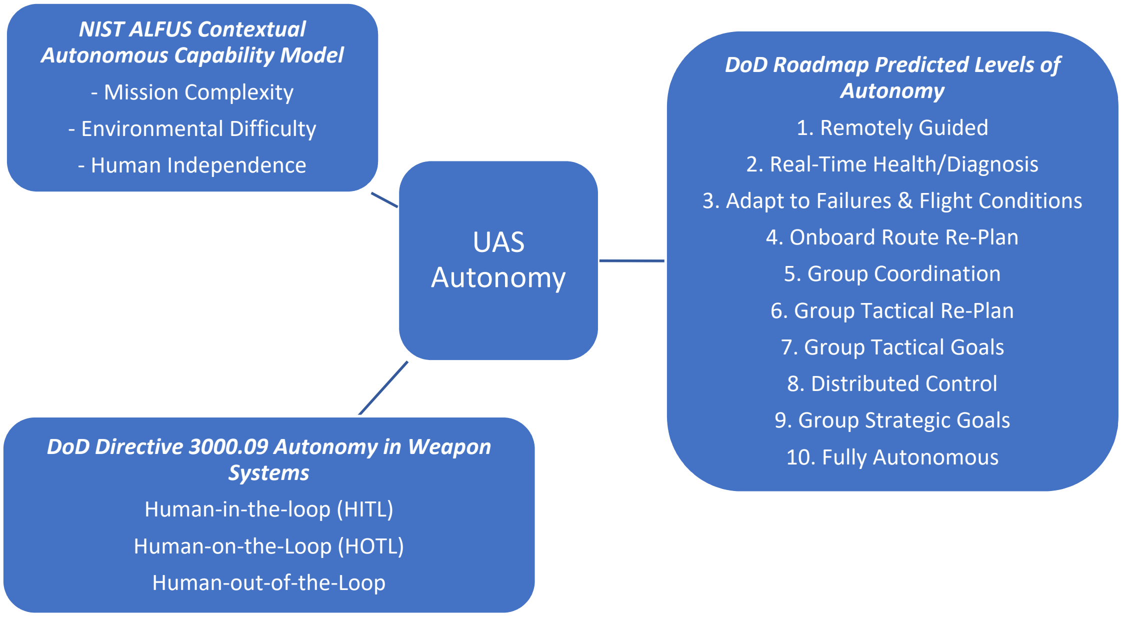


Figure 2. 5 Foundational Sources for Discussion of Autonomy

Autonomous system vernacular is important in setting expectations for deliverables, promoting interoperability, understanding current and future challenges as well as developing future capabilities. A common understanding of autonomous vocabulary or a framework for autonomous systems will be key to communicating across disciplines involved in bringing capabilities to the warfighter. Describing autonomy however, remains a challenging endeavor. This research is a to gauge future missions and predicted levels of autonomy, there are numerous reports and documents which advocate against defining levels of autonomy (Defense Science Board, 2012), (Autonomous Horizons, 2015). Interested readers are encouraged to review the 2012 DoD Defense Science Board's *Task Force Report: The Role of Autonomy in DoD Systems* for alternative framework options for describing autonomy (Defense Science Board, 2012). Still, in order to discuss future autonomous capabilities with SMEs, the sources in Figure 2.5 will be useful as a guide to describing the complex subject.

2.6 Sensors

Sensors encompasses instruments and sensing strategies that enable the UAS to gather data and enhance vehicle operation which then be leveraged to enable autonomous capabilities. Sensors enable the UAS to "sense," "see," "hear," and "understand" the world around it so that it can function intelligently in an unknown and cluttered environment in the absence of an onboard pilot. They can be active or may be comprised of all nonmoving parts. The sensor payload capability is tightly coupled with the UAS mission applications; thus mission application is partially constrained by the suite of sensors on the UAS platform. However, advances in miniaturization of electronics continue to enable the replacement of multiprocessing, power-hungry general-purpose processors with more integrated and compact electronics that contribute to more onboard sensors.

A small fraction of sensors are presented to give the reader an idea of the potential application of sensors to be used to enable autonomous capabilities, primarily as example of the sensors to support sense, detect and avoid factors critical to many UAS applications.

Navigation sensors: Inertial measurement units (IMUs) fuse together information from different sensors such as gyroscopes, accelerometers and magnetometers to provide measurements that can be used to calculate vehicle orientation and velocity. This data can also be combined with another source of information such as a GPS or vision-based navigation methods to further increase the accuracy calculations. Computer vision or vision-based navigation methods are critically important in complex environments or where the possibility of limited communication or GPS-denied environments exist (Lu, Xue, Xia, & Zhang, 2018).

LiDAR (Light Detection and Ranging) sensors, which measure the reflection time of a pulsed laser beam, also have a variety of uses in UAS. They're used for navigation and collision avoidance, as well as for mapping and other imaging applications. LiDAR provides an alternative to traditional photogrammetry methods which may be more suitable where the mapped area contains many obstructions. Other imaging sensors include thermal imaging for building inspection, search & rescue and security, as well as other electro-optical sensors that operate in the visible spectrum.

2.7 Payloads

Each UAS, whether discussing sUAS (Groups 1-3) or UAS (Groups 4 and 5), will have constraints regarding additional non-essential flight components carried on board. Payload refers to mission enabling equipment installed that performs specific tasks. The payload such as sensors, weapon, communication relays, or cargo may be internal or external to the airframe. The payload components require space, weight and power. Tradeoffs must be considered as the number and type of payloads carried by the UAS will affect the performance characteristics to varying degrees.

The sensor payload category can include: cameras for full-motion video (FMV) or still frame electro optic (EO) imagery, radio-wave sensors, infrared (IR), spectral and hyperspectral imaging sensors, synthetic aperture radar (SAR), signal intelligence (SIGINT), electronic attack sensors, etc. These and other payloads require communication with information typically accessed via the UAS data bus, such as airspeed, position, or altitude to function properly. The type of payload capacity and capability (e.g. purpose, function, range, lethality, etc.) is integral to UAS mission application. The desire for increased payload capacity continues to drive research and development in "smarter" sensors with increased processing power, smaller size, weight and power consumption (SWaP) requirements. Although payload utilization is normally controlled or overseen by a human operator, technology exists for a number autonomous payload implementations such as precision aerial drop, loitering or orbiting over objects using track and detection sensors to name just a few (Mathisen, Grindheim, & Johansen, 2017). If denser payloads are integrated into the UAS autonomous capabilities scheme, the challenge of system complexity will be a factor.

2.8 Communication and Networking

Transmitting information from sensors and payloads to GCS nodes or other UAS requires a robust and reliable communication and network design. Integrating UAS into a data sharing network architecture requires an understanding of the functions, requirements and services of a UAS-enabled communication systems. Communication and networking enables dissemination of information exchanges between nodes in a UAS network (Yanmaz, Yahyanejad, Rinner, Hellwagner, & Bettstetter, 2018). A variety of communication and network options are viable to support UAS collaboration with respect to the exchange, interpretation of, and dissemination of data, but specific constraints may apply to the UAS platform, sensors, or mission application. Communication and networking will be discussed in terms of UAS networking architecture for UAS-to-UAS (U2U) and UAS-to-Infrastructure (U2I) communication.

Group 4 and 5 UAS generally work in a single U2I construct (communication between UAS in U2U is not required) where the system is connected directly to a primary node in the form of a satellite or a ground station. This method is more standard due to the larger size and capacity to carry longer range, more powerful communication modules. The sUAS often encounter issues with an inability to operate over the horizon (OTH) or beyond-line-of-sight (BLOS). Smaller UAS typically operate in line-of-site (LOS) or U2U ad-hoc networks. Limited BLOS capabilities currently exist for Group 3 sUAS, but Group 1 and 2 must rely on other relay or gateway nodes (Jawhar, Mohamed, Al-Jaroodi, Agrawal, & Zhang, 2017). The application of sUAS in austere environments has spurred research to solve the limited capabilities mentioned with mobile ad-hoc networks (MANET) to include some newer 5G methods, flying ad-hoc networks (FANETS), wave relays, and multi-input multi-output solutions (Sharma, Srinivasan, Chao, Hua, & Cheng, 2017), (Bekmezci, Sahingoz, & Temel, 2013).

In Figure 2.6 below, UAS connected to each other represent clusters of separate UAS networks, each UAS depicted acts as a relay node which allow connections to otherwise disconnected MANET clusters. Relay nodes can connect various clusters within specific parameters (range, compatible interfaces and configurations, etc.), potentially extending the

MANET to a significantly larger geographic area. A UAS gateway node can also be used to connect the UAS network to backbone network communication infrastructure or the internet.

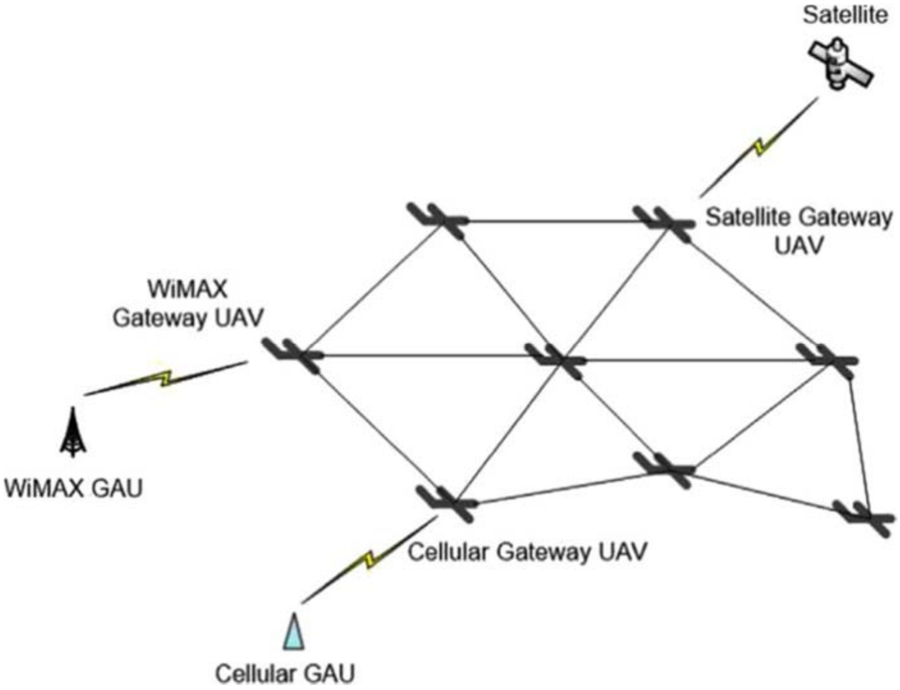


Figure 2. 6 UAS (UAV) as Gateway Node and Relay Node in U2U and U2I Communication

(Jawhar et al., 2017)

Low cost and scalability are two of the benefits of using sUAS, however, communication between sUAS has not matured to the level of U2I communication. U2U networks can result in increased reliability and efficiency through redundancy, but again, this construct could create a weakest link vulnerability (Jawhar, Mohamed, Al-Jaroodi, Agrawal, & Zhang, 2017). If multiple sUAS require a single node to act as the gateway node connected to a ground unit or a satellite, additional complexity could be introduced such as requiring higher levels of network performance.

A distinguishing characteristic of U2U systems is the collaborative nature of UAS to observe the environment, evaluate their own observations and information received from other UAS and reason from them, and respond or act in an effective way (Yanmaz et al., 2018). Due to the multi-UAS collaboration and real-time control requirement aspects of U2U, distributed control is more common. Distributed control allows for one or more UASs to be out of GCS range (or equivalent control node) while still maintaining the ability to coordinate with other UAS to share tasks and information. The extended UAS distributed control construct can include both UAS and sUAS or a mix of the two, but is of course, dependent on each platforms communication modules and capability. Either U2U or U2I also introduced data link security risks which must be considered.

Additional overarching function for communication and networking include latency, safety and operator in the loop requirements. Latency is one of the most important design factors in real time communication and networking applications (Bekmezci et al., 2013). Under safety, communication and networking must support the mechanisms for timely detection, sensing, and avoidance (DSA). DSA requires cooperative sharing to avoid collisions between UAS and other aircraft. The required bandwidth and data rate for this function depends on mission requirements to include whether the UAS is flying in controlled versus uncontrolled airspace or if full visual situational awareness is required by the operator. As can be seen from the safety DSA factors, latency, and security, many themes, technologies and capabilities overlap to enable UAS to operate in their intended environments.

2.9 UCAVs

Although this paper does not primarily focus on UAS in the strict sense as a weapon system, it is nonetheless important to comment on UAS as a combat platform, or as it frequently referred to, an unmanned combat aerial vehicle (UCAV). One motivating aspect of this study is the world stage competitiveness which has enabled allies and adversaries to obtain UAS with varying levels of autonomy. The integration of a fully autonomous UCAV deployed on or over any battlefield still faces many technological and political challenges, however, human-supervised autonomous weapon systems such as the Aegis and the Patriot are present in at least 30 countries ("Who Has What: Countries with Drones Used in Combat," 2018). The U.S. conducted its first drone strike in Afghanistan in 2001 (Boyle, 2015). In 2007, the United Kingdom (UK) purchased Reaper drones from the US; in 2008 they armed the drones with American Hellfire missiles and in 2016 announced additional acquisition from the US, but armed them with domestic Brimstone missiles. The US has also sold drones to the United Arab Emirates (UAE), Italy, and Spain, in 2011. The UAE purchased Wing Loong drones from China and in 2013 and purchased Predators from the US. That same year, in 2013, the UAE also produced a domestic UCAV known as the United 40 ("Who Has What: Countries with Armed Drones," 2018). Besides the Wing Loong drone, China also produced and successfully tested the stealth Sharp Sword armed drone (Boyle, 2015). Chinese drones have been purchased by Iran and Iran has further produced the armed Karrar drone since at least 2010 when it was first unveiled ("Who Has What: Countries with Armed Drones," 2018).

UCAVs present additional special considerations beyond collecting data or other non-lethal functionality. Governing lethal behavior in autonomous vehicles is a niche area of its own within the UAS spectrum of topics. While UCAVs are currently in use by many countries as mentioned above, UCAVs with HOTL or increasing levels of autonomy would likely require a convergence and maturity of multiple technologies and policy. The technology to automatically search, detect, locate, classify, and prioritize multiple moving and stationary targets in all weather and battlefield conditions already exists, but it is unclear when or if the human-like judgement to deliver weapons would be integrated into UAS platforms in the near future. Nonetheless, UCAVs are a key asset to projecting future mission capabilities.

2.10 Multi-UAS and Manned-Unmanned Teaming (MUM-T)

The concept of linking unmanned systems (including air, ground, and sea) with manned systems into a networked team is known as MUM-T (USMC, 2015). It combines the inherent strengths of manned and unmanned platforms to produce synergy and overmatch with asymmetric advantages (Mad Scientist Conference, 2017). While MUM-T is a term geared toward joint operational concepts, providing a range of force multiplier and synergy effects, manned aircraft with UAS teaming provides a variety of enhanced air asset capabilities not seen in single platforms. The human-machine collaboration is intended to help humans make better decisions faster. The coordinated performance interactions between human and UAS requires that control functions be passed back and forth between human operators and the autonomous system over time (Autonomous Horizons, 2015). All of the capabilities discussed in this work could potentially be integrated into the MUM-T concept to include swarming capabilities.

As one example of the MUM-T, DARPA’s System of Systems (SoS) Integration Technology and Experimentation program has developed early stages of an air multiplier effect scenario in which a jet fighter (acting as the C2 platform) launches expendable drone swarms from the back of a C-130, combined with a cruise missile fired by a transport aircraft working together to take on enemy air defenses (“DARPA Sprints toward Swarming” 2018). Other MUM-T scenarios include less complex strategies, such as using UAS as lead aircraft or as decoys, or having perimeter UAS working with manned aircraft fitted with sensors to extend situational awareness or communication with ground forces (USAF A2, 2016). Expanded precision strike capabilities, sustaining lines of communication, extended sensor coverage, standoff capabilities, and increased weapons capacity are other capabilities which fall under the umbrella of MUM-T.

In order to reach greater potential for MUM-T capabilities, advances in autonomous flight control and sense-and-avoid technology must continue to develop. Flying safely in proximity to manned or unmanned aircraft will continue to be a trust element of autonomy further hindering rapid implementation in the immediate future. The USIR does not specifically detail the challenges related to MUM-T, but is does list MUM-T as an autonomy related challenge facing all military Services (DoD USIR 2017-2042, 2016). As with other UAS interoperability challenges, MUM-T would additionally require reliable and secure data links capable of handling an increased shared traffic volume.

2.11 Swarms

An important research area for UAS autonomous technology focuses on the application of UAS swarms. Several interrelated complex research domains are at the intersection of swarm technology including AI, complex adaptive systems, particle swarm optimization, and multi-agent based modeling techniques to first simulate and understand the behaviors to ultimately be instantiated in hardware (Ilachinski, 2017). Efforts have gone toward developing simulated multi-UAS flight control and response to mimic swarming behaviors found in nature, such as the collective swarming behavior of bees, ants, flocks of birds, or schools of fish. Within the DoD, CONOPS vignettes have been developed to anticipate likely scenarios where advances in autonomy have enabled swarm UAS to adapt to new environments and emerging requirements (USAF A2, 2016).

A key aspect of swarm technology is the self-organization characteristic resulting from four basic elements: positive feedback, negative feedback, randomness, and multiple interactions (Ilachinski, 2017). In addition to the self-organizing characteristic, nodes in the swarm work collaboratively to achieve common objectives, can be reorganized to perform other missions, and are typically composed of homogeneous nodes. With these qualities, an advantage for robust, adaptable, and scalable system emerges. UAS in a swarm network are able to act as a single unit with individual UAS nodes dynamically assigned tasks based on location, available resources, shared data, and collective goals. The networked swarm remains universally aware of its surroundings by sharing both external payload data inputs as well as internal aircraft systems information. (USAF AF/A2CU, 2016)

2.12 Dynamic Data Driven Applications (DDDAS)

One technology development area that touches upon autonomous control and management of UAS swarms is a paradigm known as Dynamic Data Driven Application Systems (DDDAS) (Nguyen & Khan, 2013). DDDAS take real-time data and injects it into a running simulation, as well as allowing the running simulation to influence what real data is gathered. The DDDAS symbiotic feedback control system concept was first proposed in the 1980s at the National Science

Foundation. DDDAS is defined as a distributed system that has “the ability to incorporate dynamically data into an executing application simulation, and in reverse, the ability of [the system] to dynamically steer measurement processes” (Darema & Rotea, 2006). As the collection of sensor data continues to grow, integrating data-driven middleware becomes an important factor, particularly in the swarm UAS scenario.

With regard to current and future development of autonomy in UAS, DDDAS could play an important role where computational platforms span a diverse range, including the instrumentation platforms, stationary and mobile networked sensors, and end-user devices. DDDAS research has been implemented for traffic light and traffic control, facial and voice recognition, and many other applications. The inclusion of DDDAS here briefly touches on the dynamic data handling requirements inherent in autonomous UAS applications. DDDAS has been applied to and has created new capabilities in many applications across a multitude of domains (Darema, 2015). Given the data and communication requirements for a variety of UAS network settings, DDDAS may present a potential solution to integrating UAS with other system of systems.

For development of an eventual UAS supported DDDAS, further research would be necessary to describe the data, sensors, and mission types in existing and future UAS applications. One of the major challenges encountered in DDDAS includes effectively assimilating continuous streams of data into running simulations or software. The continuous data streams are often noisy, received from scattered remote locations (in the case of a distributed UAS network), and may contain missing bits or transmission packets. These factors underscore the need to comprehend data characteristics from UAS sensors and mission types. Data acquisition, data processing, data access, and data dissemination requirements identified in other DDDAS architectures could be examined (beyond the scope of this work) to enhance autonomous capabilities such as swarming and MUM-T (Uzkent, Hoffman, Vodacek, Kerekes, & Chen, 2013), (Ditzler et al., 2017), (Allaire et al., 2013; Allaire, Kordonowy, Lecerf, Mainini, & Willcox, 2014; Blasch & Aved, 2015; Darema, 2015).

2.13 Continued Development

Many of the missions currently carried out by manned aircraft can at least be augmented with UAS platforms. Although the USIR places much focus on increasing autonomy, it does not aim to replace the human element. On that same note, the increased focus on autonomous technology in UAS is geared toward solutions that will require minimizing human control. The decrease in required human control would ideally enable operators to supervise additional UAS. The increased autonomy and potentially, increased sensor and payload data will not necessarily make it easier for operators to supervise or control multiple UAS. As autonomous technology matures, UAS are expected to perform within a trusted man-machine collaborative environment. Operators will have to consider to what degree to oversee UAS, when shifts in autonomy are required or when intervention is needed (Autonomous Horizons, 2015). Continued development maturing technologies will progress in parallel with assessments of how much confidence to place in autonomous systems, determination if the data they’re receiving is considered ”good”, and whether the UAS is operating properly or within the envelope for situations it’s programmed to handle. In short, user-interfaces and trust are aspects that need to be developed in parallel with technology.

The potential application of UAS with increased autonomous capabilities is almost limitless. Overall, autonomous UAS capabilities enhance the warfighter in a variety of broad areas, from increased situational awareness to enhanced protection, and from newer areas of development such as cargo or supply delivery, to air-to-air refueling. The road ahead for autonomous UAS development throughout this literature review confirmed a strong focus on UCAVs, MUM-T, and swarm technology. The scope of research for UAS autonomous technology is vast, ranging many critical topics not covered here such as human systems integration (HSI), other proposed intermediate levels of human-autonomy interaction, and AI. Each could be discussed in terms of contributing to the advancement of autonomous UAS capabilities.

As one example, the Center for Naval Analysis describes AI and autonomy in UAS as demonstrating their seamlessness and interaction: “in short, autonomous systems are inherently, and irreducibly, artificially intelligent robots.” (Ilachinski, 2017) Thus, AI and autonomy are closely related, interdependent technologies that play a major role in UAS development. AI brings capabilities associated with processing data and enabling cognition-like capabilities which enhance the speed of information collected, processed, and analyzed. Overall, the autonomous related technologies are in early evolutionary stages where success in one area would likely contribute to success in another area. Figure 2.7 is an excerpt from the Mad Scientist Georgia Tech Technical Report on AI, Robotics, and Autonomy which captures the potential synergistic effects of UAS with AI enhanced autonomy.

> "We are on the cusp of a variety of breakthroughs that will be as profound as the internal combustion engine and machine gun was on combat circa WWI."
>
> - August Cole, Mad Scientist Conference, 7 Mar 2017

Figure 2. 7 Excerpt from the Mad Scientist Technical Report on AI, Robotics and Autonomy

Continued development in autonomous UAS requires collaborating efforts within each of the fields discussed in the preceding sections. Testing in modeling and simulation and testing outside of the lab presents distinctly different challenges. There are unknown and emergent behaviors inherent in autonomous systems and more so with AI enabled autonomy. As autonomous and AI enabled UAS shift toward continuous learning and adapting to their environment, unforeseen behaviors or emergent behaviors could lead to surprises during operations. The 2018 Defense Science Board's Summer Study on Autonomy suggest some strategies to respond to these challenges, however, the suggested approaches have not been tested.

