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Exploration Of The Handling Qualities Of An Autonomous Unmanned Aircraft System Using A Grounded Theory Methodology Toward The Identification Of Characteristic Traits

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EXPLORATION OF THE HANDLING QUALITIES OF AN AUTONOMOUS UNMANNED AIRCRAFT SYSTEM USING A GROUNDED THEORY METHODOLOGY TOWARD THE IDENTIFICATION OF CHARACTERISTIC TRAITS

by

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This dissertation, submitted by Michael McLean in partial fulfillment of the requirements for the Degree of Doctor of Philosophy of Aerospace Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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Chris Nelson
Dean of the School of Graduate Studies

Date

PERMISSION

Title	Exploration of the Handling Qualities of an Autonomous Unmanned Aircraft System Using A Grounded Theory Methodology Toward the Identification of Characteristic Traits
Department	Aerospace Sciences
Degree	Doctor of Philosophy

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Michael McLean
Date

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-The bar is now set at PhD.

To Trystin, Grace, Constance, and Patience who make my life full.

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ABSTRACT

This grounded theory study explores the handling qualities of an autonomous, large UAS based upon semi-structured interviews with eleven MQ-4C Triton air vehicle operators (AVO). Through inquiry into the tasks and difficulties experienced during operation of Triton, themes regarding the role of the AVO, the role of the automation, and the role of the interface were developed using the constant comparative method. Interconnections between the developed themes led to theory about the applicability of the handling quality framework to autonomous UAS, the tasks performed by the AVO, the human factors applied to AVO, and the relationship of the AVO to the UAS. Results showed that the command responsibilities and principles of human factors are little changed from piloted aircraft. However, the flying qualities and tasks required by the operator were seen to be significantly different, resulting in the system traits of intuitiveness, predictability, and flexibility as drivers for operator evaluation of the system. Ultimately the change to handling qualities characteristics suggests that the approach to system design for autonomous UAS should frame the interaction between the AVO and UAS as one of teamwork, which includes consideration of trust in the interaction.

CHAPTER I

INTRODUCTION

Background

While flight has always captured the imagination of humankind, the origin of modern flight traces back to George Cayley. Through the detailed observation of birds and the use of an ingenuous whirling arm apparatus, Cayley established "his principle of the separation of lift and propulsion and his use of a fixed wing to generate lift" (Anderson, 2016, p9). In his seminal work, *On Aerial Navigation*, Cayley proclaims that the basic concept of powered flight is "to make a surface support a given weight by the application of power to the resistance of air" (1810, p86). Cayley devised the important characteristics of flight through observation that were then proven in his experimentation. Cayley's approach to applied aerodynamic theory established the framework for modern aeronautical engineering still used today (Anderson, 2016).

Cayley's work extended into the role of stability in aircraft design. In the building of scale model gliders, he soon found that "to render the machine perfectly steady, and likewise to enable it to ascend and descend in its path, it becomes necessary to add a rudder in a similar position to the tail in birds" (Cayley, 1810, p84). Through careful observation and analysis Cayley was eventually able to build and test gliders that demonstrated positive longitudinal and lateral stability, enabling them to maintain their desired attitude during flight. In 1849, a machine called the *boy carrier* was tested carrying aloft a 10-year old boy as it glided down the side of a hill. In 1853, an improved version resulted in a successful flight of 900 feet with Cayley's coachman onboard, demonstrating the positive longitudinal and lateral stability of Cayley's design. However, the occupant of the glider had no means of guiding the vehicle, and after an abrupt landing is reported as saying “Please, Sir George, I wish to give notice. I was hired to drive, and not to fly” (Anderson, 2016, 12).

The focus on aircraft stability carried on past Cayley, and in 1896 Samuel Langley designed and built an unmanned aircraft that he called an Aerodrome. Langley’s Aerodrome was steam powered, unmanned, and thanks to its inherent stability, was able to maintain flight over level terrain for more than minute and a half, covering a distance of 3,300 ft. However, as Langley moved to build a model large enough to carry a person, his design failed resulting in its occupant, Charles Manly, being plunged into the Potomac river, on both attempts (Anderson, 1998, p188). While the exact cause of the failure of Langley’s manned aerodrome is uncertain, the reliance on inherent stability for vehicle control may have been a factor.

> “This focus on the stability of the aircraft remains an important design consideration of aerospace engineering today. However, the emergence of the consideration on how to control the vehicle divided into separate schools of thought – Chauffeurs or Airmen” (Anderson, 2016, p19).

The “Chauffer” group, “held that an airplane should hold its course in the air while the pilot decided what to do next. Then the pilot would deflect the rudder to steer it, more or less in the manner of a boat” (Abzug & Larrabee, 2002, p1). “Langley was a chauffeur. Most modern experts feel that his Aerodrome would not have been capable of sustained, equilibrium flight, had it been successfully launched” (Anderson, 2016, p 26).

The “Airmen” group was led by the Wright brothers, who were originally bicycle manufactures. Unlike the Chauffer group, which adhered to the established theory of required stability, the Wrights focused on the control of the aircraft. The Wrights were informed of the importance of aircraft control through the works of Octave Chanute and Otto Lilienthal

(Anderson, 2016). Unlike those that looked to established theory to guide their designs, the Wrights instead found inspiration in the source of experience. Through the observation of birds in flight the Wrights inductively reasoned the importance of control in sustaining flight. They followed up their observations through experimentation with an unpowered glider, gaining first-hand experiences in operation of this new type of flying vehicle. Wilbur Wright described the impact of their trips to Kitty Hawk for experimentation:

> "Although the hours and hours of practice we had hoped to obtain finally dwindled down to about two minutes we were very much pleased with the general results of the trip, for setting out as we did, with almost revolutionary theories on many points, and an entirely untried form of machine, we considered it quite a point to be able to return without having our pet theories completely knocked in the head by the hard logic of experience, and our brains dashed out in the bargain" (Wright, 1901, p496).

Through this process of observation and experimentation the Wrights were able to identify and address the challenges of flight.