Autonomous technology in UAS is advancing at a rapid pace and in an environment where the technology no longer necessarily comes primarily from the DoD, but from the commercial sector. Competition from near-peer competitors such as China and Russia underpin the need for projecting technology capabilities and addressing challenges early on. The Third Offset Strategy further underscores the DoDs long-term competitive strategy to support and strengthen autonomous system technologies to offset any potential disadvantages U.S. forces may face against anti-access and area-denial (A2/AD) systems.

2.15 Summary

This chapter covered range of topics related to UAS autonomy and technology as the foundation for understanding potential future mission capabilities. First, the general UAS was presented along with terms and definitions to describe autonomous systems and autonomy as a concept. Next, sensors, payloads, and communication were discussed as essential mission enabling equipment. Topics relevant to future autonomous UAS missions such as UCAVs, MUM-T swarms, and DDDAS were presented. Finally, a brief section on continued development on UAS autonomous technology touched on the broad topics that play a role in the overall progress of UAS autonomous technology. It's difficult to cover all UAS missions related areas likely to come up in a forecasting study, however, the information in this literature review should be sufficient to engage subject matter experts in informed future capabilities discussions.

III. Methodology

3.0 Chapter Overview

This chapter presents the motivation and logic for applying a Delphi technique in forecasting future UAS autonomous mission areas and discusses the process used in this study. Following the general Delphi method introductory section, a brief review of the origins of the Delphi method and a sampling of previous forecast examples using the Delphi as further motivation and logic for selecting the Delphi for this study. Then, details relating to the methodology as applied in this study are presented. Next, the general process of the Delphi method as applied in this study is presented in four main sections: problem definition, information on panel selection, development of the research instrument, and an overview of rounds conducted in the study. Information on criteria for SMEs, consensus criteria and number of planned number of rounds is included under the research instrument section. In one final note, a brief overview of some of the critiques and cautions for using the Delphi method are described.

3.1 General Delphi Method

The Delphi method structures and facilitates group discussion on complex topics through a series of iterative rounds of questions in an attempt to arrive at a consensus (Linstone & Turoff, 2002). The method is commonly used in policy development, technology forecasting, medical and education planning, as well as its original military application. It's primarily used as a planning or forecasting tool and is most applicable to 'deal with uncertainty in an area of imperfect knowledge. As there are no "correct" answers, a consensus of opinion is an acceptable second choice'

(Mitchell, 1991). Experts participating in a guided discussion are carefully selected based on specific criteria related to the field of interest so that a broad spectrum of opinion on the topic can be examined. The group typically involves different stakeholders so that conflicting demands can be considered by other group members. With the guidance of a facilitator (i.e. moderator or researcher), the group ultimately makes predictions about some future direction as it relates to the area of discussion.

The general process for the Delphi method is as follows: define the problem, determine expertise required, select experts based on clearly defined criteria, prepare the questionnaire(s) (i.e. research instrument), distribute the questionnaire, analyze the questionnaire responses, determine whether a consensus has been reached or not, if yes, compile final responses and disseminate results in a final report; if no consensus has been reached, provide requested information and tabulate responses, prepare the next questionnaire and return to distributing the questionnaire step. This process is outlined below in figure 3.1.

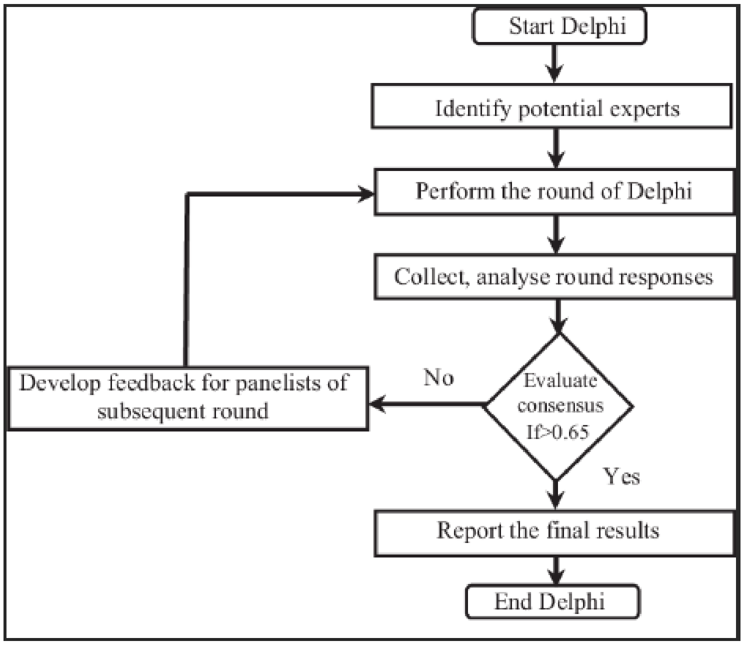


Figure 3. 1 General Example of the Delphi Method

The Delphi technique involves three attributes that distinguish the method from other group interaction methods: anonymity, iteration with controller feedback, and statistical group response (Linstone & Turoff, 2002). With a Delphi sequence, the group members maintain their anonymity and a group interaction occurs through responses to questionnaires, all without requiring participants be brought together physically. This technique is often beneficial when gathering feedback from nascent companies whom would otherwise be in competition with each other (Mitchell, 1991). While this study does not survey the opinions of traditional competitive markets, the individual SME communities may sometimes have competing priorities (e.g. pilots may be focused on training and manning needs, acquisition may be focused on cost, while academia may be most concerned with research funding) .

In this study's case, the anonymity gives panelists the opportunity to freely give responses without fear of being openly critiqued, yet allows all SMEs to see other members responses to either agree with or make a case for disagreeing. Iterations of the research instrument are sent to participants with summaries from previous responses included as feedback in attempts to help determine consensus between participants while noting other views. Thematic analysis is the primary method of interpreting responses. In thematic analysis, the researcher (i.e. facilitator) identifies concepts and categories from each participant's specific responses to less specific but more explanatory ideas found in themes. Responses are grouped depending on relationships, commonalities, and frequency or consensus. Concepts are the closest unit of analysis to the original raw data, while categories are more abstract (Harada et al., 2002). If panelists respond in vague or ambiguous phrases, the facilitator will typically discard those comments. The remaining input responses by participants are then interpreted as insights to a concise list to be reincorporated to the panel in subsequent rounds for further qualitative inquiry and possible quantitative analysis.

Where applicable (although not always possible), the Delphi study presents a statistical response which includes the opinions of the entire group. While a qualitative approach was primarily used for extracting themes from SME responses, it may include some quantitative elements. Rankings and ratings performed on returned questionnaires in the final round in preparation for the final report can comprise a quantitative portion of the study. Additional quantitative measures for the overall group and within subgroups include: response percentages, ranked level of agreement, median, range and standard deviation from central tendency.

3.2 Motivation for Applying a Delphi

In an area such as UAS autonomous technology development, the Delphi technique is suitable considering established frameworks for ‘autonomous systems’ still appear to be under development. As planning must move forward with imperfect knowledge, the expertise of RPA pilots, acquisition professionals and academic professors in the UAS community give valuable insight into not only what UAS *could* do in the future, but perhaps what mission area the community *should* be focused on.

For this research, the Delphi study was chosen as the methodology to propose potential future UAS missions from three distinct SME communities. The Delphi method “has become a fundamental tool for those in the area of technological forecasting” (Linstone & Turoff, 2002). This method of forecasting is particularly useful in areas where a lack of historical data exists, the degree of innovation is high, and industry competition exerts additional pressure in the technology development area of interest. In essence, the rapidly growing and changing demands of UAS in the military requires thoughtful consideration of how to leverage and enhance current capabilities while attempting to forecast which area of evolving autonomous technology to focus resources.

The field of UAS shares two main characteristics which make it conducive to the Delphi study: 1) the large degree of innovation present in UAS autonomous technology and 2) the abundance of subject matter experts. The exploratory composition of such a study focuses on four aspects of the UAS domain space consisting of 1) characterization of missions, 2) SME identification of autonomy levels in UAS missions, 3) identification of UAS current and future mission challenges, and 4) SME perceived importance of resolving obstacles to achieving future mission capabilities. These aspects form what the Delphi vernacular would call the “industry view” which emphasizes a greater need to understand what is best for a company—in this case, the USAF UAS community represents the company (Mitchell, 1991).

3.3 Origins of the Delphi Method

The term Delphi, originates from Greek mythology in the oracle at Delphi who was consulted to forecast the future so that correct and timely decisions could be made before embarking upon a major course of action, typically in areas such as waging war. The origins of the Delphi method come from a 1950s Air Force sponsored RAND Corporation defense research project titled “Project Delphi”. The purpose of the study was to aid in policy formulation and to forecast the impact of technology on warfare (Linstone & Turoff, 2002). The objective of the study was to obtain the most reliable consensus of opinion from a group of experts through a series of intensive questionnaires with controlled iterative feedback. Since then, the Delphi method has been applied by government agencies, the Services, and industry organizations to identify areas for future research (Oliver, Balko, Seraphin, & Calhoun, 2002). Examples of substantive fields such as engineering, economics, and medicine which have had Delphi studies applied and the various techniques for applying the Delphi method can also be found in (Mitchell, 1991) and (Linstone & Turoff, 2002).

In one commonly cited study on the accuracy of past Delphi studies, one researcher looked to a 1967 publication, “One Hundred Technical Innovations Very Likely in the Last Third of the Twentieth Century.” (Albright, 2002) The study looked to past technology forecasts to see what could be said about their future using Delphi studies. In his findings, the author builds a case for key areas and indicators that were conducive to forecasting. Below, Figure 3.1 shows the accuracy of innovation forecasts in his study more than 30 years after the 1967 publication. Technology and Defense were found to be the top two areas where experts predicted future innovations. Notably, aerospace was ranked last. However, with regard to technology development possibilities, specific growth area key indicators reveal similarities to autonomous technology in the following excerpt: “Performance capability has grown exponentially, enabling ever more sophisticated applications of technology. The scale of investment required for innovation with enabling technologies … was driven down by the declining costs of the enabling technologies. This allowed contributions by many people, working in industry, academia, and independently to advance the field.” (Albright, 2002) These indicators appear to share many characteristics in the UAS technology industry. From increased budget appropriations for UAS, to the growing field of defense and private companies catering to the UAS field, to the increase in countries around the world purchasing more and more UAS.

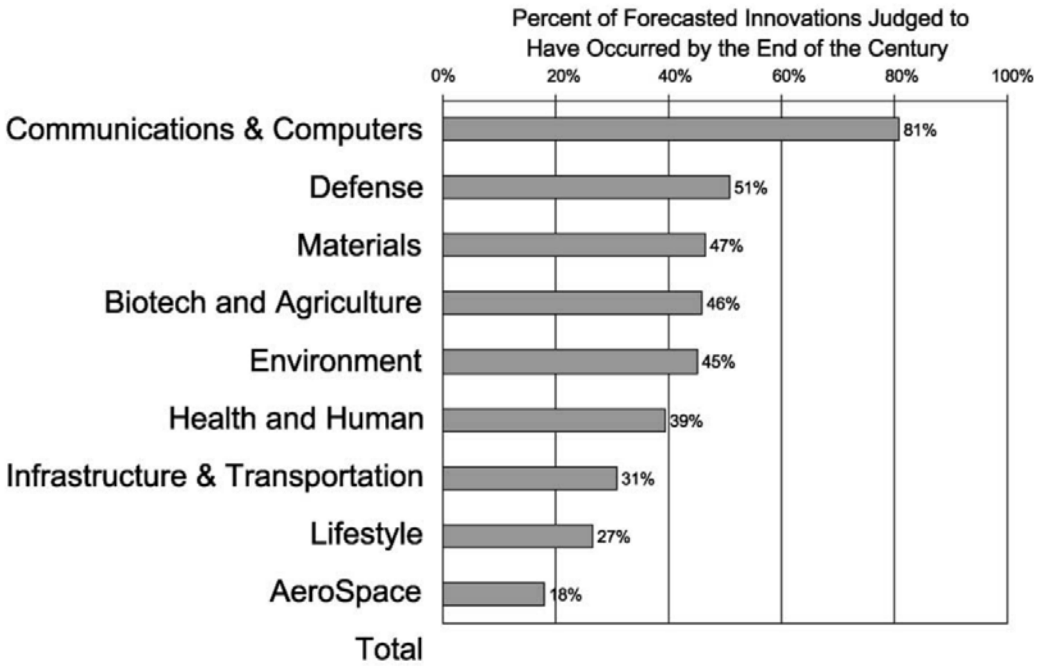


Figure 3. 2 The Quality of Forecasts Across Topical Areas (Albright, 2002)

3.4 Delphi Method as Applied in this Study

Four main elements of the Delphi method were planned for this study.

1) Problem Definition
2) Panelist Selection
3) Research Instrument
   (Includes consensus criteria and number of rounds determination)
4) Conducting Delphi Rounds

3.5 Problem Definition

The problem definition is the first step in preparing for a Delphi study. The problem definition should address the nature and scope of the area to be investigated. For this study, the problem definition was to determine the future direction for UAS autonomous missions while addressing the research questions from Chapter 1.

3.6 Panelist Selection

After defining the problem to be addressed by the Delphi study, the next step is perhaps one of the most difficult to do correctly and one of the areas most criticized when using the Delphi method: selection of "experts". When discussing the systematic use of expert opinions and systems analysis, lead researchers from the original RAND Delphi study argued that there are cases where decisions can be based on the intuitive judgment of whatever experts on a particular subject are at hand (Helmer, 1967). One of the difficulties lies in defining qualifications and measurements of a participant's level of expertise. Finding experts to participate on the panel for the Delphi study can also be difficult. One authority on the Delphi methodology suggests that participants have significant involvement in the industry both in the past and in the present and that as a criterion, selected experts should have at least five years of experience in connected industry (Mitchell, 1991). Another recommended method for finding SMEs is word of mouth; often, one SME in the community is likely to point researchers to other prominent or well qualified SMEs within the same community.

For this study, members of the UAS community from a spectrum of stakeholder perspectives were considered in order to provide a diverse outlook on autonomous mission capabilities. There are no general rules of thumb for creating panels (Linstone & Turoff, 2002). However, literature on number of panelist and panel composition for technology forecasting pointed to a range of eight to ten members (Mitchell, 1991). The panel composition goal was to have three distinct professional fields with three to six members from each group. Members from the USAF UAS community were sourced primarily through contacts at AFIT and the RPA pilot community. Within the academia community, faculty from AFIT were asked to participate. One primary point of contact from the RPA community suggested experienced RPA pilots from geographically separated locations to help with anonymity and diversity of background. Acquisition SMEs were also from geographically separate locations. In all, 20 potential panelists were contacted, 13 initially responded, and nine agreed to participate. Of the nine who agreed to participate, one was lost to attrition. The specific criteria and SME demographics are presented in more detail in Chapter 4. Information regarding confidentiality, anonymity, and expected number of rounds and time commitment was communicated to potential SME panelists to help ensure participation stability remained throughout the length of the study.

3.7 Research Instrument

After panelist selection, it was necessary to develop the research instrument. Construction of questions for the Delphi study began with careful consideration to the design and management of the format that would be presented to SMEs. The number of rounds would be primarily dependent on available time and convergence or consensus on questions presented. Researching question construction for the Delphi technique pointed to a strong need for clear and concise content to be presented to panelists with a conscious effort to not lead participants to or from answering in any particular way. Several designs of the research instrument were tested to guide participants for the three SME group panel with common and relevant USAF descriptions used for levels of autonomy. Before each round, the research instrument was sent for review by fellow AFIT students and faculty to identify any possible points of confusion and ensure clarity and purpose. The final Research Instruments used for Round 1 and Round 2 can be found in Appendices A and B respectively.

The process of designing the research question began with revisiting the problem statement and research questions. Early in the development of the research instrument, it was decided to provide a common guide for describing autonomy as found in current DoD literature which was placed at the beginning of each research instrument sent to participants for each round. Questions to be asked and subsequently assessed throughout Delphi study were as follow:

- Current missions with assigned level of autonomy
- Current perceived Challenges
- Missions not likely to change
- Future missions with expected level of autonomy
- Expected challenges to reaching future mission capabilities
- Critical data/info required to accomplish future mission capabilities
- Challenges to discussing autonomy with regard to all previous answers

Round one was a commonly used open-ended approach designed to solicit specific information from SMEs. The open-ended nature allowed respondents to answer in their own words as well as ask for clarification on areas not understood.

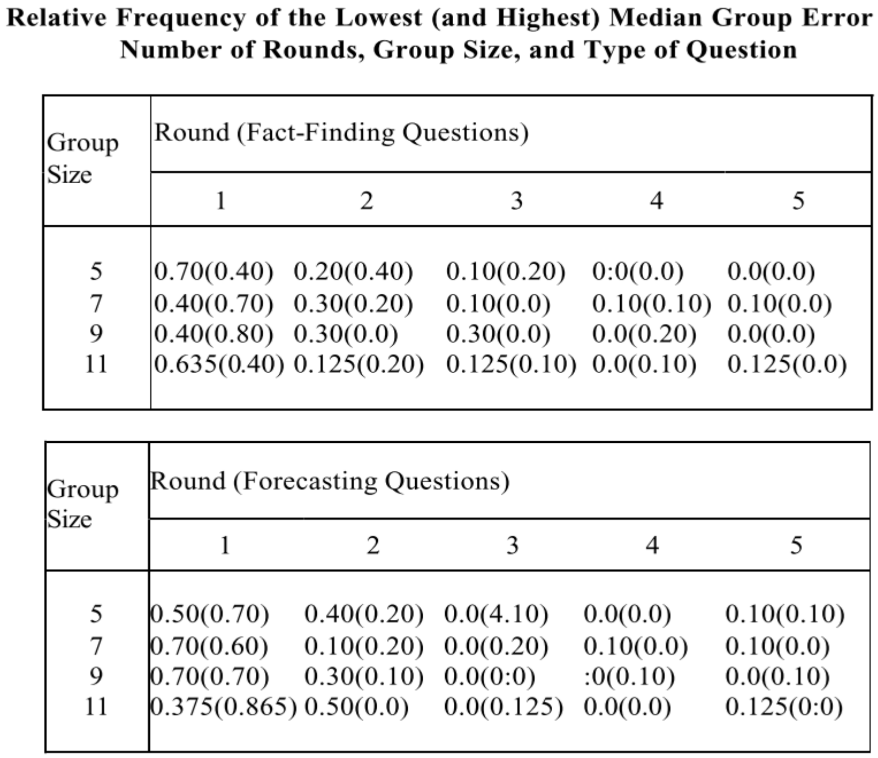
Round two would have a structured approach with information provided in round one reintroduced for assessment of consensus over previous inputs, assignment of levels of autonomy for future missions, and assessments of challenge areas to reaching future UAS autonomous capabilities.

3.8 Consensus Criteria

Consensus criteria was planned as agreement among 5 out of 8 participants, or 62.5% in the areas of future UAS mission types and assignment of levels of autonomy. With a limited number of members in the overall SME group and subgroups, a consensus within each subgroup was more difficult to achieve or gain much meaning. Additionally, the time constraint of not performing a third or fourth round prohibited further comment and feedback over levels of importance for resolving challenges and likelihood of resolving issues at the specified Likert scale timeframes. Within the context of a three or four-round Delphi, members would have an opportunity to adjust ratings (assignment of autonomy levels, timeframes for solving challenges, or ranking of challenges); this is where true convergence, divergence, and consensus could be measured. Still, comments on the results in terms of areas of convergence and divergence are made in Chapter 4.

3.9 Number of Rounds

The literature on Delphi studies shows that the number of rounds is mostly dependent on the time available to conduct the research, the scope of the study, and the desired granularity of responses from experts. A number of prominent Delphi studies argued for two to three rounds, while few extended into the four to six round range and even fewer support more than six rounds. One study separated Delphi questions into either fact-finding or forecasting categories where first and third rounds were of greater importance for fact-finding and second round was found to be of greater importance for forecasting types of questions (Brockhoff, 1984). The measure for importance for each type of question in the previously mentioned studies was the median group error by number of rounds as can be seen in the tables below. Considering the time constraint of this study, the estimated number of participants, and the forecasting nature of questions to be asked, the targeted number of rounds was of two; with an additional round should no consensus or characterization of group responses be found. Finally, if the research should only reach two rounds, one study has found that results could be considered as accurate (to some degree) after two rounds (Kim & Yeo, 2018).



Relative Frequency of the Lowest (and Highest) Median Group Error by Number of Rounds, Group Size, and Type of Question

Group Size	Round (Fact-Finding Questions)				
	1	2	3	4	5
5	0.70(0.40)	0.20(0.40)	0.10(0.20)	0:0(0.0)	0.0(0.0)
7	0.40(0.70)	0.30(0.20)	0.10(0.0)	0.10(0.10)	0.10(0.0)
9	0.40(0.80)	0.30(0.0)	0.30(0.0)	0.0(0.20)	0.0(0.0)
11	0.635(0.40)	0.125(0.20)	0.125(0.10)	0.0(0.10)	0.125(0.0)

Group Size	Round (Forecasting Questions)				
	1	2	3	4	5
5	0.50(0.70)	0.40(0.20)	0.0(4.10)	0.0(0.0)	0.10(0.10)
7	0.70(0.60)	0.10(0.20)	0.0(0.20)	0.10(0.0)	0.10(0.0)
9	0.70(0.70)	0.30(0.10)	0.0(0:0)	:0(0.10)	0.0(0.10)
11	0.375(0.865)	0.50(0.0)	0.0(0.125)	0.0(0.0)	0.125(0:0)

Figure 3. 3 Support for Number of Round Selection in Forecasting (Brockhoff, 1984)

3.10 Conducting Delphi Rounds

For round one, SMEs were given two weeks to answer four multi-part questions before returning responses via email. This process resulted in collecting, editing and synthesizing a large number of comments. The conglomeration of responses were then categorized by areas under current missions, future missions, and challenges to meeting future mission capabilities. During the review of respondent inputs, a certain level of validity can be undertaken as researchers can check to ensure the expert's definitions and statements can be generally understood by other panelists (Hasson & Keeney, 2011). Preliminary analysis on UAS autonomy levels assigned during round one were gathered and placed into tables and charts to establish trend lines for comparison with round two inputs. This information was not presented as part of the round two iteration information given to participants. Rather, it was set aside for the results and analysis section of this study.

In round two, responses were reintroduced in a table-list format to check for consensus on round one inputs and to allow for feedback over any areas of disagreement or concern. The round two research instrument was more structured in that it primarily asked for single input per item as opposed to open-ended statements. Round two parts with four tables. In part one, panelists were asked to either agree or disagree with previous current and future mission area inputs; if they disagreed, they were asked to elaborate in the comments section. Part one also included a section for SMEs to assign a level of autonomy to future mission types identified by fellow experts during round one. Part two of round two included a Likert scale for assigning levels of importance for solving challenges identified during round one and a duplicate table with a similar Likert scale for assigning a predicted timeframe for resolving the challenge items listed in the table.