> "This was the successful reduction to practice on which the brothers' famous patent was based. We suspect that their skills and technical talents as bicyclists, subsequently conditioned by their many trials in the turbulent winds of Kill Devil Hill… leading to their great emphasis on neutral stability in the lateral axis and manual control to create a stable man-machine system" (McRuer and Graham, 2004, p 162).

Ultimately through experience with the phenomenon of gliding flight, the Wrights bypassed established theory and intuitively devised a successful approach to manned powered-flight.

Soon after the Wright's successful development of manned powered-flight, Elmer Sperry began the work of implementing automation into aircraft control. As early as 1909, Sperry began experiments utilizing gyroscopic references to feedback sensed aircraft positions and motion to servomechanisms that drove the control surfaces (McRuer & Graham, 2004). Sperry's automatic stabilization reduced the pilot's workload by removing the task of aircraft control from the pilot during the cruise portion of the flight. Sperry's efforts culminated in 1931 with the implementation of the Sperry automatic pilot into Curtis Condor airplanes ordered by Eastern Airlines (McRuer & Graham, 2004).

Experimental exploration of the stability and control of aircraft began in 1919 at the National Advisory Committee for Aeronautics Langley Laboratory. The experimentation began by evaluating the stick forces required from the pilot to maintain level flight at various airspeeds (Abzug & Larrabee, 2002). The structure of the research, accounting for the input required of the pilot, inherently understood the importance of the role of the pilot in defining pertinent aircraft qualities. As a result of the research from the Langley Laboratory, specifications such as stick force gradients were used in the design of the Douglas DC-4E aircraft, marking the first-time flying-qualities were used to generate specifications for aircraft design (Abzug & Larrabee, 2002).

In *The Use of Pilot Rating in The Evaluation of Aircraft Handling Qualities*, George Cooper and Robert Harper offer an evaluation tool to quantify the workload required to perform aviation tasks, and established a basis from which the subjective end of easy to fly aircraft could be derived (1969). In their work, Cooper and Harper defined handling qualities as "those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role" (p 2). Through this definition Cooper and Harper establish a constructionist approach to handling qualities in that handling qualities were dependent on not just the design of the aircraft, but the environment in which it would be operated, the tasks the mission required the operator to perform, and the precision required to adequately complete the task. In this way, the evaluation of an aircraft's handling qualities are not just a function of the traits of the aircraft, but also the adequacy of those traits to the mission the system is asked to perform. As a result, the desired traits for an aircraft are dependent on what the aircraft will be asked to do. The traits that make an aircraft well suited to a transport mission may not be adequate for flight training or combat maneuvering, and vice versa.

Cooper and Harper furthered the utility of the concept of handling qualities through the development of a technique for the evaluation of an aircraft's handling qualities through pilot evaluation. Through the application of their rating scale by a pilot after completing tasks in an aircraft, the experience of that pilot could be quantified through the use of an ordinal scale. In the correlation of the quantized pilot experience with a variety of aircraft characteristics, an understanding of what aircraft characteristics were desirable could be derived. From this understanding, aircraft standards and certification specifications were developed. Many of these aircraft design standards are codified through regulations, such as Title 14 Code of Federal Regulations sections 23 through 29, and the Department of Defense Military Standard 1797, which establish system characteristics that will ensure adequate pilot evaluations (Abzug & Larrabee, 2005). Cooper and Harper's rating scale follows the same inductive, experimental path demonstrated by the Wright brothers, in utilizing pilot experience to build theory regarding what traits are needed for adequate performance. However, questions are raised about the continued utility of pilot evaluations in aircraft specifications when the pilot is removed from the aircraft.

Removing the human from the aircraft does not remove the importance of human factors. Regrettably, this misconception is so common that it is referred to as the *unmanned means no humans* fallacy, and is believed to underlie the neglect of human factors in UAS design (Cooke, 2006). According to a Government Accountability Office (GAO) investigation of over 4 years of Department of Defense (DOD) UAS mishap data, human factor issues caused 17 percent of the mishaps recorded in all DOD UAS (2008). A separate study discovered that human factors were found to be a causal factor for 67% of U.S. Air Force MQ-9 Predator accidents (Williams, 2004). These rates of attribution are made more pressing when considering UAS mishap rates can be as high as 385 per 100,000 flight hours (Cooke, 2006), compared to 4.69 per 100,000 flight hours for general aviation in the United States (AOPA, 2022). The prevalence of human factors as causal issues in UAS mishaps are often attributed to UAS system designs that did not adequately consider human abilities, characteristics, and limitations (GAO, 2008; Waraich, et. al., 2013; Hobbs & Lyall, 2016). While Federal regulations do exist to guide the development of manned aircraft, those regulations do not always transition well in application to UAS. Resultantly, without applicable standards and regulations, designers are either left to guess what is adequate or do not consider human factors at all.

In 2008, the GAO investigated the issue of integrating Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS) by conducting surveys of subject matter experts, aviation stakeholders, and agency officials. At the conclusion of this study, they published their results in a report titled *Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand Their Potential Uses within the National Airspace System*. In this report the GAO recognizes the potential benefits and demand for UAS operations, and acknowledges that the current method of providing individual case Certificates of Authorization

(COA) for UAS to operate in the NAS is not adequate to address future demand. To address this issue, the report recommends charging the Federal Aviation Administration (FAA) with establishing a plan to safely provide for the mass integration of UAS into the NAS.

In its 2013 *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap* the FAA identified states:

> “Unmanned aircraft systems (UAS) and operations have significantly increased in number, technical complexity, and sophistication during recent years without having the same history of compliance and oversight as manned aviation. Unlike the manned aircraft industry, the UAS community does not have a set of standardized design specifications for basic UAS design that ensures safe and reliable operation in typical civilian service applications. As a result, the UAS community often finds it difficult to apply existing FAA guidance. In some cases, interpretation of regulations and/or standards may be needed to address characteristics unique to UAS” (p. 6).

Additionally, the FAA contended that while “human factors issues in manned aviation are well known … there needs to be further analyses regarding UAS integration into the NAS” (p.30). Specifically, they identified a need for analysis of “how pilots fly UAS” (p. 30).