3.11 Critiques of the Delphi Method

Criticisms of the Delphi method primarily lie in the various interpretations for consensus, expert, and the abundance of the types of Delphi available (Hasson & Keeney, 2011). Although the concepts of 'consensus' and 'expert' are often seen as fuzzy areas and cited as a problem area, researchers argue that properly defining what these mean before the study begins is generally accepted. Disinterested panelists, insufficient guidance and sloppy application of the Delphi method are also common critiques for its application. Another main criticism of the Delphi method argues that for the Delphi method to be considered a serious reliable and valid method for forecasting, it should be evaluated by the same standard as other science methodologies. In one summary criticism article of the Delphi method, one author states "the failure of the Delphi method to incorporate such elements as standard statistical tests, accepted sampling procedures, and replication leaves the method suspect as a reliable scientific method of prediction." (Fischer, 1978) This criticism has been addressed through other studies in which previous Delphi studies were replicated and tested for reliability (Hasson & Keeney, 2011). These criticisms of the methodology serve as a warning in careful, well thought out development of the research instrument, selection of SME panelists, and expressed limitations of the final report. As a group judgment tool, the Delphi method is still viewed as a promising method among researchers (Harada et al., 2002).

3.12 Summary

This chapter presented a general Delphi method overview and motivation for using the Delphi for a 20-year forecast of potential future UAS autonomous mission areas. Characteristics of the method and a brief history of the Delphi method were presented in terms of the method's origins in Defense and its utility for technology forecasting. The remainder of the chapter covered the key areas of the Delphi method as it was applied in this research in terms of problem definition, panelist selection, research instrument development, determination of rounds selected and consensus criteria as well as a brief overview of how the rounds were conducted. Finally, information regarding common critiques of the Delphi method were presented. In the following chapter, detailed results and analysis of conducting the Delphi study will be discussed.

IV. Results & Analysis

4.0 Overview

Conducting a Delphi study to gain insights about the direction of potential UAS missions in the next 20 years required a structured and methodical approach; the technique employed and results of which are discussed in this chapter. The study was planned to consist of two to three rounds with eight to twelve participants. The desired outcome of the research was to investigate the future of UAS autonomous mission capabilities. Specifically, it was desired to observe how SMEs in the UAS community viewed autonomy and related challenges as applied to current and future mission capabilities. To that end, the Delphi process described in Chapter 3 for conducting this study is explained in further detail. The results discussed below pertain to the compiled and distilled qualitative responses provided by SME panelists of the Delphi study. These results are intended to be seen as a product of a carefully designed and managed interaction instead of 'answers' to abstract questions from following a particular prescribed method. The results discussed below give insight into potential future mission capabilities, how stakeholders from various disciplines may respond differently in describing requirements, and what each group views as being more important in terms of prioritization for resolving challenges or pursuing a capability.

This chapter first introduces information about SME panelist composition, followed by the autonomy guidelines provided throughout the study. Next, it lays out a general overview of the questions presented over the study's two rounds. The chapter then goes into an analysis of SMEs responses over current and future UAS autonomous mission capabilities and challenges.

4.1 SME Panelist Composition

For this study, in order to ascertain whether various stakeholder had similar or disparate views about current and future autonomous UAS missions, it was desirable to have multiple SME members from at least three disciplines or backgrounds. Therefore, a minimum of two members per group was desired; albeit, with the recognition that more participants per group may have given more robustness or fidelity to the study. The more similar the professional's position each individual held, the more likely it may have been possible to establish or draw conclusions about views from members of similar groups. The identified target groups were decided as RPA pilots, acquisitions professionals, and professors from academia. The anonymity characteristics of the Delphi were maintained throughout study.

Acquisition professionals from various program offices and specialty backgrounds (T&E, sUAS, MQ-9) were contacted for potential participation. Initially, five participants from acquisition backgrounds were scheduled to participate, however, two would eventually drop out prior to sending out the first research instrument. Within the RPA pilot group, one 18S career field instructor and mission commander was contacted for recommendations on possible SME participants. Of the seven pilots emailed, five agreed to participate; two were lost to attrition after receiving the first research instrument, leaving the study with three pilots who participated through the completion of the study. With direct access to academia members at AFIT with research experience in UAS technology, requests to three professors were sent via email; two were available to participate.

Figure 4. 1 Delphi SME Panelists

The figure above shows the composition of the Delphi SME panelists. As part of the Delphi method, participants were informed of the anonymity characteristic of the study as described earlier in Chapter 3. Throughout the remainder of the results section, where necessary, SMEs will be identified by a SME identification number as well as a color code which matches the above figure (blue for RPA pilots, tan for academia, and gray for acquisition). In order to convey to the reader some demographic information about each SME, as well information pertaining to criteria met for designation as a SME for this study, the table below indicates the participant's area of experience, and SME identification number. The table indicates a cross-section of participants with experience in Test & Evaluation, UAS Open Systems Architectures, research, sUAS, instructors, evaluators, and flight experience. Gathering three subgroups allowed for possible characterization of subgroups as well as enabling an exchange of views between subgroups for comparison and identification of potential opportunity gaps.

Table 4. 1 Delphi SME Identification Reference and Experience Indicators

	SME Identification Number (SID#)							
	SID01	SID02	SID03	SID04	SID05	SID06	SID07	SID08
Experience Indicators	Pilot	Pilot	Pilot	Flight T&E Engineer	NH-04 OSA	62A ASIP OT&E	Academic Professor	Academic Professor
Civilian				x	x		x	x
Mil Exp	x	x	x	x		x	x	
Researcher	x						x	x
sUAS operator	x						x	x
Technical Advisor					x			
Stan/Eval	x							
Instructor		x					x	x
Evaluator	x							
Flight Exp	x	x	x	x			x	x
Years Exp	12	7	6	12	3	4	10	8

The minimum criteria for participating as a SME in the Delphi was at least four years of continuous experience in a UAS related field of work. Due to the difficulties acquiring a larger number of participants, the originally set level of five years of experience (as indicated in Chapter 3) was slightly relaxed with supported reasoning. Additionally, participant SID05 indicated only three years of experience in UAS related work. Several factors were considered when deciding to keep the participant as part of the Delphi study. 1) The need for a large enough sample size of participant responses. 2) The researcher was curious whether someone with fewer years of UAS experience would list similar primary and future missions as well as observations on assignment of levels of autonomy as those with more years of experience. If the scope of participants were larger, it would be interesting to see how much of an outlier non-SMEs responses were when compared to someone with more experience. 3) SID05 held a uniquely related role to the future development and implementation of UAS open systems architectures (OSA). His focus on OSA could potentially lend mutual benefits for both researcher and participant.

As described above, each participant was contacted first via email to solicit participation and subsequently to verify that basic SME criteria were met. During development of round one questions, it was also important to maintain communication with members who agreed to participate, as attrition has been cited as a common problem with Delphi studies. Throughout the initial communication and question development phase, the general nature of questions and the goal of the Delphi was conveyed to include a requirement that participants meet the minimum SME criteria. Prior to sending out the research instruments, two RPA pilots and two acquisition professionals (one with a background in UAS sensors and one PM) ultimately responded that they could not participate due to either a lack of knowledge in autonomy, continuous time in UAS, or unavailability.

4.2 Guidelines and Definitions

Each research instrument began with a statement about the overall purpose of the study and provided three overarching references sources to guide the participant's consideration of autonomy as a concept. The guidelines provided for each round is provided in the form of an excerpt from the research instrument below in Figure 4.2.

1) Autonomous capabilities are defined as the technologies that enable unmanned flight and autonomous behavior in the absence of an onboard pilot.

2) Three key attributes as described by the National Institute of Standards and Technology (NIST) should be considered when discussing autonomous capabilities: 1) Operator Independence, 2) Environmental Difficulty, and 3) Mission Complexity.

3) DoD Directive 3000.09, Autonomy in Weapon Systems, defines autonomy in three categories: 1) Semi-Autonomous (man in the loop), 2) Human-Supervised (man on the loop), and 3) Autonomous (human out of the loop).

Figure 4. 2 Excerpt from Research Instruments: Autonomy Statements Guide

As the study was focused on observing how SMEs from varying communities view future autonomous UAS capabilities, it was important to create a common reference point for discussing autonomy. Throughout the study, no other specifics with respect to mission types or challenges were presented in research instruments. SMEs were expected to understand general mission types when presented by other SMEs in iterative feedback rounds. In any case where clarification was required over statements provided in the research instrument, it was encouraged for participants to provide comments on those areas for each round. In cases where a Likert scale was used, a brief description for each point on given scales was provided; these scales are presented below in the respective section of discussion.

4.3 Delphi Rounds Overview

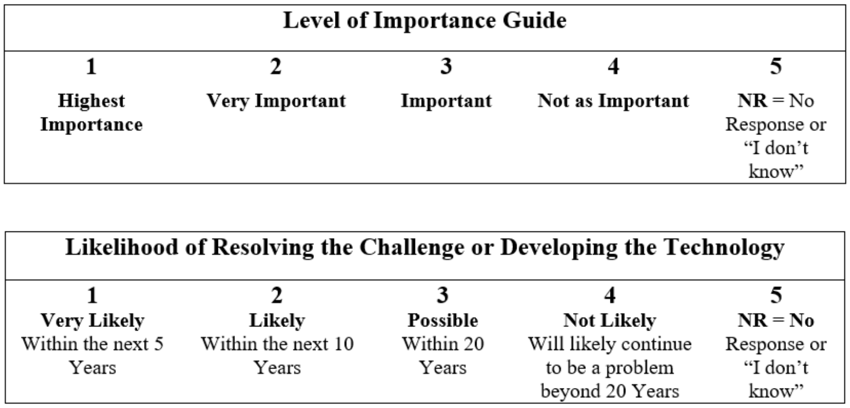
Round one and two responses are discussed in the following sections with brief comments and accompanying figures or tables. First, round one asked initial demographic questions. The questions captured each participants rank (or civilian grade), current job title, Air Force Specialty Code (AFSC) (if applicable), type of UAS and number of years of experience with each type, and lastly, in what capacity they interacted with the UAS they listed. Round one also listed four open-ended questions to allow SMEs to list missions, assign autonomy levels, and discuss challenges to meeting mission capabilities. The research instrument used for the study is provided in Appendix A. The responses were aggregated, coded, and reintroduced to participants in a second round in which SMEs were asked to agree or disagree about mission types and challenges identified by all panelists, assign levels of autonomy to future UAS missions, and assign levels of importance to solving the challenge areas as well as assigning timeframe estimates for solving identified challenges.

Round one, began with a SME assessment of current missions and assignment of autonomy levels in an attempt to establish a consensus and baseline for beginning the Delphi study. We asked participants to list current missions and assign autonomy levels as they understood them with the added references to DoD and NIST autonomy guidelines (Figure 4.2) as well as an included 5-point Likert scale for describing autonomy. This first step helped gauge the need to provide stricter definitions for mission types. It was more desirable to allow SMEs the freedom to exercise their expertise in naming primary mission types with the expectation that a majority of responses would be similar, as opposed to providing a narrower questionnaire form with ‘yes’ or ‘no’ response options. If a wide variety of responses or a lack of repeated mission types were presented through round one, we could anticipate that the effect would be compounded in subsequent rounds and questions. If the latter occurred, it would be more difficult to identify any trends or provide an analysis of individual SME subgroups. As the following section explains, there was significant consensus with regard to current mission types described by all three SME groups.

Four additional questions from round one addressed SMEs assessment of the following: future missions and predicted levels of autonomy, challenges to reaching mission capabilities, information/data required to accomplish those missions, and challenges to discussing autonomy. Throughout each round, SMEs were provided the opportunity to make comments. Where panelists provided comments that contributed to a shared common attitude or a subgroup common attitude, they were included in the associated section below.

At the conclusion of round one, responses were collected, edited, analyzed and aggregated for consensus and to prepare the round two research instrument. Round two was built upon information provided by respondents in round one. In addition to the overall purpose statement provided in both research instruments, an added overview statement (Figure 4.3) was provided to inform SMEs of the study’s end goal. As with round one, the same guides for describing autonomy were also provided.

The first section of Round two, included two tables with a list of current and future autonomous UAS mission types to determine if there was a consensus with respect to missions listed. All missions listed were those provided by SMEs from round one. SMEs were simply asked whether they agreed (Y/N?) with missions on the list. If they did not agree, they were asked to provide comments. A second question in round two, reintroduced the future missions table and asked participants to assign a predicted level of autonomy for a 20-year forecast—what level of autonomy would missions listed likely have 20 years from now. Finally, challenges identified by SMEs during round one were presented in a table-list format. SMEs were asked to use a 5-point Likert scale to assign a level of importance to solving each challenge. In a second duplicate table, SMEs were then asked to use a Likert scale to assign a timeframe to estimate the likelihood of resolving each challenge area. The Likert scales used in the research instruments are provided below (Figure 4.3). Specific challenges are listed and discussed in section 4.7 after a discussion on the analysis of future UAS missions and assigned levels of autonomy sections.



Level of Importance Guide				
1	**2**	**3**	**4**	**5**
Highest Importance	**Very Important**	**Important**	**Not as Important**	**NR** = No Response or "I don't know"

Likelihood of Resolving the Challenge or Developing the Technology				
1	**2**	**3**	**4**	**5**
Very Likely Within the next 5 Years	**Likely** Within the next 10 Years	**Possible** Within 20 Years	**Not Likely** Will likely continue to be a problem beyond 20 Years	**NR = No** Response or "I don't know"

Figure 4.3 Likert Scales used in Round Two

4.4 Current Missions and Assignment of Autonomy Levels

Round one established a common starting point to assess how SMEs viewed current primary UAS missions. Each SME was asked to list UAS primary missions and was subsequently asked to assign a level of autonomy to the extent that they understood current missions. Responses were collected and distilled down to four overall mission types with the subcategories listed in

Table 4.2 as Intelligence, Surveillance and Reconnaissance (ISR), Strike/Attack, Combat Search and Rescue (CSAR), and Communications/Relay. The complete list of responses by subject ID (SID#) can be found in Appendix C as well as a general glossary for descriptions of each mission type listed in Appendix D. For example, in Table 4.2, ISR lists 1.5 Deliberate Targeting, with the following description – Reliance on UAS surveillance to develop targets before sending other aircraft for further mission execution (i.e. bombing runs etc.). These additional descriptions were not introduced to the SMEs through the research instrument or by any other means., In round two, SMEs were asked whether or not participants agreed or did not agree that missions listed were in fact a current mission type.

Table 4. 2 Current UAS Missions Identified by Delphi participants

Current Mission Areas Identified by SMEs	
General Category	Response Subcategory
1. ISR	1.1 ISR
	1.2 Reconnaissance
	1.3 Persistent Reconnaissance
	1.4 Autotomized C2ISR Threats
	1.5 Deliberate Targeting
	1.6 Target Tracking
2. Strike/Attack	2.1 Close Air Support (CAS)
	2.2 Hunter/Killer (Full Motion Video)
	2.3 Surface Attack
	2.4 Attack
	2.5 Persistent Strike
	2.6 Interdiction/ Strike Ops
	2.7 Target Prosecution
3. CSAR	3.1 Combat Search & Rescue
4. Comm/ Relay	4.1 Communications Relay

Additionally, when SMEs first introduced current missions in round one, they were asked to also assign a level of autonomy to those missions. Figure 4.4 shows the current mission levels of autonomy each person assigned to individually listed missions. It does not include every participants view on autonomous capabilities with regards to each current missions. Rather, it only indicates the level of autonomy each assigned to the mission individually listed in round one. With that caveat, it still serves as a starting point for future comparisons. For example, only one participant listed CSAR, another single participant listed Comm/Relay, while all eight participants listed ISR and only one did not list Strike/Attack.   In subsequent comparison/analysis, we will see if there was consensus on the type of mission listed as well as see how the overall group assigns future autonomy levels to the same mission types.

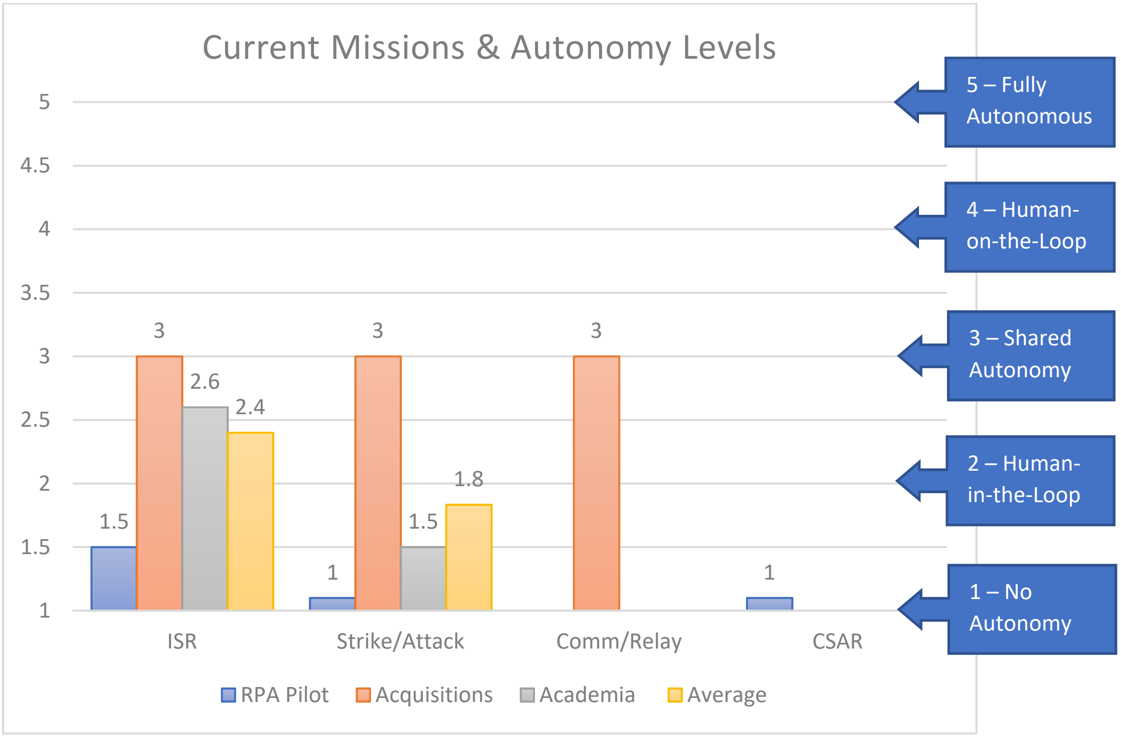


Figure 4. 4 SME Provided Current Missions & Assigned Autonomy Levels

The Pilot subgroup assigned the lowest levels of autonomy for any of the listed missions; this remained consistent through the future mission areas identified in both rounds as well. The Pilot SME subgroup also did not initially list any current missions other than ISR, Strike/Attack, and CSAR as primary UAS missions. As such, the mission type Comm/Relay did not include the Pilot group for assignment of autonomy levels in round one (see figure above). However, in a subsequent round, all SMEs were asked to agree or disagree with listed current and future mission capability areas as well as assigning a level of predicted autonomy in 20 years for each future mission type. Only one pilot disagreed with a current mission type listed under the Strike/Attack category: Hunter/Killer – this mission type was introduced in round one by an acquisition SME with two to five years of experience in multiple UAS platforms (Predator, Global Hawk, Reaper and Group1-3 sUAS). Comm/Relay and CSAR were categories of missions which also did not receive SME inputs during round one—Comm/Relay was mentioned by one acquisition SME (discussed in the Comm/Relay section), and CSAR was only mentioned once during round one by one pilot SME.

The following subsections provide additional details on the subcategories listed for current UAS missions and provide selected comment excerpts relating to each mission type listed from round one.

4.4.1 ISR

Twelve responses were combined under the mission heading of ISR during round one. Each group of SMEs listed ISR with various subheadings (e.g. SAR, EO, Radar, IR, Squad, Theater, Strategic, etc.). This type of response was expected since SME experience and backgrounds ranged from MQ-9 pilots to sUAS test and development with fixed-wing, vertical take-off & landing (VTOL), and multi-rotor expertise. 83% of ISR missions were assigned a level of autonomy between HITL and HOTL with a consensus that no current missions are fully autonomous.

Of the three SME groups, only the RPA Pilot group indicated a portion of ISR missions as having Level 1 (or fully pilot controlled) autonomy. Program managers listed ISR missions as having Level 3 autonomy which was interpreted as varying degrees between HITL and HOTL according to the scale provided in the research instrument to SME panelists. Only one member from the Academia group labeled current ISR (reconnaissance) missions with Level 4 autonomy.

4.4.2 Strike/Attack

Eight specific responses were combined under the heading of Strike/Attack during round one. There was consensus from all three groups that all listed current missions related to Strike/Attack had no autonomy (Level 1) to minimal HITL autonomy (Level 2). 75% of SMEs listed the Strike/Attack type of mission with an indicated Level 1 for autonomy, or fully remotely controlled by pilot. This type of response coincides with DoD Directive 3000.09 *Autonomy in Weapon Systems*. Close Air Support (CAS) and on-call CAS were combined simply to CAS.

Sample SME Comments

Pilot: *"While the aircraft may change, I don't anticipate a day when we don't have weapons on board to bring attack capability."*

Acquisition: *"Rules of Engagement will change when adversaries start doing what we are currently unwilling to do."*

Academia: *"CAS – don't see it as a UAS mission in near future because of current low trust in autonomy. Ground forces will not trust automated systems engaging targets in their immediate vicinity, and air assets will be reluctant to engage in CAS with UAS due to fear of fratricide."*

4.4.3 CSAR

One pilot listed the CSAR mission under current UAS missions with an assigned level of 1, or no autonomous capability involved. As mentioned in the ISR section and visible from Figure 4.4, not all participants listed each mission type. CSAR was another mission which, while not presented as a primary mission type by more SMEs in Round 1, it received 93.75% consensus in round two from other panelists with agreement to its status as a current mission type. One SME from the academia subgroup said they only partially agreed that it was a current mission type. The discrepancy in the singular mention during the first round, was likely due to the specific area of mission experience by each SME. In a later question for mission areas that are likely to emerge (before the 20 year forecast) at least two other SMEs mentioned CSAR.

Sample SME Comments

Pilot: *"CSAR – We are a fantastic platform (minus speed) for performing this mission as we have a long loiter time."*

Academia: *"I think they will have a role in search and delivering supplies. I don't see the full mission being conducted by UAS due to low trust in autonomy."*

4.4.4 Comm/Relay

Similar to the CSAR example, where only one mention of a particular mission was made during round one for current missions and assigned level of autonomy, Comm/Relay was carried through to the second round for consensus assessment. The acquisition SME who listed the Comm/Relay as a primary mission type specifically mentioned Battlefield Airborne Communications Node (BACN). BACN is typically used on a converted RQ-4 to EQ-4 (Global Hawk) as well as the USAF’s E-11A. BACN enables platforms to become what is often referred to as “gateways in the sky,” “Wi-fi in the sky,” and/or “flying gateways” with data and communications bridging capabilities enabling various datalink systems to exchange information where they would otherwise be unable to work together due to compatibility issues (i.e. Link-16, Navy F/A-18s, B-52, B-1, F-22, forward air controllers, and Joint attack controllers, etc.). As the BACN payload is often a primary mission for certain platforms, when it was presented in round two for consensus, all SMEs agreed to its status as a current mission type.

4.5 Current Mission Challenges

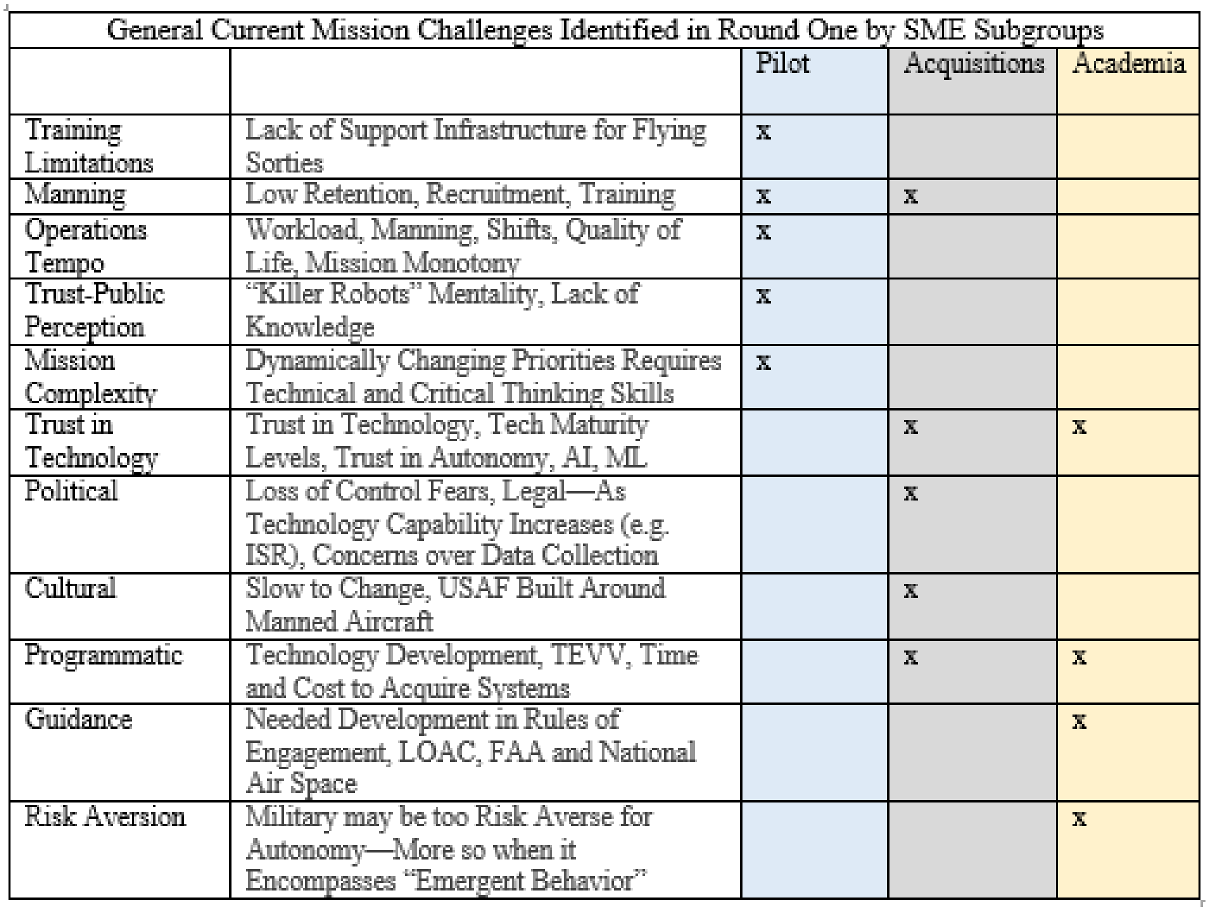
Round one included questions regarding challenges to meeting current and future mission capabilities. The responses indicated there were identifiable categories of challenges that could be attributed to particular SME groups. For instance, in Table 4.3 below, Training and Manning Limitations as well as Operations Tempo were identified by the pilot SME subgroup. The nature of executing day-to-day UAS missions resulted in the pilot group identifying quality of life (QoL) issues and challenges related to more effectively accomplishing their flying mission rather than immediately highlighting programmatic or technology development issues. The current mission challenges table below (Table 4.3) also highlighted that acquisition SMEs listed programmatic issues: cost and time for technology development, getting to the required Technology Maturity Levels (TMLs), TEVV concerns, etc. SMEs in academia mostly focused on the hurdles to developing technologies: the lack of guidance or support in fully developing capabilities and the military's risk averse nature—seen as especially problematic due to emergent behavior inherent in UAS with autonomous capabilities and related technologies such as artificial intelligence, machine learning algorithms and neural networks.

Table 4.3 summarizes the current mission challenges submitted during round one. While manning, training, and general QoL issues are recognized as important factors that have a direct impact on fulfilling current and future mission capabilities, the purpose of this study was focused more on the autonomous capabilities likely to emerge in the next 20 years. Addressing the career field specific challenges is a subject that has been covered in various journals, papers and RAND studies (Norton, 2016), (NPS, Frau, Howell, Kelly, Kulikowski, Mak, Mikulin, Nguyen, Paulsen, Wade, 2011), (Terry, Hardison, Schulker, Hou, & Payne, 2018) . Although the QoL and manning concerns were not reintroduced in round two as part of the feedback or consensus assessment, the responses from our round one pilot SME subgroup indicated a clear consensus that these issues were a top concern for meeting current mission capabilities and would likely continue as a concern for reaching future mission capabilities.

With regard to the manning issues seen within the MQ-9 career field (and commented on by each pilot in the study), one pilot attributed the mid-shift as a main source of the overall problem. Their specific problem-solution approach emphasizes the value of seeking inputs from key stakeholders in the UAS community. One pilot SME stated: "Eliminate that (mid-shift) obstacle and people will stay. As it is, because mid-shift is so anti-family and so negatively impacts people's health, people are unwilling to endure it after their first operational squadron." They went further and suggested opening OCONUS bases (at logistically sound and desirable locations) to MQ-9s as well as implementing only dayshift and swing-shifts at all locations versus the more problematic rotation of people through days, swings, and mid-shifts.

The table below was a generalized synthesis of challenges presented in round one. A detailed analysis of future mission challenges, including data related challenges and challenges to discussing autonomy are discussed in Section 4.7.

Table 4. 3 General Current Mission Challenges Identified in Round One by SMEs



General Current Mission Challenges Identified in Round One by SME Subgroups				
		Pilot	Acquisitions	Academia
Training Limitations	Lack of Support Infrastructure for Flying Sorties	x		
Manning	Low Retention, Recruitment, Training	x	x	
Operations Tempo	Workload, Manning, Shifts, Quality of Life, Mission Monotony	x		
Trust-Public Perception	"Killer Robots" Mentality, Lack of Knowledge	x		
Mission Complexity	Dynamically Changing Priorities Requires Technical and Critical Thinking Skills	x		
Trust in Technology	Trust in Technology, Tech Maturity Levels, Trust in Autonomy, AI, ML		x	x
Political	Loss of Control Fears, Legal—As Technology Capability Increases (e.g. ISR), Concerns over Data Collection		x	
Cultural	Slow to Change, USAF Built Around Manned Aircraft		x	
Programmatic	Technology Development, TEVV, Time and Cost to Acquire Systems		x	x
Guidance	Needed Development in Rules of Engagement, LOAC, FAA and National Air Space			x
Risk Aversion	Military may be too Risk Averse for Autonomy—More so when it Encompasses "Emergent Behavior"			x

4.6 Future Missions and Assignment of Autonomy Levels

Future UAS Missions identified in Table 4.4 are from round one and present a projection of what panelists believed the military could or should be doing 20 years from now. A key aspect of this question was to assign a predicted level of autonomy to each mission listed. Participants collectively provided 31 responses. Of the 31 responses from round one, the list was distilled down to the 12 General and 21 Subcategory future missions as listed Table 4.4. Each panelist submitted at least 3 future mission areas.

Table 4. 4 Future Mission Areas Identified by SMEs

Future Mission Areas Identified by SMEs	
General Category	Response Subcategory
1. ISR	1.1 ISR (Enhanced)
2. Strike/ Attack	2.1 Suppression of Enemy Air Defenses (SEAD)
	2.2 Air Defense
	2.3 OCA/DCA (Offensive/Defensive Counter Air)
	2.4 Air-to-Air
	2.5 Fighter UAS Similar to Manned Fighter Aircraft
	2.6 Decoy/Wingman
	2.7 CAS/Strike Support
3. Supply/ Resupply	3.1 Supply Delivery
	3.2 Logistics Resupply
4. Cargo	4.1 Cargo – Current Cargo Aircraft Missions
5. Aerial Refueling	5.1 Various types – UAS to UAS, UAS to Manned Aircraft, Manned Aircraft to UAS
6. sUAS Battlefield Coverage	6.1 Wide Area Search/Engagement
	6.2 Networked UAS
7. C2	7.1 Command and Control
8. Sentry Ops	8.1 Sentry/Base Protection
9. EW/ Cyber	9.1 Electronic Warfare
	9.2 Cyber Operations/Support
10. BMD	10.1 Ballistic Missile Defense
11. Swarms	11.1 Various Swarm Enabled sUAS Capabilities
12. Counter Space	12.1 Counter-Space Operations

Figure 4.5 showed the assigned levels of autonomy for future UAS missions by all panelists after round two inputs. Figure 4.6 shows a comparison between autonomy levels assigned for two categories of missions which were both presented in current and future mission capability areas,

ISR and Strike/Attack. For Figure 4.6, autonomy levels were taken from Figures 4.4 and 4.5. It should be noted that while the stage of data collection (round one and round two respectively) is very different, primarily in terms of the number of participants who evaluated autonomy levels, Figure 4.6 is presented here to show a general shift in perceptions about future autonomous capabilities. An upward trend in levels of autonomy assignment was seen across the two categories compared in Figure 4.6. The bars represent the average assignment of all three subgroups. Each subgroup assigned increased autonomy levels to similar current UAS autonomous mission areas.

Pilots remained the most conservative toward assignment of autonomy levels across all mission types. However, it should be noted that the pilot SME group was consistent with other groups in shifting toward more autonomous capabilities in future predicted autonomy levels.

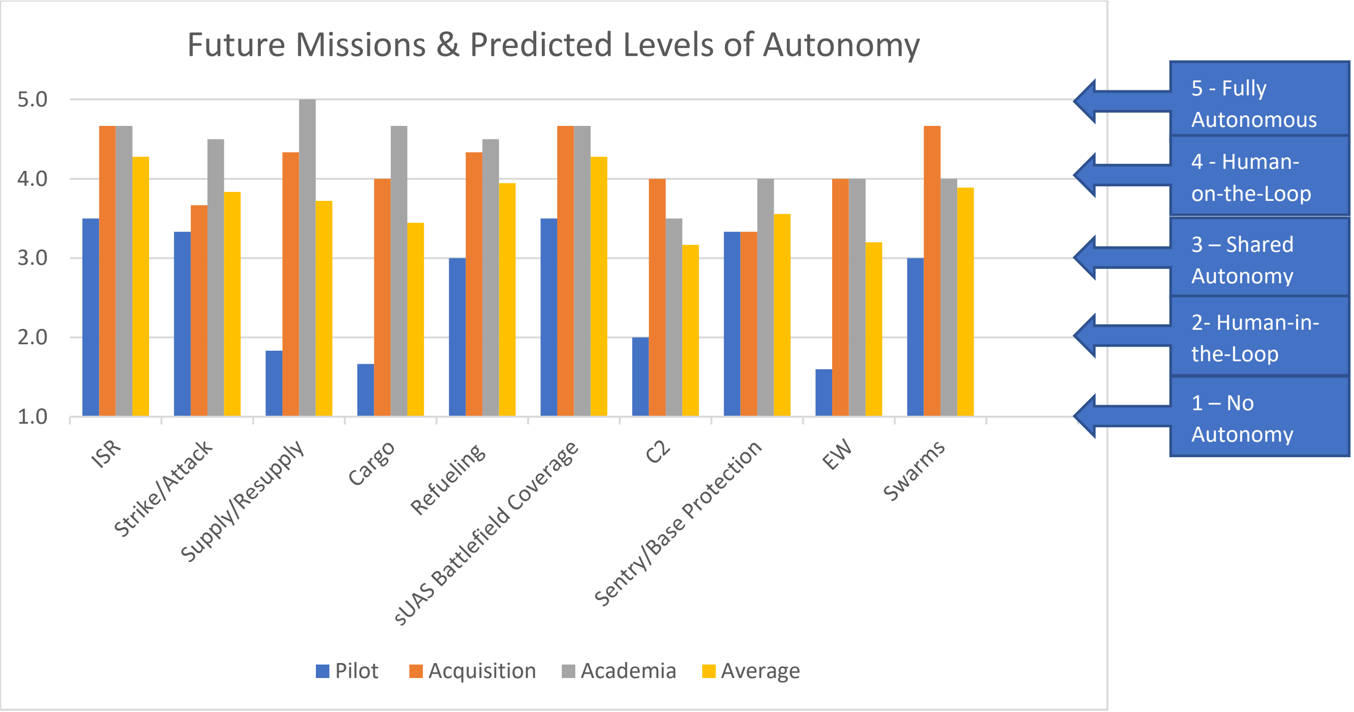


Figure 4. 5 SME Provided Future Missions & Predicted Levels of Autonomy

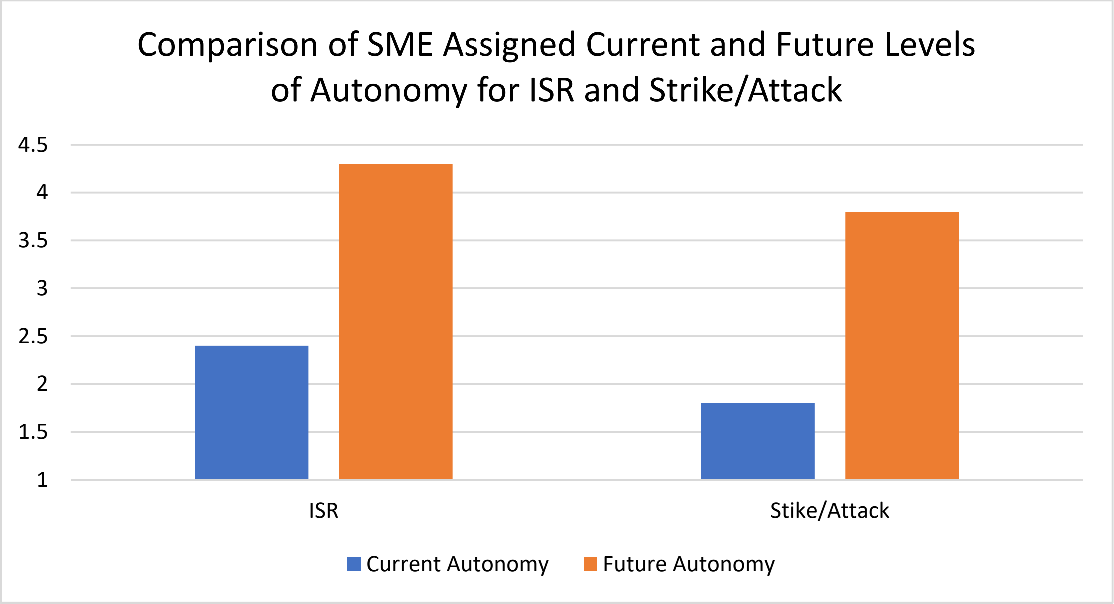


Figure 4. 6 Comparison of Current and Future Assigned Levels of Autonomy

The following section provides detailed information on each category of future missions presented during round two. The list is derived from the 31 inputs provided by SMEs in round one. Each subsection discusses consensus information, details on subgroup and overall assignments of autonomy levels changes from round one to round two.

4.6.1 ISR

There was consensus on ISR as a future mission type, but not on levels of autonomy assigned. In round two, future ISR was collectively presented as one mission type rather than the multi-subcategory breakdown list for current mission types. The range of autonomy assigned for general ISR by the pilot subgroup was 2 to 5. The acquisitions and academia subgroup assigned future autonomy levels as 4 and 5. Under ISR, the overall SME average (pilots, acquisition and academia) assignment increased from round one 2.4, or closer to HITL, to above 4.0, or a majority of HOTL assignment in the round two iteration. This increase in autonomy to human-on-the-loop assignment likely indicates the expectation of overcoming many of the challenges associated with reaching fuller autonomous capabilities, such as maturing technology levels, establishing the infrastructure to support a more robust interoperability for intel or data exchanges and data fusion, as well as an increased trust or understanding of autonomous systems.

Previously, under current ISR missions, pilot SMEs assigned autonomy levels to be on average, halfway between no autonomy and HITL, translated to a 1.5 on the autonomy scale provided in the research instrument and corresponding to the levels shown in Figure 4.4. Under future ISR mission predicted levels of autonomy, the same subgroup (pilot SMEs) averaged a 3.5, or closer to HOTL than to HITL. The small number of participants for each subgroup made it difficult to discuss consensus with respect to autonomy levels. However, it can be said that both acquisition and academia subgroups believe that in 20 years, ISR missions will be capable of HOTL levels of autonomy.

4.6.2 Airborne Refueling

There was a strong consensus for autonomous aerial refueling (AAR) as a mission type. All three subgroups listed AAR as a future mission type in round one. One SME from the pilot subgroup commented that they didn’t see the need to refuel UAS in air, but instead anticipates that most platforms will be designed to carry enough fuel for their mission area. The same SME doubted the possibility of UAS to manned-platform refueling due to system and safety complexity. Overall, AAR received 87.5% agreement by all SMEs that AAR would have at least a HITL level of autonomy.

The remaining two pilots from the subgroup both assigned an autonomy Level 3 for future AAR missions. The academia and acquisitions subgroups assigned this category an average of Level 4, or human-on-the-loop. All three groups predicted a level of autonomy above the current trend in autonomous capabilities enabled missions which are typically described as having human-in-the-loop autonomy (Level 2 on our scale and in accordance with DoD Directive 3000.09). The overall group assigned level of autonomy averaged a 3.9 on our autonomy scale. To reach such a level, sense & avoid, traffic alert and collision avoidance systems (TCAS), and manned-unmanned team (MUM-T) technology would need to be developed and tested to appropriate levels.

Defense companies are currently competing to provide the Armed Services with autonomous aerial refueling (AAR) unmanned platforms such as the X-47B and MQ-25. As an example of the expanding multi-role capabilities expected of future mission platforms, companies such as Northrup Grumman, Lockheed Martin, Boeing and General Atomics aim to integrate interfaces for compatibility with ISR, land and ship-based systems, and C2 capabilities, extending mission functionality beyond AAR. SMEs from the UAS community are likely familiar with these efforts and as such, understandably expect this capability to make its way into the Air Force in the foreseeable future.

4.6.3 Strike/Attack

Similar Strike/Attack missions were presented by SMEs in both current and future mission areas. Currently, UAS designated as UCAVs or with otherwise weaponized autonomous capabilities have the strongest restrictions as outlined by DoD Directive 3000.09. Yet, of all the future mission types identified, this category received the most inputs as a future capability.

Seven subcategories were listed under Strike/Attack. Of the seven subcategories, only the Decoy/Wingman mission type received an input on assignment of autonomy. The Decoy/Wingman mission also had the overall highest average level of autonomy assigned at 3.9, or very close to HOTL. When all Strike/Attack projected levels of autonomy are averaged, the projected level of autonomy was 3.6, which is closer to HOTL than to HTIL. Although the pilot subgroup continued assigning the lowest levels of autonomy for future missions, on average, they assigned a minimum of HITL autonomy for Strike/Attack missions. The multiple weapons related missions listed warranted an additional bar graph figure for the subcategories as can be found below in Figure 4.7.

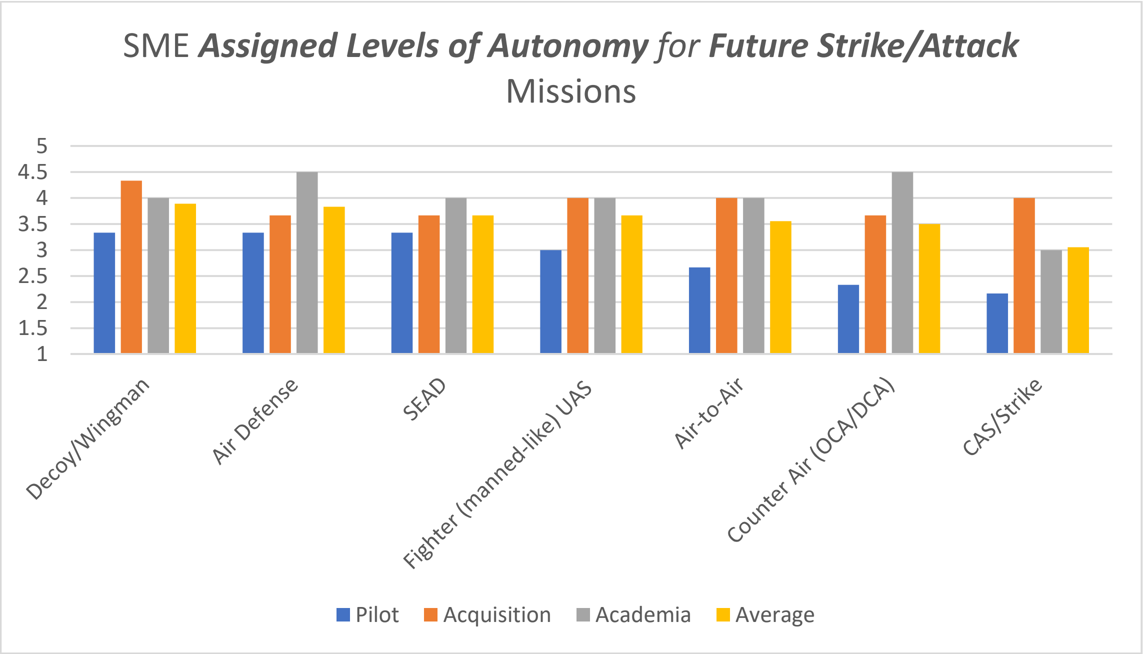


Figure 4. 7 Future Levels of Autonomy for Strike/Attack Missions

The pilot SME subgroup was the only group with panelists providing an autonomy level of 1 to some subcategories in the Strike/Attack (CAS and OCA/DCA). One SME from the acquisition subgroup, SID05, disagreed that OCA/DCA, Air-to-Air, CAS, and Fighter UAS would be a mission type in a 20-year forecast for UAS. Accordingly, this SME did not assign a level of autonomy to any of the aforementioned future missions from Table 4.4. The SME cited concerns over legal and technical requirements for humans to walk through the "kill chain". However, under the Decoy/Wingman mission type, the same SME assigned an autonomy level of 4 (HOTL). Under the subcategory of Suppression of Enemy Air Defenses (SEAD), at least one member from each subgroup predicted some aspect of fully autonomous capabilities, or an assignment of autonomy Level 5.