Statement of the Problem

As UAS proliferate and fill the skies, it is imperative that those systems be made safer to avoid accidents with other air traffic and injury to the populous on the ground. Aircraft regulatory and certification systems are relied upon to ensure the safe and efficient operation of aircraft; however, the current standards are based upon piloted manned-aircraft. While the FAA has acknowledged that its current system is not adequate for UAS (FAA, 2013), it is attempting to address this shortcoming by allowing UAS to be certified as a special class of aircraft under 14 CFR part 21.17 b (FAA, 2020). This process allows UAS to be certified if they can demonstrate an equivalent level of safety to manned aircraft. However, this places a burden on UAS designers who must either adapt rules that are inadequate or prove system safety through rigorous flight test. An effective and comprehensive set of UAS certification standards are needed, and those standards cannot be developed until the pertinent system characteristics are identified.

Purpose of Study

The purpose of this study is to explore the experience of MQ-4C Triton Air Vehicle Operators (AVO) to build theory about the UAS characteristics that affect the handling of the system. Specifically, this study will attempt to identify the characteristics of UAS that influence the evaluation of the ease of operating that system. By determining what characteristics affect the effort required to operate UAS, design standards can be derived that will improve the safety and efficiency of future UAS. Additionally, this research demonstrates the utility of applying a grounded theory methodology to handling qualities research. Validation of this method will provide future researchers with an additional tool to discover and refine handling qualities characteristics.

Research Questions

1. What are the perceptions of AVO of their role in UAS operations?
2. What difficulties do AVO experience when operating UAS?
3. How do AVO perceive the effect of UAS design on operating a UAS?
4. What, if any, strategies or techniques do AVO use to overcome system limitations?

These questions are not intended to limit or even define the effort of this research. They are presented as a starting point from which the research began, and were allowed to adapt as the research progressed. Ultimately the inquiry was informed by the data collected to explore the codes, themes, and theory that was developed. This process is not intended to specifically answer these questions but to discover and generate theory regarding the operation of autonomous UAS.

CHAPTER II

LITERATURE REVIEW

Grounded Theory

Grounded theory is a research method that uses data to build theory about the phenomenon studied. This method is in contrast to the typical scientific method that starts with theory and then collects data to test a hypothesis, resulting in acceptance or rejection of the a priori theory. Grounded theory reverses the process by applying inductive reasoning; starting with collecting data about a topic, and then using that data to guide the creation of theory. As such the goal of this process is to build theory that is grounded in the inherently true observations or experiences, and produce theory that this free from preexisting notions (Glaser & Strauss, 1967).

While there are different implementations of grounded theory, the validity of the resultant theory is dependent on the robustness of the analysis of the data. This generally is contingent upon using the constant comparative method, in which data from different sources is constantly and repetitively compared to any new data that is collected. This comparison filters the results and allows for the emergence of consistent themes and categories that not only build the structure of the theory but can also be used to guide the collection of additional data to challenge the theory. The method is complete when the data has reached a saturation point where the addition of more data no longer provides conflicting results or new insight into the phenomenon (Charmaz, 2006).

Grounded theory traces its origins back to *The Discovery of Grounded Theory* by Barney Glaser and Anselm Strauss in 1967. According to the authors, grounded theory was a response to the state of social science research, which was focused on the quantitative verification of existing theory. They describe a "trend toward emphasizing verification … [that] the assumption by many sociologists [was] that our 'great men' forefathers had generated a sufficient number of outstanding theories" (p 10). However, Glaser and Straus felt that this resulted in a "de-emphasis on the prior step of discovering what concepts and hypotheses are relevant for the area that one wishes to research" (p 1). This left researchers simply attempting to fit existing theory to the observed data rather than actually trying to understand what was occurring.

The first major effort to utilize grounded theory was *Awareness of Dying* in 1966 by Glaser and Straus in which terminally ill patients were interviewed regarding their experience in dealing with their impending death. Through use of a rigorous coding and comparative analysis method, the researchers were able to piece together the relationships between recurring responses and themes. These relationships were formed into theories about the experience of understanding mortality. Because the theory was based upon actual experiences of the phenomenon, and therefore inherently valid, the rigorousness of the analysis process provided inherent authentication of their conclusions. While grounded theory did not initially gain wide acceptance, it eventually found its way into modern research methods.

In becoming more widely accepted, the theory was adapted by researchers who critiqued and then adapted the method to meet their needs. One critique of the original grounded theory methodology was its strict rejection of prior theory. Glaser believes that only data related to the phenomenon should be considered in the creation of theory, and that literature reviews, previous (non-grounded theory) research, and even professional discussion regarding the theory can all prejudice the researcher (Glaser, 1992). In 2001, Glaser referred to this as reflexivity paralysis in which the researcher is impaired by trying to fit their results within existing theory. To avoid this, he advocated for the rejection of literature reviews and professional theory in order to avoid contamination of the researcher's thoughts and data collection. However, Strauss eventually disagreed with Glaser's rigid approach. In response to criticism of grounded theory, Strauss opened to the concept grounded theory could not be completed in a bubble, isolated from preexisting thought (Strauss & Corbin, 1990). This led Strauss to advocate for reviewing literature to provide theoretical sensitivity for the researcher. Strauss maintained that theoretical sensitivity would provide context for observed data, potentially provide a secondary source of data, and set the effort in line with ongoing discussions about the subject.

This split was examined in *Grounded theory research: literature reviewing and reflexivity* (McGhee, Marland, & Atkinson , 2007). While the article did not arrive at a definitive result, it did conclude that a literature review can be useful in guiding research without irreparably biasing the researcher. Further, that the influences of existing theory and previous experience can be partially controlled through the use of purposeful reflexivity; a process that involves an introspective awareness and review of the researchers preconceived notions and experiences that may color how they collect and interpret the data. In this way the researcher becomes aware of their preconceived notions while still approaching the research from an informed position.