As with the AAR in the previous section, it's very likely that SMEs have read or seen news stories related to the future capability of a Wingman/Decoy mission such as Air Force Research Laboratory (AFRL) 2018 USAF 2030 video depicting what aerial warfare may look like by the end of the decade. In the video, stealthy, semi-autonomous UCAVs fly in a wingman formation creating a barrier of protection and surrounding an F-35 in a manned-unmanned team which is referenced as the "Loyal-Wingman" concept. The subcategory with the overall lowest level of autonomy assigned was CAS/Strike Support. This lower assignment of autonomy coincides with the overall consensus on overcoming trust challenges, especially where UAS are expected to operate with greater degrees of autonomous capabilities in close proximity to ground forces in a congested or contested environment.

4.6.4 Cargo, Supply/Resupply

Although Cargo and Supply/Resupply are presented as two separate categories in Table 4.4, the autonomy levels assigned for these mission areas were similar and consistent across all three subcategories for all three SME subgroups. Thus, here, they are presented under one heading. All three subcategories received 100% consensus as a future mission type. One pilot SME assigned all three subcategories a Level 1 autonomy; another pilot assigned all HITL, the third assigned a 2, 3, and 4. Acquisition and academia SMEs assigned autonomy levels of 4 and 5. The scenarios typically described for these types of missions include delivery of logistics resupply or other essential supply, such as ammo or medical supply to ground troops in difficult to reach areas or in dangerous areas with high threat levels. In the past, the Army and USMC have primarily taken the lead role for initiatives in this area with UAS (e.g. the joint tactical autonomous resupply system (JTARS) and the Kaman K-MAX helicopter respectively) due to the ground operations inherent to each branch. Varying requirements related to payload capability and take-off & landing (TO&L) will be unique to CONOPS and mission applications. Ground troops in austere environments would likely need rotary wing and VTOL capable UAS, easy enough to transport but capable of carrying and delivering supplies to designated locations. However, as evidenced by SME responses, the Air Force could potentially play an important role in these mission areas, most likely for fixed-wing solutions.

4.6.5 EW, Cyber and C2

There was a consensus that Electronic Warfare (EW) and C2 would be a future UAS autonomous mission. Cyber received an 87.5% consensus as a future mission type; one pilot

SME questioned how Cyber could be a UAS mission. The range of autonomy assigned for each of the three missions was consistent within the subgroups. The pilot subgroup assigned EW and C2 autonomy levels of 1, 2, and 3. The acquisition subgroups assigned EW, C2 and Cyber a level of autonomy ranging from 3 to 5, corresponding to an average HOTL as seen in Figure 4.5. The academia subgroup assigned an autonomy level of 4 (also HOTL) for all three mission types.

As the three mission areas were presented separately by SMEs during round one, they were reintroduced in round two, but with EW/Cyber as one category with two subcategories (Cyber operations/support and Electronic Warfare) and C2 as its own category. Figure 4.7 (above) shows that the pilot SME subgroup assigned C2 with an average autonomy level of HITL and EW at a lower 1.6. These two categories were rated by the pilot subgroup only slightly higher than their lowest mission category, Supply/Resupply and Cargo.

The three mission areas of EW, Cyber and C2 are important aspects for UAS to operate in A2/AD environments. EW typically encompasses three subcategories: Electronic Attack (EA), electronic protection (EP) and Electronic warfare support (ES). The objective in EW is to control the electro-magnetic spectrum (EMS) to enable friendly forces to operate while denying or denying the enemy EMS. This could mean anything from controlling, blocking, or redirecting cellular phone traffic to directed energy applications. It’s often included in the broader context of SEAD. EW is a mission area which has already been implemented in some UAS platforms for development as well as theater applications (Pocock, 2014), (UAS Vision Editor, 2017). Of course, UAS are also susceptible to EW and cyber-attacks by adversaries. Because of the EMS related nature of EW, cyber-attack/defense strategies could be another closely related, separate, or multi-function mission for UAS. Both EW and Cyber create opportunities and risks to UAS through the C2 and sensor-data link architecture.

4.6.6 sUAS Applications

Several categories were geared toward sUAS, such as Swarms, sUAS Battlefield Coverage, and Sentry/Base Protection. All of the sUAS categories listed above received full 100% consensus as future UAS autonomous mission areas. All three categories also received inputs for associated future levels of autonomy. The category of sUAS Battlefield Coverage, received the most consistent subgroup level of autonomy assignments. The pilot subgroup assigned a consistent HITL, while acquisition and academia subgroups all agreed to assign HOTL autonomy. The sUAS Swarm category was predicted to reach HOTL autonomy by the academia subgroup, with the acquisition subgroup leaning more toward full autonomous capability. Sentry/Base Protection was not specifically presented as a sUAS mission type, but in comments, SMEs referred to the mission as primarily a sUAS role. The range of autonomy assignment across the three subgroups was 3 to 4 for the acquisition and academia subgroup and 2 to 4 for the pilot subgroup.

The majority of USIR and other UAS future vectoring documents portray sUAS as taking a prominent role in swarm missions. Sentry and Base Protection mission scenarios are often described as rotary-wing or sUAS which may be used to persistently or periodically monitor military installation or forward operating location perimeters for breaches, suspicious signals, or incoming threats.

4.6.7 Ballistic Missile Defense

Ballistic Missile Defense and Counter-Space Operations UAS received the most comments in round two when presented as a potential future mission type. There was no consensus that it would become a mission area in the next 20 years. However, several panelists considered it a mission in some future state beyond the 20 year forecast. At least one SME from each subgroup disagreed that it would be a future mission type and subsequently did not assign a level of autonomy. The range of autonomy levels assigned for both mission types for the acquisition and academia subgroups was 3 to 4, while the pilot subgroup assigned a future autonomy level of 2 to 5.

Future missions were listed in an order somewhat consistent with how confident SMEs believed UAS would be used in 20 years. Overall, as one SME put it, ISR is the UASs 'bread and butter' that is to say, ISR will likely continue to be the primary mission for UAS. Many other areas are currently in practice, progress, or under development. It is well known that UAS with hellfire missiles are used in today's military arsenal. There's still much debate about governing lethal behavior in autonomous systems and creating the right level of policy to guide developers and stakeholders in the UAS community. Areas such as AAR and cargo and supply delivery are already being tested and utilized by other military branches. Other growing areas of opportunity for UAS are EW, Cyber, and C2 as well as many applications for sUAS, all with opportunities to maximize the evolving capabilities of autonomous technology. One important linking element to connect current capabilities to future predicted mission areas is to properly identify a comprehensive list of challenges as seen by key stakeholders. The next section discusses four broad challenge areas that were identified during round one and reintroduced to panelists to be rated by level of importance and prediction of time estimates to resolving those challenges listed.

4.7 Challenges to Future UAS Autonomous Capabilities

Using SMEs to forecast potential future UAS missions likely to develop over the next 20 years and predicting their levels of autonomy set the frame of reference to allow SMEs to explore the challenges to reach those capabilities. After panelists were asked to identify current and future missions, they were asked to list at least two of the primary challenges to reaching the listed autonomous mission capabilities. The challenge areas identified will become a key element for recommendations to those interested in the findings of this research. This section helps to bridge the gap between what could be and creating planning strategies to address obstacles to achieving more advanced autonomous UAS capabilities.

Challenges to meeting current and future autonomous UAS mission capabilities identified by SMEs during round one were categorized into four areas: Discussing Autonomy (Taxonomy), Technology, Data, and Programmatic related challenges. Each of these four areas were further broken down into six to eight associated subcategories. In round two, challenges were reintroduced to SMEs in a table format along with Likert scale for panelists to indicate the level of importance they would assign to each identified challenge as well as to estimate a timeframe for which they believe the issue would likely be resolved. The rating-scale method was used to then translate values assigned (derived from Likert scales) for each subcategory into a graphical representation of the scales. The following section discusses panelist responses, identifies trends, areas of convergence, and areas of divergence.

In round two, 30 challenges were reintroduced to SMEs. Four categories were created to make rating similar or related challenges more orderly and easier to rate. Two figure pairs were created for each of the four categories. A complete set of ratings assigned to challenges is available in Appendix C with figures from each subgroup for estimated timeframe ratings attached in Appendix D. In the subsections below, an abbreviated version with only the top five average rated challenge areas by level of importance will be presented. Each figure shows an ordered list of the top five subcategories with the highest level of importance by mean score of the three SME subgroups in descending order. Observations on SME subgroup estimates and average estimates will also be made. The full list of challenges identified by SMEs presented in round two for Likert scale assignment can be seen below in Table 4.5. A summarized table with panelist responses is also available in Appendix C.

Table 4. 5 SME Identified Challenges to Future UAS Mission Capabilities

Identified Challenges to Future UAS Mission Capabilities		
	Level of Importance	Likelihood of Solving Issue
1. Technical 1.1 Sense & Avoid Technology		
1.2 Cognitive Decision making – AI, ML		
1.3 Human - Machine (Teaming) Interaction Technology		
1.4 System Complexity and Emergent Behavior		
1.5 DoD Adopting/Keeping Pace with Evolving Technology		
1.6 Data Links Improvement		
1.7 Secure and Reliable Connectivity		
1.8 Mission Planning and Command & Control		
2. Information/Data Needed to Accomplish Missions 2.1 Sense, Detect, and Avoid Data Required for Swarms, AAR, etc.		
2.2 Improved Data Links to Handle Increased Volume of Data		
2.3 Networking Capability to Integrate Connect Existing Systems		
2.4 Applications to Integrate Civil and Military Domain Data		
2.5 Need for Middleware to Address/Handle Interoperability/Volume of Data		
2.6 Software Development to Handle/Managing Increased Volume of Data		
2.7 Algorithms/Methods to Access/Use Existing Data while Collecting Data		
2.8 Information Analysis and Decision Support		
3. Programmatic/ Acquisition 3.1 Acquisition Time/ Development Time		
3.2 General Cost/Time to Develop New Aircraft or UAS Technology/Systems		
3.3 Increased Cost of Networking Capability		
3.4 DoD Adopting/Keeping Pace with Evolving Technology		
3.5 Need for UAS Autonomy Program Office/ Guidance/ Program of Record		
3.6 T&E V&V – Current T&E Inadequate for Autonomous UAS		
3.7 Risk Aversion – Belief that Failure Means it Can't be Done		
4. Challenges to Discussing Autonomy 4.1 No Common Agreed upon Language for 'Autonomous Systems'		
4.2 Tech Maturity Levels and Tech Readiness Levels do Not Match Evolving Nature of Autonomous Capabilities (e.g. for 'Learning/Predicting' Technology)		
4.3 Political – Competing Budgeting and Control of Resource Issues		
4.4 Political – Lack of Trust in UAS – Fear over Loss of Control/Mishaps/Accidents		
4.5 Misconception about UAS Control – Currently, UAS are 'Pilot Controlled'		
4.6 Lack of Policy Guidance or Sufficient Guidance		
4.7 Cultural – Years of Manned Aircraft Mentality		

4.7.1 Technology Challenges Discussion

Technology Challenges to reaching future UAS autonomous mission capabilities included eight subcategories. There was consensus that all listed technology challenges listed were areas of importance to solving future UAS mission capabilities, but there was no consensus by all participants that any challenge listed at a particular level of importance. However, within the subgroups, the pilot SME subgroup all agreed that solving the challenges improving Data Links technology was of the "Highest Importance." Likewise, in the challenge area of sense-and-avoid technology, the acquisition SME subgroup agreed this was an area of the 'Highest Importance' to future autonomous UAS capabilities. At least on SME from each subgroup mentioned the need for continued development in the areas of sense-and-avoid technology and improved data links technology in round one. These two subcategories received the highest mean score in terms of assignment of highest level of importance. When asked to predict a time estimate or likelihood for developing the technology or resolving the challenge area of these top two subcategories, all SME groups showed optimism that the issues would be resolved within the next ten years. The pilot SME group showed the most optimism in these two categories indicating that on average, they believe the issues could be resolved in as little as five years. This observation was particularly interesting in terms of contrasting optimism or confidence when considering their position on predicting levels of autonomy; pilots on average, were the subgroup most likely to assign the lowest levels of autonomy for any give mission type.

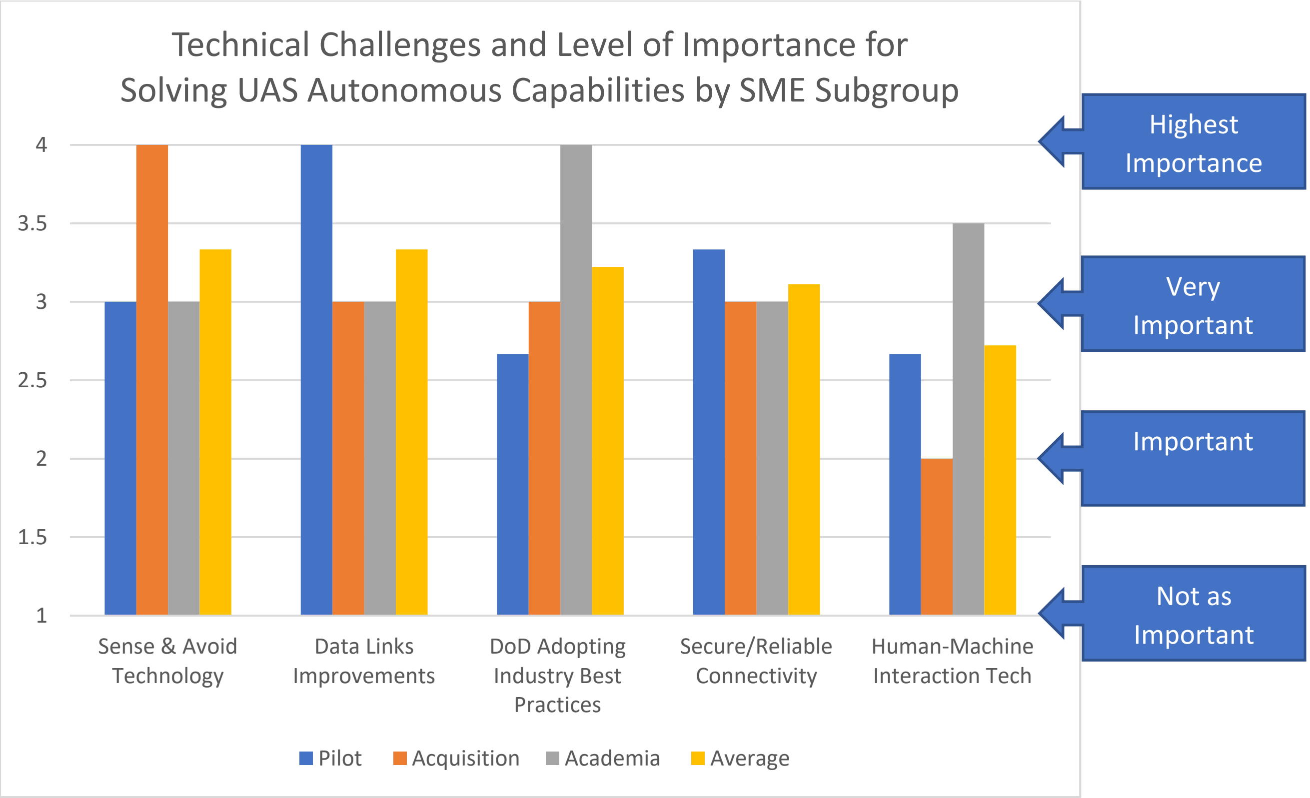


Figure 4. 8 Top Rated Technical Challenges by SME Subgroups

The next three challenge areas that received the highest level of importance by SME subgroup mean were DoD Adopting/Keeping Pace with Evolving Technology, Secure and Reliable Connectivity, and Human-Machine (Teaming) Interaction Technology. The Academia subgroup had consensus that DoD needing to adopt or keep pace with evolving technology was of the "Highest Importance." In the comments section, this challenge area was described in the context of the commercial UAS industry achieving faster development and testing and the military's bureaucratic and acquisition hurdles to integrating COTS solutions. There was also mention of agile acquisition methods being implemented at a more rapid pace in the same industry while the DoD is perceived to be more risk averse. The need for technology development for Secure and Reliable Connectivity received the highest level of consensus at 85% on “Very Important” with one pilot SME assigning the subcategory one level of importance higher. The last of the top five technical challenge areas was Human-Machine (Teaming) Interaction Technology. There was no consensus from any subgroup on the level of importance for this subcategory. The academia SMEs rated this area with the highest level of importance among the three subgroup of SMEs. There was consensus in the opinion of SMEs that all five challenge areas would be resolved within the next 20 years. There were minimal comments made to elaborate or support the ratings given to levels of importance or time estimates in the challenges section of the Delphi.

4.7.2 Data Related Challenges

Round one included a question which asked panelists to identify the data/information that would be needed to accomplish missions they listed. A list of eight data related challenges were reintroduced in round two for the same rating consideration as other challenge areas. Below, Figure 4.9 shows the top five data related challenge areas as rated by SMEs.

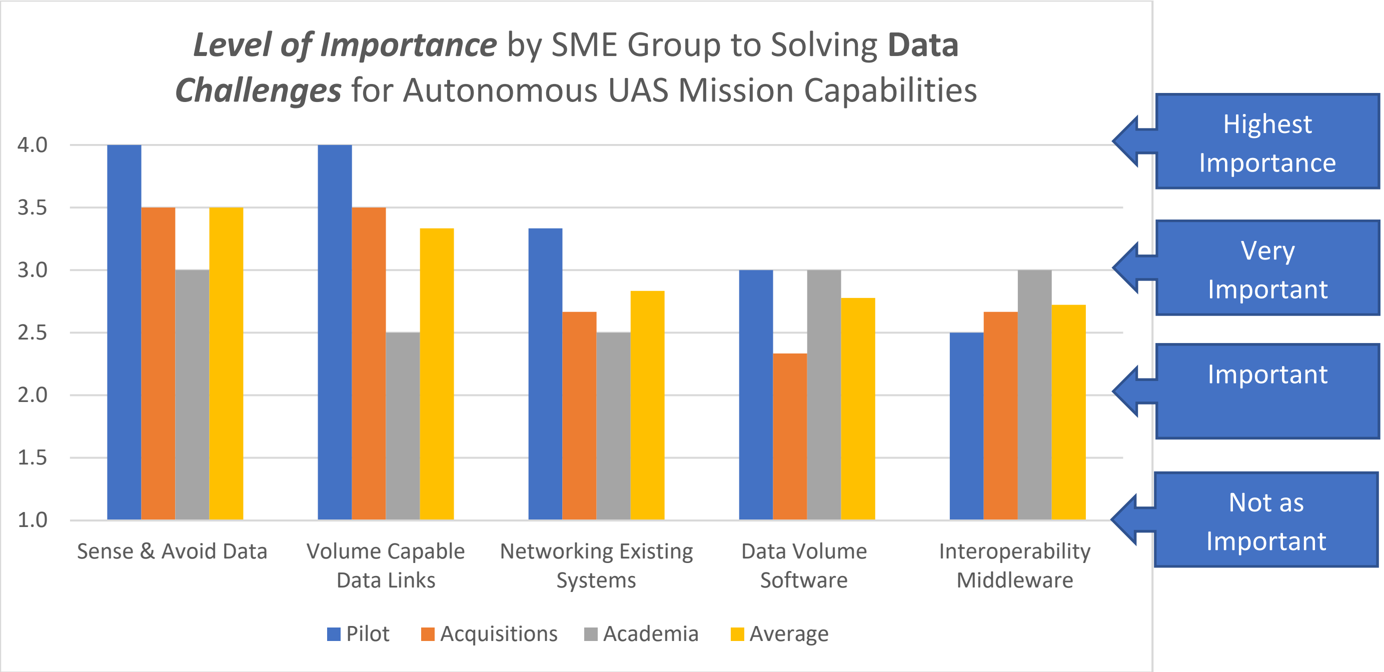


Figure 4. 9 Top Rated Data Related Challenges by SME Subgroups

Again, sense-and-avoid was rated as having the 'Highest Importance' level with all responses indicating a level of "Very Important" or higher. In this case, the specific challenge area is focused on solving the data handling side of the problem. In estimating the timeframe for solving sense-and-avoid data challenges, the overall group of SMEs was optimistic and predict a solution is within the next five to ten years. Both technical and data related challenges to sense-and-avoid were estimated to be resolved in the nearest amount of time. However, as mentioned in the previous section, minimal comments were provided to elaborate on the reasoning behind ratings. Volume Capable Data Links, Networking Existing Systems, Software to Handle Volume of Data, and Interoperability Middleware (items 2.2, 2.3, 2.6 and 2.5 from Table 4.4, Identified Challenges to Future UAS Capabilities) were next most important data challenge as viewed by SMEs.

Again, as with the technology challenges section above, the data links related challenge item was ranked second in terms of SME rated level of importance to reaching future mission capabilities. In questionnaire data challenge section, the item was titled Improved Data Links to Handle Increased Volume of Data, in the above bar graph (Figure 4.9), it is abbreviated to Volume Capable Data Links. As with the technical challenge section, the three subgroups were consistent in assigning higher levels of importance on the Likert scale. The pilot SME subgroup assigned a “Highest Importance” level, which was the same rating as the technical challenge item of Data Links Improvements. There was no consensus on the remaining items listed under data related challenges. The top five data related challenges also happened to be the five areas estimated to be resolved in the nearest future. This interrelated connection between how important a particular challenge area is and how confident or how soon SMEs estimate the problem will be resolved is interesting to say the least. Further, the data related subcategories of Decision Analysis Support and Agency Data Integration were rated as least important and were similarly predicted to be issues resolved with the most pessimistic view; most SMEs estimated the issues to be resolved within 20 years.

4.7.3 Programmatic Related Challenges

Figure 4.10 shows the top areas of importance as rated by SMEs to related programmatic challenge areas. In round one, panelists listed various programmatic/acquisition related issues in the open-ended section for describing perceived challenges to reaching future UAS autonomous mission capabilities. Overall, the levels of importance given to programmatic challenges was not as high when compared to technical and data related challenges.

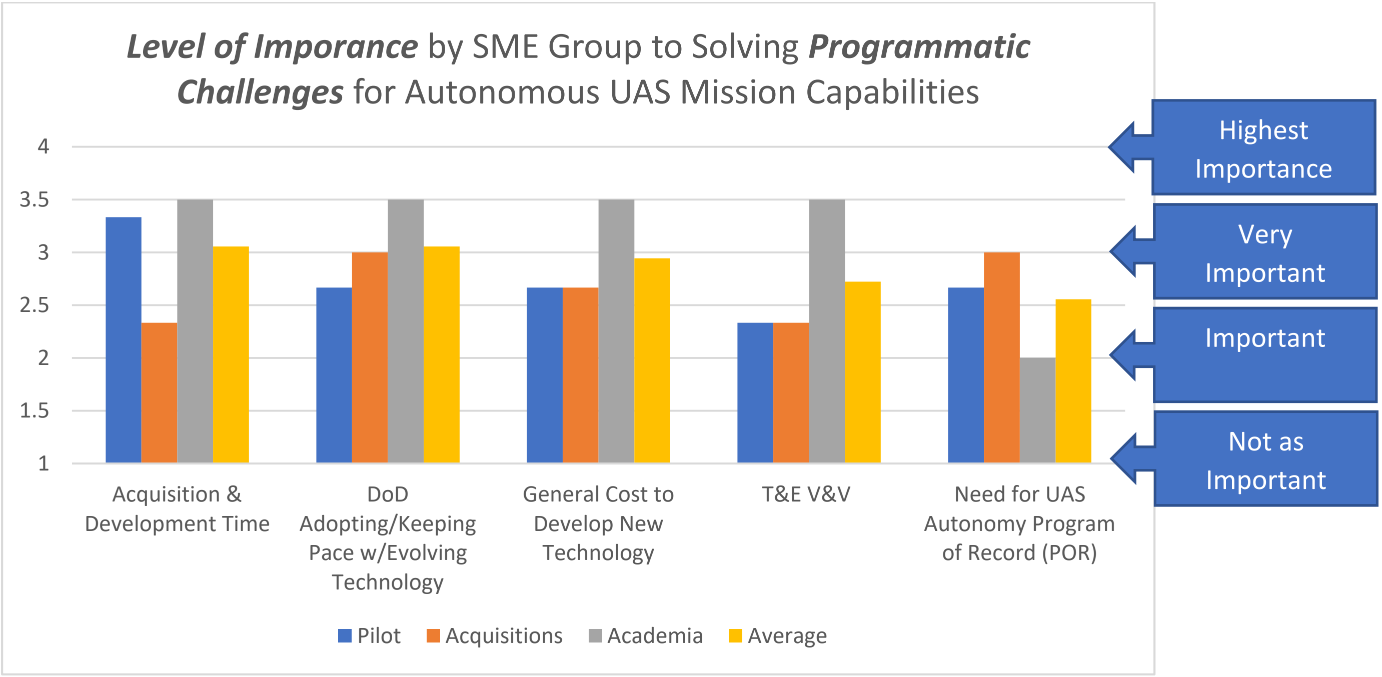


Figure 4. 10 Top Rated Programmatic Related Challenges by SME Subgroups

Acquisitions and Development Time and DoD Adopting/Keeping Pace with Evolving Technology were the two highest rated challenge subcategories for level of importance assigned by SME mean rating. The next top rated area of importance in the programmatic challenges was a subcategory titled General Cost to Develop New Technology. This third subcategory was very closely related to Acquisition & Development Time, but received slightly different ratings. The first subcategory emphasized time, while the third emphasized cost. There was also less consensus across the subcategories for programmatic challenge areas. Although the fourth subcategory on the list, T&E V&E and the third subcategory show the pilot and acquisition SME subgroups agreeing on a mean rating level, the individual ratings ranged from "Not as Important" to "Highest Importance" for the acquisition subgroup while for the pilot subgroup, it ranged between "Very Important" to "Important." Each SME subgroup had individuals who assigned a rating of "Not as Important" to at least one of the seven subcategories listed; the acquisition SME subgroup assigned the most "Not as Important" ratings and the academia SME subgroup assigned the least. Here again, a similar subcategory from another challenges section was presented (before sense-and-avoid and data links were repeated). DoD Adopting/Keeping Pace with Evolving Technology was presented here in the programmatic section and again in the technical challenges section. Again, the item was in the top three (third for technology and second for programmatic challenges) subcategories for perceived level of importance by SME group to solving challenges. Whereas before, the timeline estimates for resolving the problems seemed to match the levels of importance for that challenge, in the programmatic section, this was no longer seen; Acquisition & Development Time and General Cost to Developing New Technology were seen as likely resolved within 20 years.

4.7.4 Challenges to Discussing Autonomy

In the earliest stages of preparing for this study, disparate views about definitions of autonomy, levels of autonomy, and autonomous UAS capabilities were a found in key documents, such as the NIST's ALFUS and the Defense Science Board (DSB) Task Force on the Role of Autonomy in DoD Systems. As the Delphi pertained directly to discussing future autonomous capabilities, the last question in the round one instrument addressed the challenges to discussing autonomy. In addition to asking an open-ended question to allow SMEs to identify challenges they perceived to reaching future mission capabilities and a specific question to identify data challenges, they were also asked to discuss "autonomy." Panelists were asked to consider previous responses—answering questions about challenges to reaching autonomous UAS mission capabilities and assignment of autonomy levels to missions listed.

Seven subcategories were listed under Challenges to Discussing Autonomy. This section referred to the taxonomy related issues to addressing all other challenges when discussing autonomy. There was the least consensus over level of importance assigned by SMEs for this area. Two subcategories were presented to panelists with the heading of *political*: 1) Political - Competing Budgets and Control of Resources and 2) Political - Lack of Trust in UAS—Fear Over Loss of Control/Mishaps/Accidents. In round one, there were eleven mentions of the word "political" by various SMEs in discussing challenges to reaching future UAS autonomous capabilities. The political related issues often blurred the line between funding, data rights (to ISR info obtained), cultural pushback, and general fear over "Skynet"-type concerns. The comments were abstracted to the above two headings. Panelists did not disagree with the categorization of the issue and in fact rated them as having the highest levels of importance as challenge areas that needed to be addressed.

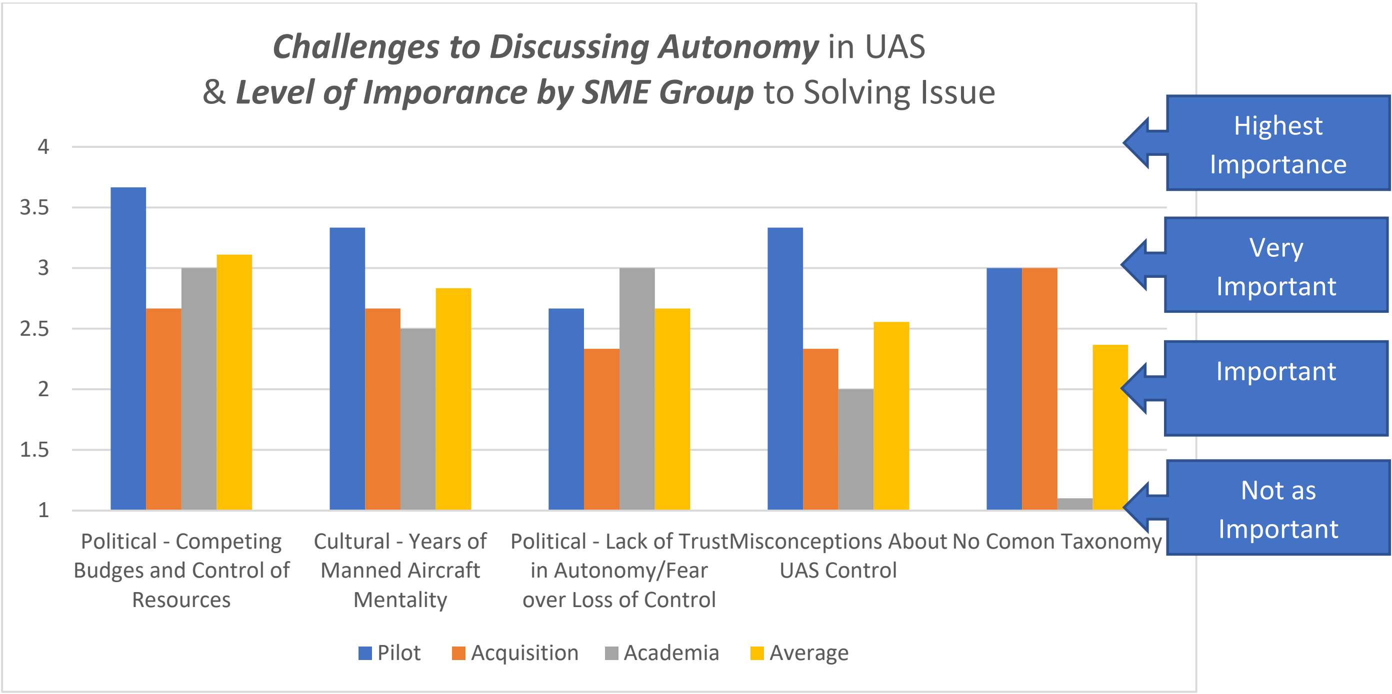


Figure 4. 11 Top Rated Taxonomy Related Challenges by SME Subgroups

The second highest mean rated level of importance on the graph was Cultural—Years of Manned Aircraft Mentality. Every SME in round two assigned a level of "Important" or higher with the pilot SME subgroup assigning it the highest importance rating from the Likert scale. The subcategories Misconceptions About UAS Control received a similar perceived level of importance rating as the closely related lack of trust subcategory, but with a higher level of importance rating assigned by the pilot SME subgroup. Finally, No Common Taxonomy was rated as "Very Important" by both the pilot and acquisitions SME subgroups as a challenge area that needs to be resolved. The academia SME subgroup rated the problem of not having a common taxonomy as "Not Very Important."

4.8 Summary

This chapter discussed results of the two-round Delphi study. First, the set-up of the Delphi was discussed in terms of criteria and demographics of the SME panelists, guidelines and definitions provided to panelists for each round, and an overview of the Delphi rounds administration was presented. Then, we discussed consensus and details about SME identified current mission and levels of autonomy assigned along with current mission challenges. Next, the focus was shifted consensus assessment and discussion of round two feedback on future missions and levels of autonomy assigned to those missions. The last section discussed four general areas SMEs identified as challenges to reaching future mission capabilities. SMEs assigned levels of importance to resolving challenge areas and assigned estimated timeframes for resolving the challenge areas.

V. Conclusion

5.0 Overview

This chapter discusses the overall findings from the research effort. Discussion of predicted future UAS mission areas over the next 20 years with estimated levels of autonomy are based on SME feedback. SMEs clearly and confidently anticipated increased levels of autonomous capabilities across numerous future UAS mission areas compared to current autonomy levels. Additionally, challenges related to reaching future mission capabilities are presented in a ranked order in terms of how important SMEs considered those challenges listed. With over 960 input responses from three key stakeholder communities, recommendations are presented for decision makers in UAS leadership positions to consider for maximizing the potential of UAS capabilities. Recommendations for UAS decision makers are presented after the summary of findings are discussed. The Delphi study is discussed in the post qualitative research context and lessons learned are also presented. Additionally, the limitations of this study and the Delphi technique in general are presented. Finally, future areas of research are suggested

5.1 Findings Summary

The results from the two-round Delphi study reflect the insights of the stakeholder SMEs from the RPA pilot, the acquisition, and academic communities. Future UAS autonomous mission capabilities were identified by SMEs and were subsequently evaluated for consensus or divergence. A total of eight SME panelists were used in the study. In an open-ended round one iteration of the Delphi, panelists provided responses and comments identifying current and future missions, levels of autonomy for those missions, and the challenges they considered most pressing to reaching UAS autonomous mission capabilities. Round two provided the information necessary to determine areas of consensus and other opportunities to characterize how SMEs within and across subgroups were similar or different. A total of 120 responses were required of SME panelists during round two.

From the current mission challenge areas provided by SMEs in round, a summarized table of challenges (Table 4.3) indicated that it was potentially possible to characterize SME subgroups (pilot, acquisition, academia) by the challenges each subgroup listed. Information provided by SMEs in round one was categorized, edited, abstracted, and organized into tables for a round two iteration. In round two, SMEs were asked to either agree with or disagree with current and future missions listed by fellow panelists. They were also asked to assign levels of autonomy to future missions using a provided guide for either no autonomy, human-in-the-loop (HITL), human-on-the-loop (HOTL), an option for somewhere between HITL and HOTL which we termed 'shared autonomy', or fully autonomous. The guides were derived from DoD Directive 3000.09, the UAS Roadmap, and the National Institute of Standards and Technology (Intelligent Systems Division). For Part II of round two, challenges to reaching future autonomous UAS capabilities from round one were listed under four categories as: Technology Related Challenges, Data Related Challenges, Programmatic Related Challenges, and Taxonomy Related Challenges. SMEs were asked to use a Likert scale to gauge two aspects of each challenge item listed—they were asked to assign a level of importance to solving the challenges listed as well as assigning an estimated timeframe of when they believed the issue would likely be resolved.

A total of 31 future missions were provided during round 1. The missions were categorize into 12 general categories and 21 subcategories and provided back to the panelists during the round 2 iteration to check for consensus and to assess where the groups estimated levels of autonomy to be in 20 years for the missions listed. Table 5.1 is similar to Table 4.4, but with an additional column to indicate which missions the panelists agreed would likely occur within 20 years. There was consensus on all but BMD and Counter-Space Operations (items 10 and 12 on the list below).

Table 5. 1 Table of Future Mission Areas Identified by SMEs with Consensus

Future Mission Areas Identified by SMEs		
General Category	Response Subcategory	Consensus?
1. ISR	1.1 ISR (Enhanced)	Y
2. Strike/ Attack	2.1 Suppression of Enemy Air Defenses (SEAD)	Y
	2.2 Air Defense	Y
	2.3 OCA/DCA (Offensive/Defensive Counter Air)	Y
	2.4 Air-to-Air	Y
	2.5 Fighter UAS Similar to Manned Fighter Aircraft	Y
	2.6 Decoy/Wingman	Y
	2.7 CAS/Strike Support	Y
3. Supply/ Resupply	3.1 Supply Delivery	Y
	3.2 Logistics Resupply	Y
4. Cargo	4.1 Cargo – Current Cargo Aircraft Missions	Y
5. Aerial Refueling	5.1 Various types – UAS to UAS, UAS to Manned Aircraft, Manned Aircraft to UAS	Y
6. sUAS Battlefield Coverage	6.1 Wide Area Search/Engagement	Y
	6.2 Networked UAS	Y
7. C2	7.1 Command and Control	Y
8. Sentry Ops	8.1 Sentry/Base Protection	Y
9. EW/ Cyber	9.1 Electronic Warfare	Y
	9.2 Cyber Operations/Support	Y
10. BMD	10.1 Ballistic Missile Defense	N
11. Swarms	11.1 Various Swarm Enabled sUAS Capabilities	Y
12. Counter Space	12.1 Counter-Space Operations	N

Table 5.2 lists the top ranked challenge areas by mean scored Level of Importance as identified by SMEs. Four categories listed a total of 30 subcategory challenge areas identified by SMEs. The list below shows the nine challenge areas that were assigned a mean rating of "Very Important" on a scale of Not Important (1), Important (2), Very Important (3), and Highly Important (4). The category column indicates the broader challenge area while the right-hand column lists the overall mean score from all three subgroups.

Table 5. 2 Challenges to Future Missions Rated Most Important by SME Panelists

Level of Importance: 4=Highest Importance, 3=Very Important, 1=Not as Important Categories: Technology (T), Data (D), Programmatic (P), Taxonomy (O)	Category T, D, P, O	Overall Mean Rated Level of Importance
Challenge Areas Identified by SMEs		
Sense, Detect, and Avoid Data Challenges (Required for AAR, Swarms, etc.)	D	3.50
Sense & Avoid Technology (Sensors, Software)	T	3.33
Improved Data Links to Handle Increased Volume of Data	D	3.33
Data Links Improvements (Connectivity, Security, Latency, etc.)	D	3.33
DoD Adopting Keeping Pace w/Evolving Technology (Industry Best Practices)	T	3.22
Political – Competing Budgets and Control of Resources	O	3.11
Secure/Reliable Connectivity	T	3.11
Acquisition & Development Time	P	3.05
DoD Adopting Keeping Pace w/Evolving Technology (Industry Best Practices)	P	3.05

Overall, each SME subgroup increased assigned levels of autonomy for future mission capabilities. The RPA pilot SME subgroup consistently assigned lowest levels of autonomy. Identifying future missions helped to guide SMEs to think about potential challenges to reaching future autonomous UAS mission capabilities. By identifying challenges from the perspective of the stakeholder subgroup, decision makers can compare other forecasting documents such as the various USIRs to identify potential gaps or to investigate technology development areas tied to challenges listed by SMEs. As seen in the results and analysis section, each subgroup of SMEs listed different challenges as being most important within their own subgroups. In general however, the top five challenge areas identified by each subgroup for the general challenge categories showed similarities across all panelists. In other words, the lesser important challenges were overall ranked as low by the entire group, while the top ranked challenge areas showed more variation in how each subgroup prioritized concerns.

5.2 Study Conclusions

This Delphi study research provides new insight to decision makers for what current pilots, acquisition professionals, and academics believe to be the current and future challenges to maximizing the potential of autonomous UAS capabilities. The Delphi method also proved to have some utility (with caution given to consider the limitations of the technique in section 5.5). There was utility in that the technique proved to yield similar results to USIRs, which shows some consistency with the DoD's "Unmanned Systems Vision" and SMEs outlook for future capabilities. Although the FY 2019 DoD budget has increased with a focus on modernization and includes many areas related autonomous technology, specific decisions must still be made about where to focus funding and efforts. Leveraging the expertise of stakeholders could identify gaps that could otherwise prove to be costly. Further, the study provides an assessment of challenges, gaps and opportunities as viewed by key stakeholders. The qualitative analysis of the study can be used as input for decision makers toward development areas and where to dedicate resources for the advancement of autonomous UAS capabilities. Although the results, findings and recommendations are non-exhaustive, the study could be aligned with other findings to further identify gaps. This Delphi technique could also be expanded to a wider population either within the communities explored in this paper or to other key stakeholders such as policy makers, members of the T&E community, industry vendors, or other technical experts and decision makers.

It is clear UAS with increased autonomous capabilities are evolving rapidly to emerge as indispensable tools for the Air Force and the DoD at large. As decision makers prepare for future mission needs, platforms and technology development areas, a diversity of key stakeholders throughout the unmanned systems community provide a comprehensive view to bridge the gap between needs and challenge areas. Air Force leaders can bring alignment within its professional UAS organizations to maximize performance by ensuring DoD and USAF policies and guidance on autonomy are consistent and understood by the appropriate stakeholders in that community. This research helps to identify where potential gaps exist in the technological vision set in documents such as the USIRs and how individual SME communities view challenges to reaching future capabilities. As adversaries and competitors have easier access to UAS technologies in ways that is categorically different than that of traditional manned-aircraft platforms and systems, the Air Force must find ways take advantage of opportunities to develop areas which may otherwise be overlooked. One of the potentially overlooked area and seemingly innocuous areas for assessing development needs is to allow organizations and stakeholder communities to operate in stovepipes where lessons learned aren't shared, where the right mix of perspective and expertise is not fully considered, and where hindrances to achieving fuller capabilities go unchecked.

5.3 Recommendations

No concrete recommendations can be made from this study alone, however, it is strongly recommended that decision makers and stakeholders further investigate opportunities to leverage a comprehensive view that includes subject matter experts from key communities. Further discussions should be considered for challenge areas identified in this study. The main challenge areas that require discussion in this section are on the areas of Sense and Avoid, Data Links Improvements, and DoD Adopting practices to keep pace with industry progress. Although many of the 30 challenge areas were viewed as having lower priority and/or lacking consensus as to their perceived level of importance for reaching UAS autonomous capabilities, it should not be overlooked that the challenges listed were nonetheless introduced by various SMEs during round one. A majority of these lesser 'ranked' challenges were acknowledged by a majority of the study's participants as valid concerns which present potential hindrances to reaching future UAS capabilities and should not be dismissed. It is recommended that all areas listed be incorporated into future discussions to ensure a diverse stakeholder perspective is considered comprehensive strategic planning.

Sense and avoid technology plays a vital role in the adoption and integration of UAS in civilian airspace. It also is key to development of other technology areas such as swarms and AAR as it is the primary mechanism by which aircraft avoid collisions with each other. A variety of active and passive sensor technology solutions such as machine vision, radar and wireless transmitter pairs are currently used, but sensor data fusion solutions are needed to provide more robust-sense and-avoid capabilities (Yanmaz et al., 2018). Data links improvements was rated as the second and third most important challenge area by SMEs. Data links was presented in two broader categories: technology and data related challenges. In both cases, it was consistently ranked as a top concern. As missions increase in the near future, new bandwidth strategies will need to be developed to handle the volume of data and number of connections to ground operators or ground stations. SMEs as a whole also highlighted the time and cost to acquire and develop autonomous UAS technologies.

Another recommendation is to consider incrementally adopting proven civilian and commercial industry best practices where advances in autonomous UAS technology development outpace the military. As technology becomes more readily available on the global market, adversaries are able to take advantage of more advanced capabilities compared to the much slower defense acquisition strategy currently practiced. Although shifting paradigms in the acquisition process does appear to be underway as evidenced by a limited number of program transformations (Rapid Acquisition Programs, Agile Acquisition, Big Safari, BBB3.0, etc.) the stakeholders identified in this Delphi study still see a gap between current technology development capabilities and the adoption of acquisition programs adequately matched to the rapidly evolving area of autonomous systems.

When we discuss the challenge of the DoD needing keep pace with industry, we’re really saying that the DoD needs to adopt some of the commercial “best practices”. The Government IT Modernization Act initiative by TIA Now provided a number of recommendations to the president in 2017 (“Report to the President on Federal IT Modernization - Introduction to the Report,” 2017): Build on what’s already known, change gears from building custom code to an open architecture so we don’t have to spin our wheels on redevelopment efforts.

Other challenge areas that weren't ranked as being most important are still nonetheless areas which should be considered by decision makers. For example, the challenge of developing appropriate metrics for Technology Readiness Levels (TRLs) to match descriptions with autonomous capabilities was rated as 'Not Important' by at least one panelist in each subgroups (others rated it Important, Very Important and Highest Importance), yet to progress through current the current acquisition process, TRLs would still be a factor. In the case of the TRL challenge, one could interpret the level of importance assigned to mean that it's more important to develop the actual technology capabilities. Still, it's important to consider these lesser rated challenges as development and funding are dedicated to other priorities.

The study showed that SMEs from different subgroups shared priorities in some areas while having different priorities in others in terms of which challenge areas they saw as being most important to solve. Guidance and policy updates can be provided to subgroups or the larger UAS community wherever challenges were identified as being highly important. Many of the overarching challenges related to discussing autonomous systems dealt with taxonomy and a common understanding of what it means for a UAS to have "autonomy". However, the Taxonomy related challenges section received the lowest levels of importance. Some researchers and leaders in UAS technology have advocated abandoning the use of levels of autonomy. For some, including SMEs from the academia subgroup, getting hung up on definitions has been viewed as a hindrance to making progress. However, there appears to be a need for guidance and specific meanings to describing capabilities in terms of levels of autonomy (HITL, HOTL, and fully autonomous). Policy makers must strike the right balance of defining autonomous capabilities while enabling innovation within industry. Guidance on common terminology, frameworks and architectures will lead to interoperability and a more flexible and responsive Joint enabled force.