Qualitative Methods Applied to Systems Analysis

The study of aircraft handling qualities normally involves quantitative research methods, with strong ties to the postpositivist frameworks of science and engineering (Creswell & Creswell, 2017). Conversely, the roots of the grounded theory methodology lay in the social sciences of sociology and psychology (Charmaz, 2014). Initially, these two frameworks appear to be incompatible, and there are no prominent examples of research efforts applying grounded theory to aircraft operations or aircraft design. However, in *The Discovery of Grounded Theory Practices for Software Engineering Research* grounded theory is shown to be adaptable to a technical process. Like aircraft handling qualities, “Software engineering research addresses not only technical issues but also human behavior” (Razali et al, 2020, p1). Razali et al, describe the application of grounded theory to software engineering, and that it “is able to transform less and unknown [software engineering] phenomenon into cohesive theories through the systematic discovery of empirical data from the ground.” (p1). Consequently, efforts to apply grounded theory methods have been shown “to assist researchers in understanding individuals and the context in which their actions and decision are made” (p1). In this way the qualitative grounded theory method has been demonstrated to be applicable to inherently quantitative engineering fields.

Nomenclature

The terminology used to refer to Unmanned Aircraft Systems is widely varied throughout society. The FAA offers a definition of UAS as “an unmanned aircraft and its associated elements related to safe operations, which may include control stations, control links, and support equipment … it consists of three elements: Unmanned Aircraft, Control Station, and Data Link” (2013, p8). This is compared to a direct definition the FAA provides for an Unmanned Aircraft (UA) as “a device used or intended to be used for flight in the air that has no onboard pilot …[this] includes all classes of airplanes, helicopters, airships, and powered-lift aircraft” (2013, p8). The importance of this distinction between the UAS and the UA is to emphasizes that the part of the system that is in flight, the actual air vehicle, is only a part of a larger group. According to the FAA “the term UAS is used to emphasize the fact that separate system components are required to support airborne operations without a pilot onboard the aircraft" (2013, p1). Unlike manned aircraft, which are contained within the air vehicle, UAS may be geographically dispersed, with control stations on the other side of the planet from the UA that they are controlling. This not only removes the pilot from direct observation of the status of the aircraft, but also places a vital importance on the data link connecting the UA to the control station. A depiction of a UAS system is shown in figure 1.

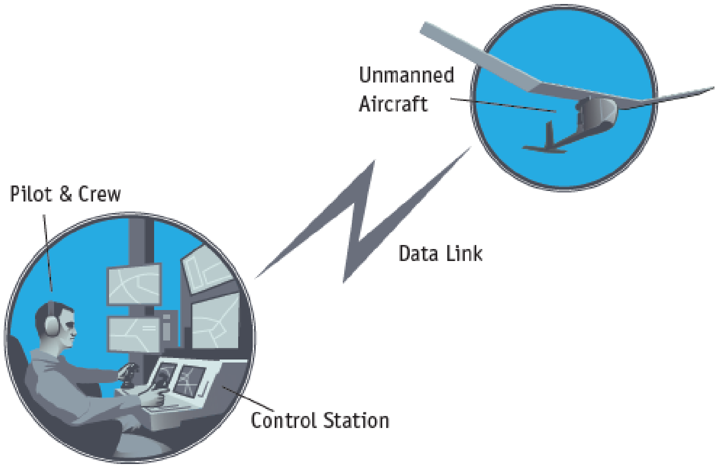


Figure 1
Unmanned Aircraft System Elements (FAA, 2013)

While UAS have the distinct characteristic of not having a pilot on board the UA, it does not mean that the UAS is removed from human involvement. This point is sometimes emphasized by referring to UAS as Uninhabited Aircraft Systems or Uncrewed Aircraft Systems. In addition to making the term gender neutral, these slight variations in naming also address the misconception that UAS operation require less human involvement to operate the system (Barnhart et al, 2012, p 18). With the acronym for these three terms being the same, the effective difference is often unnoticed and the meaning for the terms believed to be the same.

Another term that is commonly used to describe UAS is drone. While an exact definition of a drone is elusive, the media commonly refer to nearly any type of UA or UAS as a drone.

The term appears to relate to the autonomous and long endurance capability of many UAS. While the term does appear to be better understood by the general public than the more technical sounding UAS, it can also be conflated with the military use of UAS and is not the preferred term in research or regulations (Pilot Institute, 2020). Others offer that in recent usage the term drone has also become associated with hobbyist UAS which are becoming increasingly wide spread (Farrier, 2017). This would explain the common use of the term drone by the FAA in many of their public outreach efforts (FAA, 2022). Either way, the term drone is typically not used in professional references.

While there is a variety of terms to refer to UAS in general, there are additional terms that may be applied to specific UAS to impart a distinction. One such term is Small UAS (SUAS). This term is applied to UAS where the UA element is less than 55 lb, or about 25 Kg. This term is well defined in 14 CFR § 107 where it is the basis for allowing limited operation of uncertified UAS in the NAS. While the term SUAS is only a description of the weight of the UA, it is often conflated with the broader rules in 14 CFR § 107 which establish limits on airspeed and altitude, location of operation, and mandates that the aircraft remain in sight of the operator. Most of the Radio Controlled (RC) aircraft operated by hobbyists fall into the SUAS category, though many SUAS utilize higher levels of automation and on-board cameras not typically found on the manually controlled RC aircraft.

Remotely Piloted Aircraft (RPA) is another term that provides some distinction from other UAS. Associated with use by the United States Air Force, the term RPA is general considered to have come into favor because it highlighted that the particular system still required a qualified pilot for operation This distinction separated the Air Force UAS from the increasingly common SUAS that did not require the same level of training and professionalism to operate.

Additionally, the use of the term hoped to reinforce the understanding that a pilot was in control of the vehicle, many of which were engaged in combat operations (Farrier, 2017).