A program office in charge of spearheading many of the overall challenges identified in this study was recommended by all three SME subgroups. One possible solution to address many of the problems listed is to stand up a Program of Record (POR) to be responsible for coordinating efforts and disseminating critical information. However, the group listed resolving the challenge of standing up a POR as being ranked among the least important with a mean score of 2.5; still, halfway between important and very important. Such a program office would be in charge of disseminating guidance and policy on taxonomy, sharing information across Services and program offices who deal with UAS, focusing efforts on common architectures to enable interoperability between systems, and reviewing and developing the best strategies for the important aspects of T&E and V&V (TEVV) requirements needed for fielding the enhanced capabilities autonomous systems bring to the warfighter.

5.4 Lessons Learned

During round two, panelists were asked to provide a number of responses which in retrospect, may have been too many. For Part II of round two, the Identified Challenges to UAS Mission Capabilities, panelists were asked to assign a two-part Likert scale rating for four sections with a total of 30 subcategories. This section alone amounted to 60 inputs from participants. Prior to the Part II, panelists were also asked to agree or disagree (and comment) on current and future missions identified by other SMEs, as well as assigning levels of autonomy for future mission areas, this section also amounted to a total of 60 input responses. As a result, it is believed that the Part II section of the Delphi received the least number of comments or questions in the section provided which was intended to allow panelists to elaborate on answers. While no specific SME gave any indication of burnout or the same response for consecutive listed items (or a firewall response), it is possible that the list was excessive and that such a long list may have dissuaded participants from spending additional time to provide valuable information that could have been gathered from a comments section. Upon performing the analysis, there were items which could have been combined or not included, if for example they were similar enough subcategories or if minimal participants listed a low count challenge in round one. Additionally, had a round three occurred, panelist responses from round two could have been made clearer. For example, one panelist rated all levels of importance as only either "Important" or "Not as Important". It wasn't until the analysis of responses that it was realized that the SME most likely transposed the Likert scale. In future efforts, it would be recommended to administer three rounds, reduce the number of responses required to stimulate responses in the comments section and reduce the possibility of burnout, and use a method to ensure panelists understood the rating scale; perhaps in this study's case, panelists could have been asked to respond with HI, VI, I, NI, or an intermediate section which reminds panelists of what the scale values indicate.

5.5 Limitations

Due to the complexity of issues and technologies covered, no guarantee can be made about future mission capabilities or how experts might change their minds about the importance of solving the listed challenges. Nonetheless, the current assessment is in essence, checking the pulse of a community at large to see what underlying technology and scientific advances may be required to meet future capability needs. One limitation which should be highlighted is that the small sample size (n=8) of participants used in this study may not adequately represent each the each subgroup represented or the larger community as a whole. Still, the future mission capability forecasts and challenges identified in the study were consistent with many of the challenges identified in other key DoD unmanned systems forecasts and roadmaps which to a limited degree, validates both the Delphi technique and the subgroup's views. Due to the small sample size, the results of the study should be viewed with some caution and followed up with a larger similar study.

By identifying potential future mission areas and the challenges to reaching those capabilities, the forecasted areas of development represent *one* component of a more comprehensive strategic approach to selecting more effective research and development investments or program initiatives. While the Delphi can be used to obtain certain types of information not usually available from other scientific methods (namely comments and consensus versus strictly quantitative data), it should also be emphasized that the technique should be combined or compared with other analytic materials. In this study, efforts were not made to compare nor combine the results with other relevant UAS documents. The Delphi as a standalone technique for suggesting recommendations is in itself, an inherent limitation. It will be recommended in the future work section, to make such comparisons with related UAS materials as well as expanding the number of iterations to reveal additional information about challenge areas identified. The third and last limitation mentioned addresses additional information that could have been gathered from a third iteration of the research instrument. Although information on which challenges were viewed as being most important were rated by the participants and analyzed and ranked by the researcher, a third round would have allowed the group to respond to the overall ranked order. Thus, panelists would have had the opportunity to comment on whether they agreed with the interpretations made in the results section and additionally, they would have been able suggest adjustments to the rank order or make comments based on the groups' overall inputs. By adding the third round, additional information or reasoning behind responses as well as confirmation over consensus or divergence of opinions could be better represented.

5.6 Future Research

The findings and results summarized in round two present a starting point for many additional areas of continued or future research. First and foremost, a third round of the Delphi study would be the immediate follow-on recommendation to this study. A third round would allow further clarification and validation of the synthesized responses and would allow panelists the opportunity to evaluate recommendations made within this study. While it has been discussed that there are literature references to the sufficient quality of a two round Delphi, there appeared to be much more support suggesting that three rounds would add rigor and validity to the methodology and results (Kim & Yeo, 2018). Likewise, it could be beneficial to take a similar panel of experts and re-administer the study to further verify characterizations of subgroups; further confirming or challenging the technique as it was applied in this study.

Additionally, the practice of combining Delphi results with other analytic tools was discussed earlier in the methodology section. It was recommended that the Delphi should ideally be part of a comprehensive futures planning exercise, joining with other qualitative and quantitative methods in order to create confidence in a more robust cross impact analysis to decision makers. To this end, multi-criteria decision making analysis or market analysis related to key challenge areas for reaching future UAS autonomous capabilities identified in this study could provide in depth information to help decision makers plan and fund programs and initiatives with reduced risk.

A third option could be to conduct an additional forecasting Delphi study within the next five, ten, or twenty years to reevaluate the direction of future UAS autonomous mission capabilities. Such a study would have a two-fold benefit: 1) the study could assess the accuracy of the forecast estimates stated within this study, and 2) lessons learned from this study could be applied to jump-start a more focused Delphi in key challenge areas or specific future UAS autonomous mission areas. Building on the previous two future research recommendations, a subsequent study could combine other related analytic planning tools with information from this study. In the subsequent study, a narrower focus area (e.g. MUM-T, AAR, EW) conducted among a similar panelist-makeup could present analysis at a granular level with more specific recommendations.

Finally, any single future UAS autonomous mission area could be investigated further from a requirements perspective with the results of this study as a tool for assessing potential gaps in traceability. Researchers could compare the list of priorities found in table 5.3 with system requirements for the given system of interest to verify whether or not the autonomous UAS stakeholder priorities found in this study are consistent

5.7 Summary

This chapter summarized the results stemming from a two-round Delphi study utilizing stakeholder SME subgroups from UAS pilot, acquisition, and academia communities. Future UAS autonomous mission capabilities were presented by the subgroups and subsequently evaluated for consensus or divergence over the challenge areas of technical, data, programmatic, and discussing autonomy. From the discussion section, key areas for discussion and development are presented as recommendations to UAS or autonomous system decision makers. This section also discusses recommendations and benefits with respect to combining the Delphi forecast findings with other analytic types of reports. Before concluding, limitations of the study are briefly presented. The last section discussed recommendations for possible continued areas of research related to this work.

Appendix A. Round 1 Research Instrument

Air Force Institute of Technology
Demographics & Research Questionnaire – Round 1

Purpose: The purpose of this study is to project the future of UAS technology given USAF focus on autonomous mission capabilities. UAS have varying degrees of autonomous technology, as such autonomy is an important factor when considering current and future UAS mission sets.

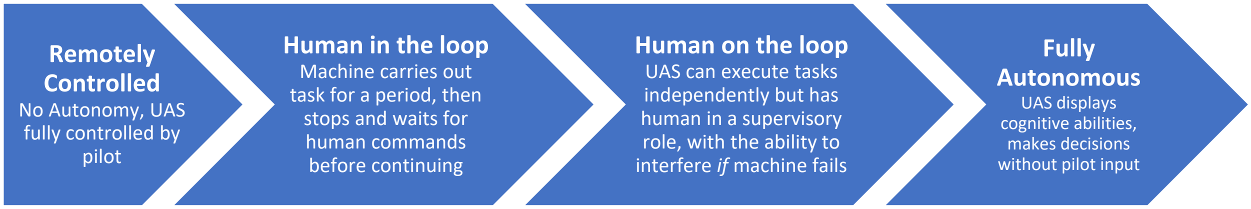
The following statements guide this studies consideration of autonomy as a concept:

1) Autonomous capabilities are defined as the technologies that enable unmanned flight and autonomous behavior in the absence of an onboard pilot.

2) Three key attributes as described by the National Institute of Standards and Technology (NIST) should be considered when discussing autonomous capabilities: 1) Operator independence, 2) Environmental Difficulty and 3) Mission Complexity.

3) DoD Directive 3000.09, Autonomy in Weapon Systems, defines autonomy in three categories: 1) Semi-Autonomous (man in the loop), 2) Human-Supervised (man on the loop), and 3) Autonomous (human out of the loop).

4) The spectrum of autonomous control ranges from remotely guided to fully autonomous.



The goal of this research is to evaluate and understand the direction UAS capabilities are likely to take over the next 20 years. Professionals in the UAS community provide a valuable perspective on challenges and opportunities for near and long-term planning. The desired outcome is to create a forecast of key technologies in order to more effectively plan for and dedicate resources. One technology forecasting method used in the research community is the Delphi Study. This research will be conducted via the Delphi Study method, in which the researcher engages subject matter experts to help develop a consensus of opinion. The researchers will send out subsequent questionnaires to develop and refine expert opinions. At the conclusion of this research effort the researchers intend to publish and present the results, as well as brief those results to leaders in the UAS acquisition community.

Researchers: Capt Alberto Sigala AFIT/ENV advised by Dr. Brent Langhals AFIT/ENV

Disclaimer: As a survey respondent, you have the ability to self-eliminate from participating in any current or future surveys, at any time. No adverse action will be taken against anyone who chooses not to not participate in current or future research. Survey responses will be recorded anonymously, and your comments will not be attributable to you when/if the research is published. Your responses will be maintained IAW the Privacy Act Statement of 1974. By filling out and responding to this questionnaire, you are hereby acknowledging and consenting to your participation in this research.

Privacy Act Statement: Your survey response contains FOR OFFICIAL USE ONLY (FOUO) information which must be protected under the Freedom of Information Act (5 U.S.C. 552) and/or the Privacy Act of 1974 (5 U.S.C. 552a). Unauthorized disclosure or misuse of this PERSONAL INFORMATION may result in disciplinary action, criminal and/or civil penalties. Further distribution is prohibited without the approval of the author of this survey unless the recipient has a need to know in the performance of official duties. If you have received this survey in error, please notify the sender and delete all copies of this survey.

Demographics

Part 1: Participant Demographics

1. What is your Rank:
2. What is your current Job Title:
3. What is your Air Force Specialty Code (if applicable)?
4. What type of UAS(s) do you have experience with? How many years?
5. In what capacity did you interact with the UAS system listed in question 4?

Round 1: Research Questions

Part 2: Research Questions

1. Based on your experience and expertise, what primary missions does the USAF currently assign to UAS?

    a. List primary missions as you understand them:

    b. Assign a level of autonomy on a scale of 1 - 5 to each mission you listed. 1 equals no autonomy (pilot fully controls) and 5 equals fully autonomous (UAS Control). Place the corresponding number next to the missions you listed in 1a.

1	2	3	4	5
No autonomy (fully remote controlled)	Human-in-the-loop (HITL)	Pilot & UAS share control	Human-on-the-loop (HOTL)	Fully autonomous (No pilot – UAS makes cognitive-like decisions)

*As a reminder, **HITL** is described as: *UAS carries out task for a period, then stops and waits for human commands before continuing.*
HOTL is described as: *UAS can execute tasks independently but has a human in a supervisory role, with the ability to interfere if/as necessary.*

    c. Based on the missions listed in question 1a, what are the two greatest challenges to accomplishing those missions (manning, technical, political, other) and why you believe the challenges exit?

2. How do you envision the USAF will/could use UAS technology ***20** years from now*? Respond in 2a and 2b with respect to missions that are likely to stay the same and consider any new missions types that could emerge?

    a. List missions that you believe are not likely to change and why:

    b. List any new missions you expect may/could emerge:

    c. Assign a level of autonomy on a scale of 1 - 5 to each mission you listed in 2b. Where 1 equals no autonomy (pilot fully controls) and 5 equals fully autonomous (UAS Control). Place the corresponding number next to the missions you listed in 2a and 2b.

1	2	3	4	5
No autonomy (fully remote controlled)	Human-in-the-loop (HITL)	Pilot & UAS share control	Human-on-the-loop (HOTL)	Fully autonomous (No pilot – UAS makes cognitive-like decisions)

d. Based on the missions listed in question 2b, what are at least two of the greatest challenges to accomplishing those missions (manning, technical, political, other, etc.) **and** *why* do you believe the challenges exit?

3. For questions 1 and 2, *what critical data/info is needed to accomplish the missions* identified? *Does the data/info currently exist* or *do we need to develop new technology* (sensors, architecture, software, etc.) to collect and use the data/info?

4. Consider your responses to the above questions, what are some of the challenges to ***discussing*** "autonomy" in UAS?

If you have any questions about this research request, please contact Capt Alberto Sigala (primary investigator) – Phone 850-529-2314; Email: Alberto.sigala@afit.edu, or Dr. Brent Langhals, Brent.Langhals@afit.edu

Appendix B. Round 2 Research Instrument

Air Force Institute of Technology
Demographics & Research Questionnaire – Round 2

Purpose: The purpose of this study is to project the future of UAS technology given USAF focus on autonomous mission capabilities. UAS have varying degrees of autonomous technology, as such autonomy is an important factor when considering current and future UAS mission sets.

The following statements guide this study's consideration of autonomy as a concept:

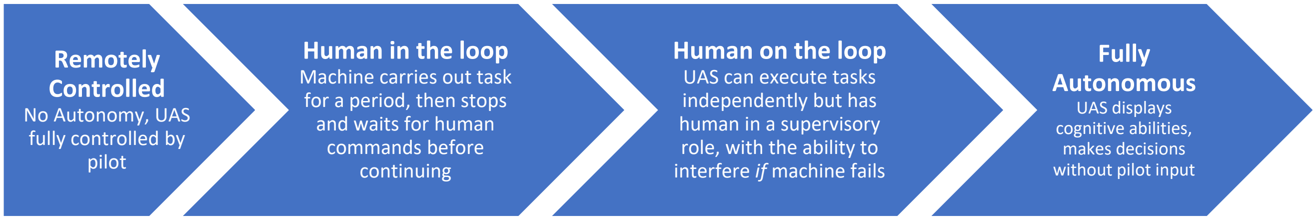
1) Autonomous capabilities are defined as the technologies that enable unmanned flight and autonomous behavior in the absence of an onboard pilot.

2) Three key attributes as described by the National Institute of Standards and Technology (NIST) should be considered when discussing autonomous capabilities: 1) Operator Independence, 2) Environmental Difficulty, and 3) Mission Complexity.

3) DoD Directive 3000.09, Autonomy in Weapon Systems, defines autonomy in three categories: 1) Semi-Autonomous (man in the loop), 2) Human-Supervised (man on the loop), and 3) Autonomous (human out of the loop).

4) The spectrum of autonomous control ranges from remotely guided to fully autonomous.

Guide for Level of Autonomy Assignment



Remotely Controlled
No Autonomy, UAS fully controlled by pilot

Human in the loop
Machine carries out task for a period, then stops and waits for human commands before continuing

Human on the loop
UAS can execute tasks independently but has human in a supervisory role, with the ability to interfere *if* machine fails

Fully Autonomous
UAS displays cognitive abilities, makes decisions without pilot input

1	2	3	4	5
No autonomy (fully remote controlled)	Human-in-the-loop (HITL)	Pilot & UAS share control *	Human-on-the-loop (HOTL)	Fully autonomous (No pilot – UAS makes cognitive-like decisions)

* Autonomous control level of 3 indicates a level of autonomous functionality between HITL and HOTL.

Round 2 Research Instrument

Round 2: Overview

The participants of this Delphi study comprise a cross section of experts from various disciplines in the UAS and sUAS community. This round of questions presents an opportunity for feedback to determine if members across the various backgrounds view the future of UAS through a similar lens. The results may help gain insight into soliciting better requirements from stakeholders in the acquisition process. Participants are asked to respond as thoroughly as possible (by answering each item in the tables below) in order to determine if a consensus of opinions can be reached in the final round.

Round 2 consists of two parts. Part 1 asks participants to review mission types provided by SMEs during Round 1 and indicate whether they agree or disagree with the provided lists; reasons for disagreeing with a mission area should be provided in the comment section. Part 2 addresses the challenges identified by participants during Round 1. SMEs should review the provided list and rank the challenges in terms of importance and likelihood of being resolved. A guide for responding is provided in Part 2. Each Part is followed by an optional comments section for participants to make any comments.

Part 1:

The following tables list current and future mission types identified by SMEs participating in round one of this Delphi Study.

1. Do you agree with the mission types listed in Tables 1 and 2?

   In the right-hand column in the table below, please fill in a 'Y' (Yes) or 'N' (No) to indicate that you agree (Y) or disagree (N) for each mission type listed. If you disagree with the mission listed or the categorization of mission type, please provide statements as to your reason why you disagree in the comments section below Tables 1 and 2.

   Comments: (use section after Table 3 if more space is needed)

Current Missions Identified by Delphi Participants

General Category	Response Subcategory	Agree (Y/N)?
1. ISR	1.1 ISR (general)	
	1.2 Reconnaissance	
	1.3 Persistent Reconnaissance	
	1.4 Autotomized C2ISR Threats - (collect, detect, report)	
	1.5 Deliberate Targeting	
	1.6 Target Tracking	
2. Strike/Attack	2.1 Close Air Support (CAS)	
	2.2 Hunter/Killer (Full Motion Video)	
	2.3 Surface Attack	
	2.4 Attack	
	2.5 Persistent Strike	
	2.6 Interdiction/Strike Ops	
	2.7 Target Prosecution	
3. CSAR	3.1 Combat Search & Rescue	
4. Comm/ Relay	4.1 Communications Relay	
5. Other	5.1 Various support functions	

Table B2. Future Missions Identified by Delphi Participants

General Category	Response Subcategory	Agree (Y/N)?
1. ISR	1.1 ISR (Enhanced)	
2. Air Defense/ Strike/ Attack	2.1 Suppression of Enemy Air Defenses (SEAD)	
	2.2 Air Defense	
	2.3 OCA/DCA (Offensive/Defensive Counter Air)	
	2.4 Air-to-Air	
	2.5 Fighter UAS similar to manned fighter aircraft	
	2.6 Decoy/Wingman	
3. Supply/ Resupply	3.1 Supply Delivery	
	3.2 Logistics Resupply	
4. Cargo	4.1 Cargo – Current cargo aircraft missions	
5. Aerial Refueling	5.1 Various types – UAS to UAS, UAS to manned aircraft, manned aircraft to UAS	
6. sUAS Battlefield Coverage	6.1 Wide Area Search/Engagement	
	6.2 Networked UAS	
	6.3 CAS/Strike support	
7. C2	7.1 Command and Control	
8. Sentry Ops	8.1 Sentry/Base Protection	
9. EW/ Cyber	9.1 Electronic Warfare	
	9.2 Cyber Operations/Support	
10. BMD	10.1 Ballistic Missile Defense	
11. Swarms	11.1 Various Swarm enabled sUAS capabilities	
12. Counter Space	12.1 Counter-Space operations	
13. Other	13.1 Various support or existing manned aircraft missions	

2. For the future missions identified in round one, what level of autonomy would you expect to exist in 20 years?

   Table 3 lists the same missions listed from Table 2, but asks Delphi participants to identify a Projected Level of Autonomy for Future UAS Missions (right hand column). Assign a level of autonomy for **each** mission type listed using the following guide.

1	2	3	4	5
No autonomy (fully remote controlled)	Human-in-the-loop (HITL)	Pilot & UAS share control *	Human-on-the-loop (HOTL)	Fully autonomous (No pilot – UAS makes cognitive-like decisions)

* Autonomous control level of 3 indicates a level of autonomous functionality between HITL and HOTL.

Projected Level of Autonomy for Future UAS Missions		
General Category	Response Subcategory	Level of Autonomy 1 2 3 4 5
1. ISR	1.1 ISR (Enhanced)	
2. Air Defense/ Strike/ Attack	2.1 Suppression of Enemy Air Defenses (SEAD)	
	2.2 Air Defense	
	2.3 OCA/DCA (Offensive/Defensive Counter Air)	
	2.4 Air-to-Air	
	2.5 Fighter UAVs similar to manned fighter aircraft	
	2.6 Decoy/Wingman	
3. Supply Resupply	3.1 Logistics Resupply	
	3.2 Supply Delivery	
4. Cargo	4.1 Cargo – Current cargo aircraft missions	
5. Aerial Refueling	5.1 Various types – UAV to UAV, UAV to manned aircraft, manned aircraft to UAV	
6. sUAS Battlefield Coverage	6.1 Wide Area Search/Engagement	
	6.2 Networked UAS	
	6.3 CAS/Strike support	
7. C2	7.1 Command and Control	
8. Sentry Ops	8.1 Sentry/Base Protection	
9. EW/ Cyber	9.1 Electronic Warfare	
	9.2 Cyber Operations/Support	
10. BMD	10.1 Ballistic Missile Defense	
11. Swarms	11.1 Various Swarm enabled sUAS capabilities	
12. Counter Space	12.1 Counter-Space Operations	
13. Other	13.1 Various support or existing manned aircraft missions	

Part 2: Addressing Challenges to UAS Mission Capabilities

Development of UAS autonomous technology will have a direct impact on future mission capabilities. In Round 1, SMEs identified multiple challenges associated with reaching the maximum potential of current and future mission types. Many of the challenges listed in Table 4 below are well known, yet continue to exist within the UAS development community. Use the following guide to ***assign a level of importance*** to solving the challenges as well ***your predicted estimate*** of when the issue is likely to be resolved. Add any additional comments in the section below Table 4; optionally, provide a solution to any of the challenges presented.