However, as the usage progressed, the distinction of the term also continued. In *Handling Qualities of Unmanned Aircraft Systems* Baughman and Longeuay identify the term RPA as a categorization of UAS related to automation level (2015). While they continue to differentiate RPA from SUAS, they maintain

> "that UAS are one of three configurations: remotely-piloted, fully-autonomous, or a mixture of the two. The remotely-piloted system uses a controlling station interfaced with a pilot that sends flight control commands to the aircraft using a data link. A fully-autonomous system also uses a controlling station but instead of piloted control, a mission plan is sent to the aircraft … but the operator does not have direct control of the aircraft" (p7).

In their approach "the RPA is very similar to manned vehicles in almost every regard with the exception of communication and control" (p11). This establishes the only challenge to RPA designers as to how to overcome the limitations posed by these links, although they do not address what challenges would be present for autonomous UAS.

A complication to UAS nomenclature is the commonly found term Unmanned Air Vehicle (UAV). The initial use of this term came from the Department of Defense in the 1990's and was intended to highlight the sophistication and capabilities of these new systems. Ironically, the term replaced the previously used Remotely Piloted Vehicle (RPV) which was used to describe RC controlled systems that were used since the Vietnam war. The term UAV intended to convey that these new systems were no longer controlled through simple radio controls, but were also capable of autonomous operation (Newcome, 2004) (Cotting, 2010).

In addition to the variety of terms referring to UAS, there is also variety in the terms referring to the operators of those systems. The FAA refers to the operators of UAS as pilots. Both in policy documents, such as the *Integration of Civil UAS in the NAS Roadmap,* and in the terminology used in regulation, “remote pilot” is used in 14 CFR part 107, and the FAA refers to the operators of UAS as pilots. In contrast, the Department of the Navy uses the term Air Vehicle Operator (AVO). While, in general, the Navy uses the term Naval Aviator instead of pilot, it defines a Naval Aviator as “an officer or warrant officer in the United States Navy or Marine Corps that is qualified as a pilot” (CNAF M-3710.7, 2016, p. 34). By contrast it defines an AVO as “the person who has been trained, qualified, and properly designated as an AVO … and is in positive control of the UA” (p 14-8). The reasoning for referring to UAS operators as AVOs instead Naval Aviators is not disclosed. It may be due to the term Naval Aviator referring only to officers and warrant officers, but in practice separates those who fly manned aircraft from those that operate UAS.

The terms used to describe UAS and their operators do not offer a clear line of distinction. The terminology used is blurred through a myriad of organizations and consumers with wide ranging and dynamic points of view, objectives, and technical abilities. While the vacillation between referring to these systems as remotely piloted or unmanned has little effect on the actual capabilities of the system, it does convey an uncertainty or unsettled dynamic in understanding the role of the operator to the system. However, it is clear that there is an intended segregation that occurs in the terminology used. It either groups systems into the previously established aircraft and pilot roles and capabilities, or sets apart into the new and different of an unsettled emerging technology.

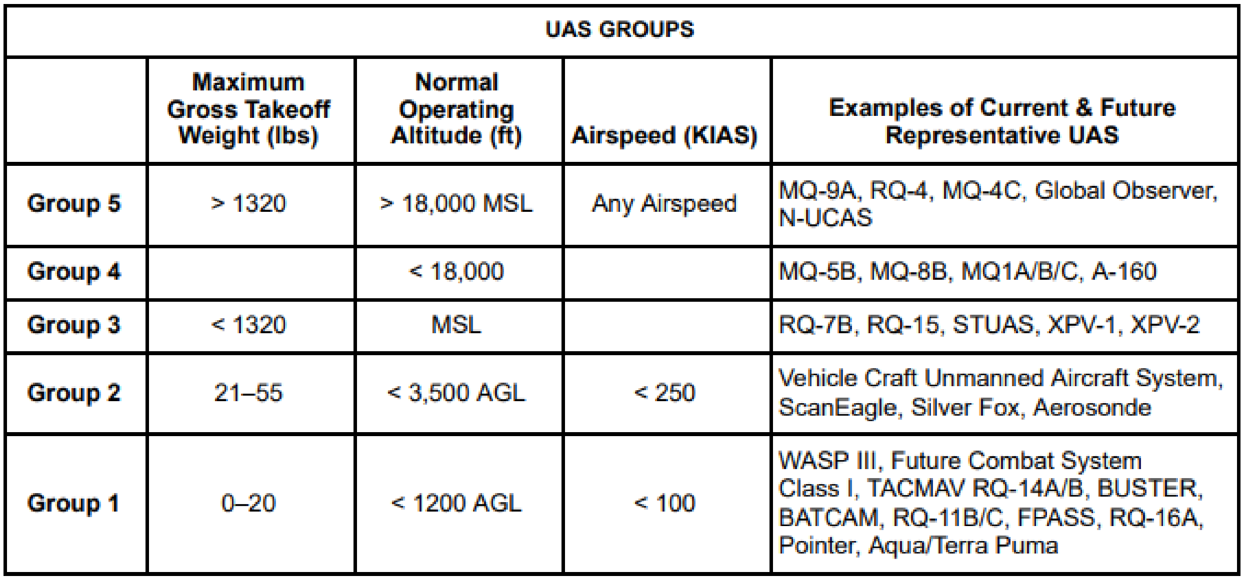
Taxonomy

The FAA does not have an established method for categorizing UAS. With the implementation of 14 CFR part 107, the FAA did permit limited use of UAS less than 55lbs, within constrained limits without the requirement to certify the aircraft. However, the ability to operate these uncertified Small UAS (SUAS) was contingent on the risk reduction imposed by the constrained limitations. This is in contrast to the FAA's approach to manned aircraft, which sets differing certification specifications based upon the type, size, and intended use of manned aircraft, and established in 14 CFR parts 23, 25, 27, 29, 31, 33, and 35. These wide-ranging standards are tailored for the appropriate application to ensure that these distinctly different aircraft are all safe for operations in the NAS. In 2014, the Government Accountability Office found that this lack of classification by the FAA "does not adequately account for the different performance characteristics across a wide range of UAS" (p. 8). Indeed, even the distinctions offered by the colloquial UAS definitions appear to be missing from the FAA's consideration.