Level of Importance Guide				
1	**2**	**3**	**4**	**5**
Highest Importance	**Very Important**	**Important**	**Not as Important**	**NR** = No Response or 'I don't know"

Likelihood of Resolving the Challenge or Developing the Technology				
1	**2**	**3**	**4**	**5**
Very Likely Within the next 5 Years	**Likely** Within the next 10 Years	**Possible** Within 20 Years	**Not Likely** Will likely continue to be a problem beyond 20 Years	**NR = No** Response or 'I don't know"

Identified Challenges to UAS Mission Capabilities		
	Level of Importance	**Likelihood of Solving Issue**
1. Technical 1.1 Sense & Avoid Technology		
1.2 Cognitive Decision making – AI, ML		
1.3 Human - Machine (teams) Interaction Technology		
1.4 System Complexity and Emergent Behavior		
1.5 DoD Adopting/Keeping Pace with Evolving Technology		
1.6 Data Links Improvement		
1.7 Secure and Reliable Connectivity		
1.8 Mission planning and Command & Control		

2. Information/Data Needed to Accomplish Missions 2.1 Sense, detect, and Avoid data required for swarms, Air-to-Air refueling, etc.		
2.2 Improved Data Links to handle increased volume of data		
2.3 Networking Capability to integrate connect existing systems		
2.4 Applications to integrate civil and military domain data		
2.5 Need for Middleware to address/handle interoperability/volume of data		
2.6 Software development to handle/managing increased volume of data		
2.7 Algorithms, methods, techniques to access/use existing data while collecting data		
2.8 Information analysis and decision support		
3. Programmatic/ Acquisition 3.1 Acquisition Time/ Development Time		
3.2 General cost/time to develop new aircraft or UAS tech		
3.3 Increased Cost of Networking Capability		
3.4 DoD Adopting/Keeping Pace with Evolving Technology		
3.5 Need for UAS Autonomy Program Office/ Guidance/ Program of Record		
3.6 T&E V&V – Current T&E inadequate for Autonomous UAS		
3.7 Risk Aversion – Belief that failure means it can't be don		
4. Challenges to Discussing Autonomy 4.1 No common agreed upon language for 'Autonomous Systems'		
4.2 Tech Maturity Levels and Tech Readiness Levels do not match evolving nature of autonomous capabilities (e.g. for 'learning/predicting' tech)		
4.3 Political – Competing Budgeting and Control of Resource issues		
4.4 Political – Lack of Trust in UAS – Fear over loss of control/mishaps/accidents		
4.5 Misconception about UAS control – Currently, UAS are 'pilot controlled'		
4.6 Lack of Policy guidance or sufficient guidance		
4.7 Cultural – Years of manned aircraft mentality		

Comments Section:

Appendix C. Research Instrument Responses

Summary of Identified Challenges to UAS Mission Capabilities
Perceived Level of Importance by SME Group to Solving Challenges

	Level of Importance							
1. Technical 1.1 Sense & Avoid Technology	**2**	**1**	**3**	**1**	**NR**	**1**	**2**	**2**
1.2 Cognitive Decision making – AI, ML	**2**	**2**	**4**	**1**	**4**	**2**	**2**	**2**
1.3 Human - Machine (teams) Interaction Technology	**1**	**3**	**3**	**3**	**4**	**2**	**2**	**1**
1.4 System Complexity and Emergent Behavior	**2**	**NR**	**4**	**2**	**4**	**1**	**3**	**2**
1.5 DoD Adopting/Keeping Pace with Evolving Technology	**4**	**1**	**2**	**1**	**3**	**2**	**1**	**1**
1.6 Data Links Improvement	**1**	**1**	**1**	**2**	**3**	**1**	**2**	**2**
1.7 Secure and Reliable Connectivity	**2**	**2**	**1**	**2**	**NR**	**2**	**2**	**2**
1.8 Mission planning and Command & Control	**1**	**1**	**4**	**3**	**4**	**3**	**3**	**3**
2. Information/Data Needed to Accomplish Missions 2.1 Sense, detect, and Avoid data required for swarms, Air-to-Air refueling, etc.	**1**	**1**	**NR**	**1**	**NR**	**2**	**2**	**2**
2.2 Improved Data Links to handle increased volume of data	**1**	**1**	**1**	**2**	**NR**	**1**	**3**	**2**
2.3 Networking Capability to integrate connect existing systems	**2**	**1**	**2**	**2**	**4**	**2**	**3**	**2**
2.4 Applications to integrate civil and military domain data	**1**	**3**	**3**	**4**	**3**	**3**	**4**	**2**
2.5 Need for Middleware to address/handle interoperability/volume of data	**2**	**NR**	**3**	**3**	**3**	**1**	**2**	**2**
2.6 Software development to handle/managing increased volume of data	**2**	**1**	**3**	**3**	**4**	**1**	**2**	**2**
2.7 Algorithms, methods, techniques to access/use existing data while collecting data	**2**	**1**	**3**	**3**	**4**	**1**	**3**	**2**
2.8 Information analysis and decision support	**1**	**3**	**4**	**2**	**4**	**2**	**5**	**2**
3. Programmatic/ Acquisition 3.1 Acquisition Time/ Development Time	**1**	**2**	**2**	**1**	**4**	**3**	**1**	**2**
3.2 General cost/time to develop new aircraft or UAS tech	**2**	**2**	**3**	**1**	**4**	**2**	**1**	**2**
3.3 Increased Cost of Networking Capability	**1**	**2**	**3**	**3**	**4**	**2**	**3**	**3**
3.4 DoD Adopting/Keeping Pace with Evolving Technology	**3**	**2**	**2**	**2**	**3**	**1**	**1**	**2**

3.5 Need for UAS Autonomy Program Office/ Guidance/ Program of Record	**2**	**3**	**2**	**1**	**3**	**2**	**2**	**4**
3.6 T&E V&V – Current T&E inadequate for Autonomous UAS	**4**	**1**	**3**	**3**	**3**	**2**	**1**	**2**
3.7 Risk Aversion – Belief that failure means "*it can't be done*"	**2**	**3**	**NR**	**3**	**3**	**2**	**1**	**4**
4. Challenges to Discussing Autonomy 4.1 No common agreed upon language for 'Autonomous Systems'	**1**	**1**	**4**	**2**	**3**	**1**	**4**	**4**
4.2 Tech Maturity Levels and Tech Readiness Levels do not match evolving nature of autonomous capabilities (e.g. for 'learning/predicting' tech)	**2**	**2**	**4**	**3**	**3**	**2**	**4**	**3**
4.3 Political – Competing Budgeting and Control of Resource issues	**1**	**1**	**2**	**2**	**3**	**2**	**2**	**2**
4.4 Political – Lack of Trust in UAS – Fear over loss of control/mishaps/accidents	**1**	**3**	**3**	**3**	**3**	**2**	**3**	**1**
4.5 Misconception about UAS control – Currently, UAS are 'pilot controlled'	**2**	**2**	**1**	**3**	**3**	**2**	**4**	**2**
4.6 Lack of Policy guidance or sufficient guidance	**3**	**NR**	**4**	**3**	**3**	**3**	**2**	**4**
4.7 Cultural – Years of manned aircraft mentality	**2**	**1**	**2**	**1**	**3**	**3**	**2**	**3**

Summary of SME Identified Challenges to UAS Mission Capabilities ***Timeframe Estimates to Solving Challenges***								
	Likelihood of Solving Issue							
1. Technical 1.1 Sense & Avoid Technology	**1**	**1**	**1**	**2**	**2**	**1**	**2**	**1**
1.2 Cognitive Decision making – AI, ML	**2**	**2**	**3**	**3**	**3**	**4**	**4**	**3**
1.3 Human - Machine (teams) Interaction Technology	**3**	**1**	**3**	**3**	**3**	**2**	**2**	**2**
1.4 System Complexity and Emergent Behavior	**2**	**NR**	**NR**	**3**	**3**	**3**	**3**	**3**
1.5 DoD Adopting/Keeping Pace with Evolving Technology	**4**	**2**	**3**	**3**	**3**	**3**	**4**	**2**
1.6 Data Links Improvement	**1**	**2**	**1**	**3**	**2**	**3**	**2**	**2**
1.7 Secure and Reliable Connectivity	**3**	**2**	**1**	**3**	**3**	**2**	**4**	**2**
1.8 Mission planning and Command & Control	**1**	**2**	**NR**	**3**	**1**	**2**	**1**	**1**
2. Information/Data Needed to Accomplish Missions 2.1 Sense, detect, and Avoid data required for swarms, Air-to-Air refueling, etc.	**2**	**1**	**NR**	**2**	**2**	**3**	**1**	**2**

2.2 Improved Data Links to handle increased volume of data	2	2	2	3	1	3	2	2
2.3 Networking Capability to integrate connect existing systems	3	2	2	3	1	2	2	2
2.4 Applications to integrate civil and military domain data	1	3	1	3	2	3	4	3
2.5 Need for Middleware to address/handle interoperability/volume of data	2	NR	2	3	1	3	1	3
2.6 Software development to handle/managing increased volume of data	2	2	2	3	1	3	1	3
2.7 Algorithms, methods, techniques to access/use existing data while collecting data	4	2	3	3	1	1	1	3
2.8 Information analysis and decision support	1	2	3	3	1	2	NR	3
3. **Programmatic/ Acquisition** 3.1 Acquisition Time/ Development Time	1	2	3	3	4	3	4	4
3.2 General cost/time to develop new aircraft or UAS tech	2	2	2	3	4	3	4	4
3.3 Increased Cost of Networking Capability	1	1	2	2	4	2	4	2
3.4 DoD Adopting/Keeping Pace with Evolving Technology	NR	2	3	2	3	2	4	2
3.5 Need for UAS Autonomy Program Office/ Guidance/ Program of Record	2	3	2	2	2	3	4	4
3.6 T&E V&V – Current T&E inadequate for Autonomous UAS	4	3	2	2	3	3	4	3
3.7 Risk Aversion – Belief that failure means it can't be don	2	2	2	2	4	2	4	NR
4. **Challenges to Discussing Autonomy** 4.1 No common agreed upon language for 'Autonomous Systems'	2	3	4	1	3	2	4	NR
4.2 Tech Maturity Levels and Tech Readiness Levels do not match evolving nature of autonomous capabilities (e.g. for 'learning/predicting' tech)	2	3	2	2	4	3	4	2
4.3 Political – Competing Budgeting and Control of Resource issues	2	4	2	2	4	3	4	4
4.4 Political – Lack of Trust in UAS – Fear over loss of control/mishaps/accidents	NR	4	3	2	4	3	4	2
4.5 Misconception about UAS control – Currently, UAS are 'pilot controlled'	NR	3	3	2	3	4	4	2
4.6 Lack of Policy guidance or sufficient guidance	3	5	4	2	2	2	4	1
4.7 Cultural – Years of manned aircraft mentality	4	3	3	2	2	3	3	2

Projected Level of Autonomy for Future UAS Missions

General Category	Response Subcategory	Level of Autonomy 1 2 3 4 5							
		01	02	03	04	05	06	07	08
1. ISR	1.1 ISR (Enhanced)	5	2	*	5	4	5	4	4
2. Air Defense/ Strike/ Attack	2.1 Suppression of Enemy Air Defenses (SEAD)	5	3	2	5	2	4	4	5
	2.2 Air Defense	4	4	2	4	3	4	4	*
	2.3 OCA/DCA (Offensive/Defensive Counter Air)	1	4	2	5	-	3	4	*
	2.4 Air-to-Air	2	4	2	5	-	3	4	*
	2.5 Fighter UAVs similar to manned fighter aircraft	2	5	2	5	-	3	4	*
	2.6 CAS/Strike support	4	1.5	1	4	-	4	4	2
	2.7 Decoy/Wingman	3	4	3	5	4	4	4	4
3. Supply Resupply	3.1 Logistics Resupply	1	3	2	5	4	4	5*	5
	3.2 Supply Delivery	1	2	2	5	4	4	5*	5
4. Cargo	4.1 Cargo – Current cargo aircraft missions	1	2	2	5	3	4	5*	5
5. Aerial Refueling	5.1 Various types – UAV to UAV, UAV to manned aircraft, manned aircraft to UAV	3	3		5	4	5	5*	4
6. sUAS Battlefield Coverage	6.1 Wide area search/engagement	2	2	2	4	4	4	4	4
	6.2 Networked UAS	0	4.5	2	5	4	5	4	5
7. C2	7.1 Command and Control	1	3	2	4	3	5	4	*
8. Sentry Ops	8.1 Sentry/Base Protection	4	4	2	4	3	3	4	3
9. EW/ Cyber	9.1 Electronic Warfare	1	3	2	5	3	4	4	4
	9.2 Cyber operations/support	1	*	1	4	3	5	4	4
10. BMD	10.1 Ballistic Missile Defense	2	5	*	4	-	3	4	*
11. Swarms	11.1 Various Swarm enabled sUAS capabilities	1	5	3	5	4	5	4	4
12. Counter Space	12.1 Counter-Space operations	3	4/5	3	4	-	4	4	*

Appendix D. SME Estimated Timeframes to Resolving Challenges

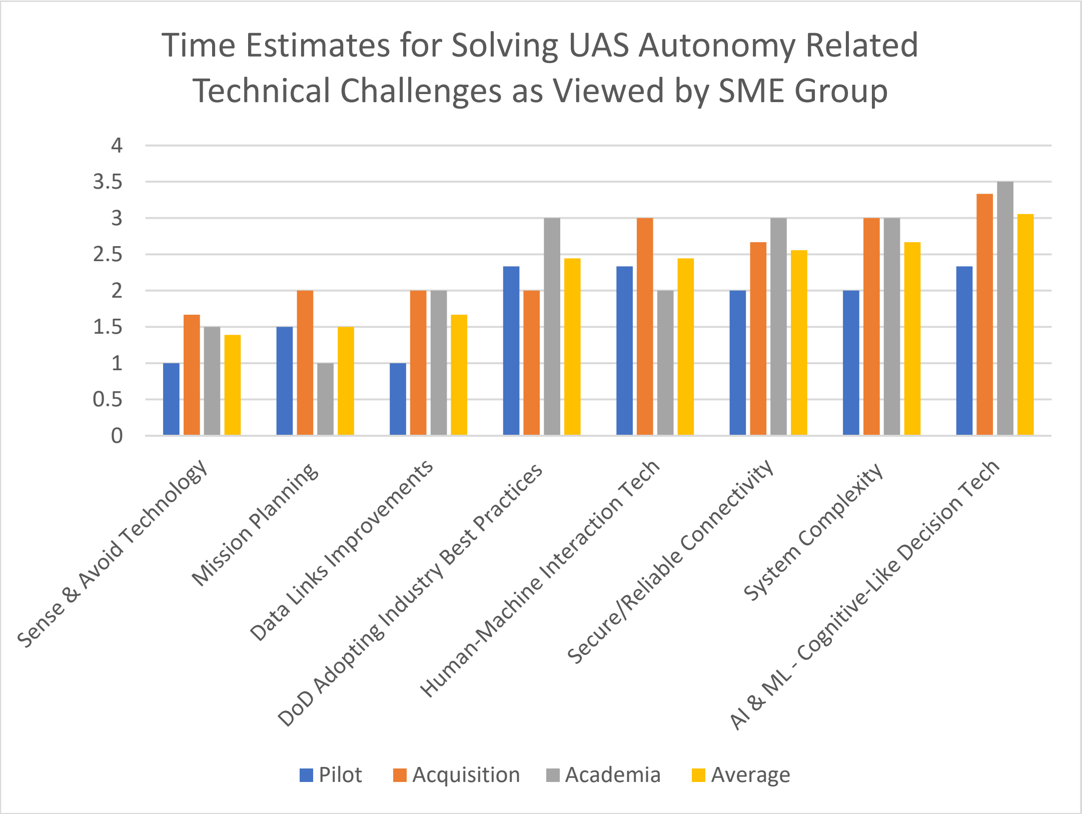


Figure D. 1 SMEs Estimates for Solving UAS Autonomy Technical Challenges

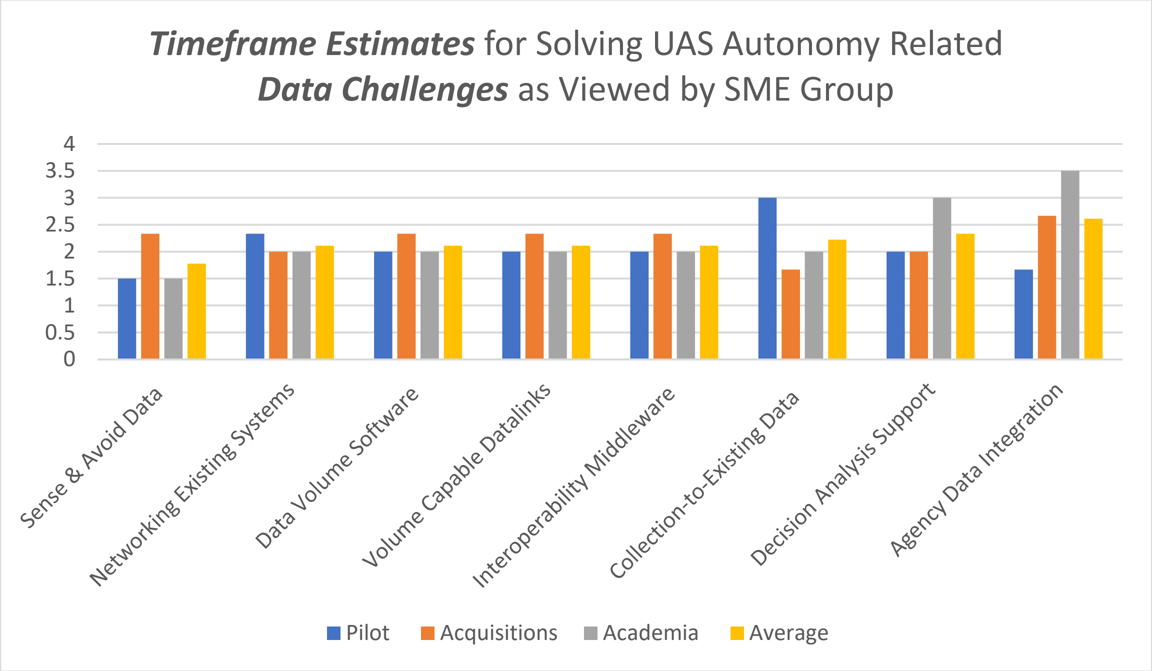


Figure D. 2 SMEs Estimates for Solving UAS Autonomy Data Challenges

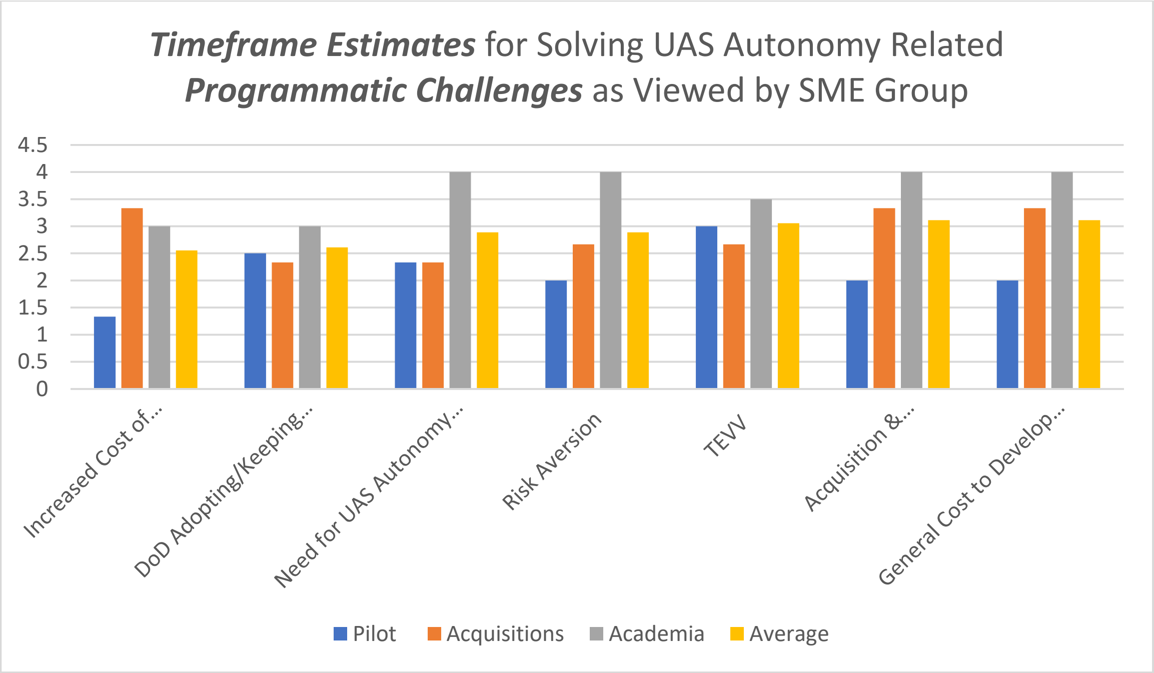


Figure D. 3 SMEs Estimates for Solving UAS Autonomy Programmatic Challenges

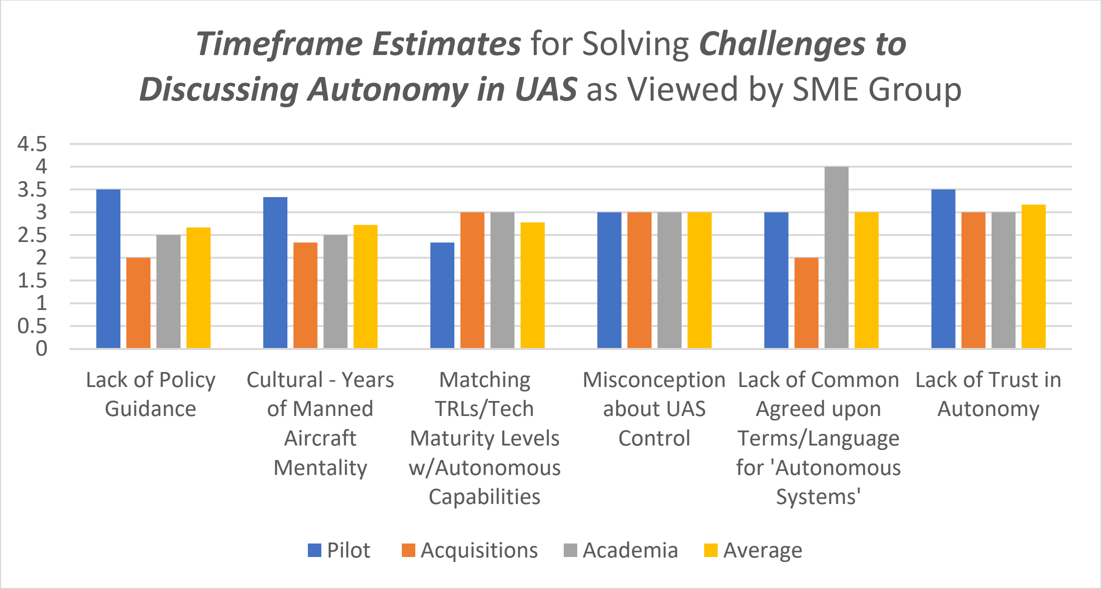


Figure D. 4 SMEs Estimates for Solving Challenges to Discussing UAS Autonomy

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14. ABSTRACT

As UAS technology continues to grow and enable increased autonomous capabilities, acquisition and operational decision makers must determine paths to pursue for existing and emerging mission areas. The DoD has published a number of 25-year unmanned systems integration roadmaps (USIR) to describe future capabilities and challenges. However, these roadmaps have lacked distinguishable stakeholder perspectives. Following the USIRs concept, this research focused on UAS autonomy through the lens of UAS subject matter experts (SMEs). We used the Delphi method with SMEs from USAF communities performing day-to-day operations, acquisitions, and research in UAS domains to forecast mission capabilities over the next 20 years; specifically, within the context of increased UAS autonomous capabilities. Through two rounds of questions, the study provided insight to the capabilities SMEs viewed as most important and likely to be incorporated as well as how different stakeholders view the many challenges and opportunities autonomy present for future missions.

15. SUBJECT TERMS

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