Any UAS that is to operate outside of the limits of Part 107 is required to be certified by the FAA. In a notice of policy in 2020, the FAA stated its intention to treat applications for certification of UAS as a type rating for a special class of aircraft. This policy was predicated on 52 FR 8040, which created the category of special class and defined them as "those aircraft that would be eligible for a standard airworthiness certificate but for which certification standards do not exist" (p. 58251). In doing so, UAS will be accountable to either the portions of the existing federal aviation regulations that are applicable, or other airworthiness criteria that the FAA may find that provides an equivalent level of safety (FAA, 2020). However, this leaves little guidance to aircraft designers, and the general public, as to what means and to what level UAS will be evaluated.

The United States Department of Defense has developed its own categorizations of UAS, shown in table 1. This system separates UAS into five groups based upon weight, operating altitude and top airspeed. This loosely follows the categorization of manned aircraft, but has been adjusted to accommodate the larger span of characteristics possible with UAS (Cotting, 2009). This categorization is used by Naval Aviation to establish separate certification and operator requirements, with the general trend that the higher group UAS which are larger and faster are subject to more stringent requirements (NATOPS General Flight and Operating Instructions Manual, 2016). However, while this categorization is clearly more robust and useful than what is offered by the FAA, it still lacks any direct differentiation for automation level or method of operator interface with the system.

Table 1
UAS Categories (NATOPS General Flight and Operating Instructions Manual, 2016)



UAS GROUPS				
	Maximum Gross Takeoff Weight (lbs)	**Normal Operating Altitude (ft)**	**Airspeed (KIAS)**	**Examples of Current & Future Representative UAS**
Group 5	> 1320	> 18,000 MSL	Any Airspeed	MQ-9A, RQ-4, MQ-4C, Global Observer, N-UCAS
Group 4		< 18,000		MQ-5B, MQ-8B, MQ1A/B/C, A-160
Group 3	< 1320	MSL		RQ-7B, RQ-15, STUAS, XPV-1, XPV-2
Group 2	21–55	< 3,500 AGL	< 250	Vehicle Craft Unmanned Aircraft System, ScanEagle, Silver Fox, Aerosonde
Group 1	0–20	< 1200 AGL	< 100	WASP III, Future Combat System Class I, TACMAV RQ-14A/B, BUSTER, BATCAM, RQ-11B/C, FPASS, RQ-16A, Pointer, Aqua/Terra Puma

In “An Assessment of Pilot Control Interfaces for Unmanned Aircraft” (Williams, 2007) 15 separate UAS systems were surveyed and offered a taxonomy for the systems based upon the level of control. The basis of the taxonomy was the control devices used to interface with the vehicle. It emerged that these inceptors correlated to levels of control the operator had over the vehicle, with the lowest level of control utilizing joystick type inceptors that directly manipulated the control surfaces of the UA and higher levels utilizing computer screens and pointing devices like a mouse to edit waypoints. These levels of control were revisited in “A Decadal Revisiting of the Assessment of Pilot Control Interfaces for Unmanned Aircraft Systems” (Pankok & Bass, 2017) where, in addition to confirming William’s findings, it went on to highlight the importance of level of control to vehicle design. It offered that “the input device is inherently related to the level of control” and that “the input device is critical to system design because the potential benefits of automation can be negated if an input device … is not compatible with the level of control” (p63). This establishes that UAS designs, and the specifications that regulate them, are dependent on the level of control available to the pilot and should be matched to the category that is employed. While Pankok and Bass approached the interaction with UAS as a function of the control inceptors, others have approached this interaction with a focus on the automation employed by the UAS.

Automation

Automation is defined as “any sensing, detection, information-processing, decision-making, or control action that could be performed by humans but is actually performed by machines” (Morey Et Al., 2000, p44). This relatively broad definition is refined by considering the terms automatic and autonomous. Both of these terms may refer to automation, but they have distinctly different meanings. “Automatic means that a system will do exactly as programmed, it has no choice. Autonomous means that a system has a choice to make free of outside influence” (Clough, 2002, p 1). While the exact distinction of when an action was completed autonomously is fairly subjective, and better addressed with philosophy than engineering, a system's ability to decide which course to take appears to be one of the traits. Clough cautions against confusing autonomy with intelligence:

> "Intelligence is the capability of discovering knowledge and using it to do something. Autonomy is the ability to generate one's own purposes without any instruction from outside… What we want to know is how well a UAV will do a task, or better yet, develop tasks to reach goals, when we're not around to do it…. We really don't care how intelligent it is, just that it does the job assigned" (2002, 1).

The implementation of "automation is not all-or-nothing; rather it is an agent that interacts with the human operator," and that:

> "Automation has behavior. This behavior interacts with the operator's behavior, the operator's mental model of the system, and the operator's trust of the system. As a result, automation itself changes an operator's training, task assignments, workload, situational awareness, trust, and even the operator's skill set" (Elliott and Stewart, 2012, p 100).

This view is reinforced by Woods who saw automation as a change in the dynamic between the operator and the system (1996).

As cited in "Human performance on the flight deck", Dekker suggests "developing the anthropomorphic aspects attributed to automation … making it into a 'team player'." He offers "that the question for successful automation should not be 'who has control' but 'how do we get along together'" (Harris, 2016, p 231). To achieve that goal Dekker suggested the following design philosophy regarding automation:

- The pilot must be in command
- To command effectively, the pilot must be involved
- To be involved, the pilot must be informed

- The pilot must be able to monitor the automated aircraft systems
- The automated systems must be predictable
- The automated systems must also be able to cross monitor the pilot
- Each element of the system must have knowledge of the other's intent

Attempts have been made to apply a taxonomy to automation. The National Institute of Standards and Technology (NIST) developed the Autonomy Levels for Unmanned Systems, seen in figure 2. These levels progress from zero, where no automation is present, to ten, where the system requires no human interaction. While the exact distinction between the levels may be slightly subjective, the progression is from complete human control to autonomous systems that require little human interaction (Elliot & Stewart, 2012).

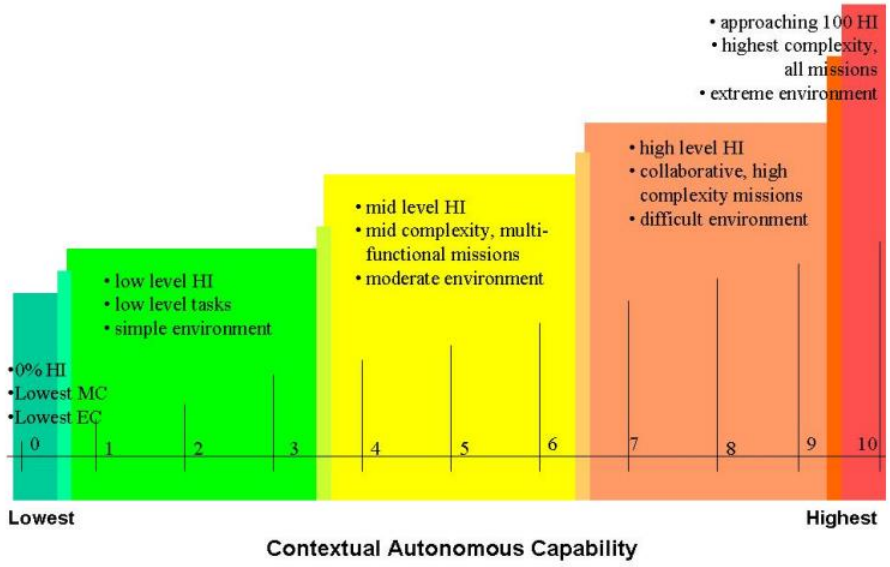
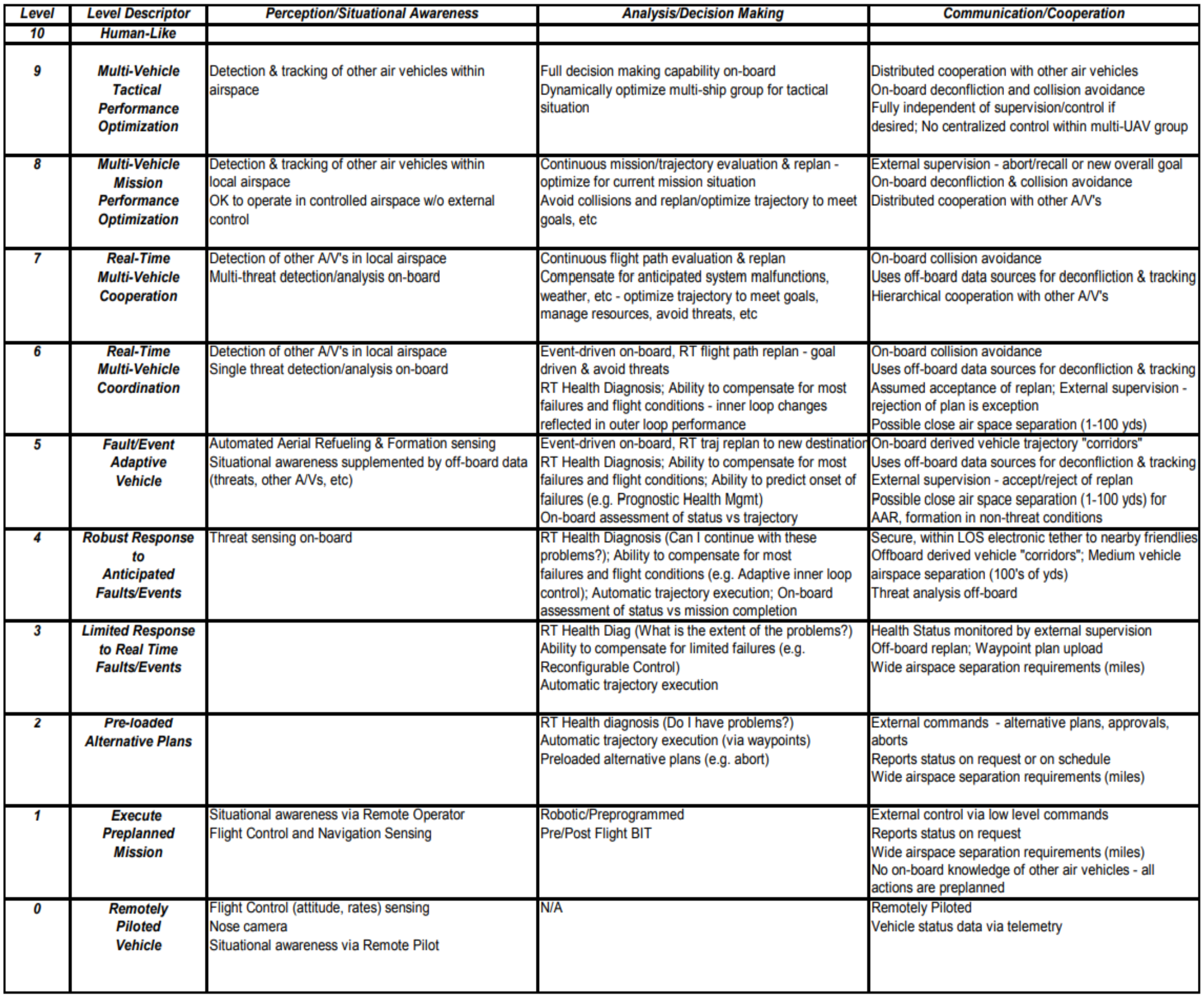


Figure 2
NIST Autonomy Levels for Unmanned Systems, (Huang et al, 2005)

The Air Force Research Lab, in response to a perceived need to measure and quantify the autonomy of UAS, developed the Autonomous Control Level (ACL) chart seen in table 2. This taxonomy also relies upon the UAS autonomy capabilities to quantify the level of the system, and like the NIST model progresses from zero to ten. Unsurprisingly, the lowest level of automation is referred to as remotely piloted, which corresponds to the UAS terminology of Remotely Piloted Aircraft. However, no distinction is made as to at what automation level a UAS would be considered an RPA vs a UAS. While the ACL also addresses the autonomous characteristics of the UAS, like the NIST taxonomy, the ACL also considers the ability of the system to communication and coordinate with other systems.

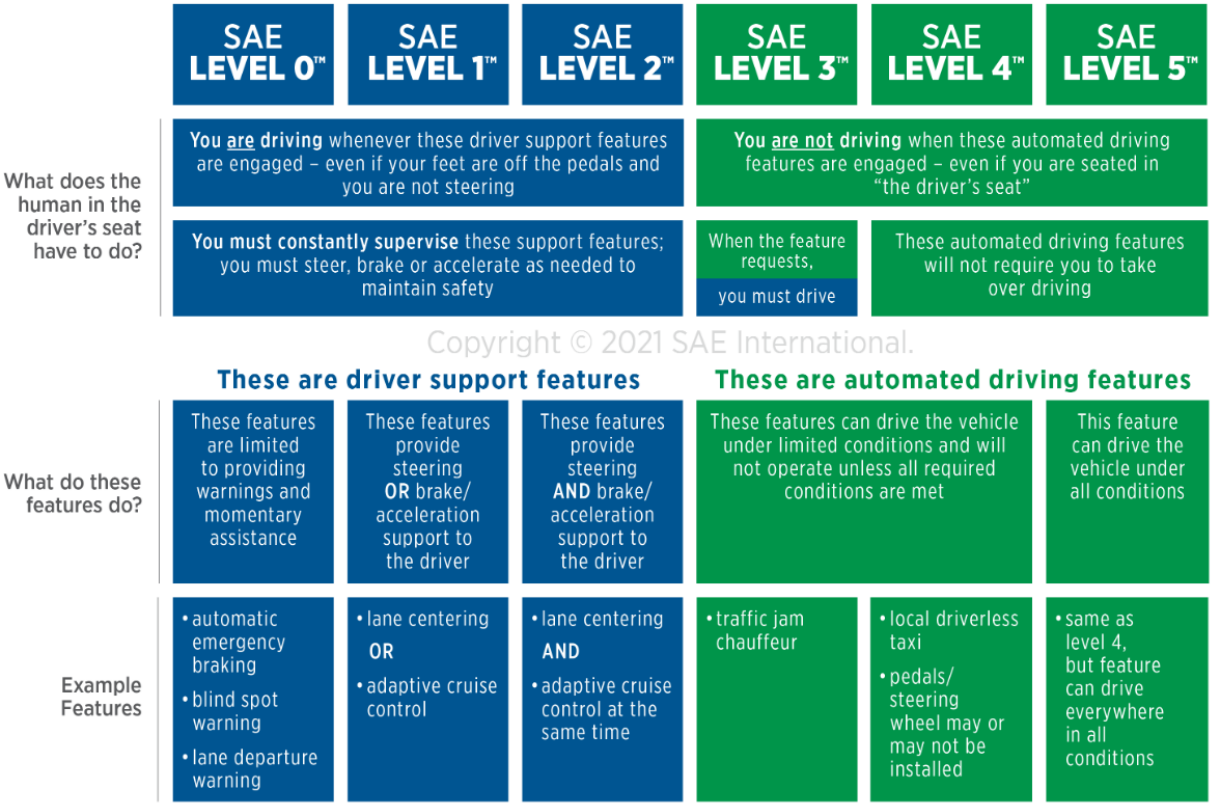
Table 2

Autonomous Control Levels, (Clough, 2002)



Level	Level Descriptor	Perception/Situational Awareness	Analysis/Decision Making	Communication/Cooperation
10	**Human-Like**			
9	**Multi-Vehicle Tactical Performance Optimization**	Detection & tracking of other air vehicles within airspace	Full decision making capability on-board Dynamically optimize multi-ship group for tactical situation	Distributed cooperation with other air vehicles On-board deconfliction and collision avoidance Fully independent of supervision/control if desired; No centralized control within multi-UAV group
8	**Multi-Vehicle Mission Performance Optimization**	Detection & tracking of other air vehicles within local airspace OK to operate in controlled airspace w/o external control	Continuous mission/trajectory evaluation & replan - optimize for current mission situation Avoid collisions and replan/optimize trajectory to meet goals, etc	External supervision - abort/recall or new overall goal On-board deconfliction & collision avoidance Distributed cooperation with other A/V's
7	**Real-Time Multi-Vehicle Cooperation**	Detection of other A/V's in local airspace Multi-threat detection/analysis on-board	Continuous flight path evaluation & replan Compensate for anticipated system malfunctions, weather, etc - optimize trajectory to meet goals, manage resources, avoid threats, etc	On-board collision avoidance Uses off-board data sources for deconfliction & tracking Hierarchical cooperation with other A/V's
6	**Real-Time Multi-Vehicle Coordination**	Detection of other A/V's in local airspace Single threat detection/analysis on-board	Event-driven on-board, RT flight path replan - goal driven & avoid threats RT Health Diagnosis; Ability to compensate for most failures and flight conditions - inner loop changes reflected in outer loop performance	On-board collision avoidance Uses off-board data sources for deconfliction & tracking Assumed acceptance of replan; External supervision - rejection of plan is exception Possible close air space separation (1-100 yds)
5	**Fault/Event Adaptive Vehicle**	Automated Aerial Refueling & Formation sensing Situational awareness supplemented by off-board data (threats, other A/Vs, etc)	Event-driven on-board, RT traj replan to new destination RT Health Diagnosis; Ability to compensate for most failures and flight conditions; Ability to predict onset of failures (e.g. Prognostic Health Mgmt) On-board assessment of status vs trajectory	On-board derived vehicle trajectory "corridors" Uses off-board data sources for deconfliction & tracking External supervision - accept/reject of replan Possible close air space separation (1-100 yds) for AAR, formation in non-threat conditions
4	**Robust Response to Anticipated Faults/Events**	Threat sensing on-board	RT Health Diagnosis (Can I continue with these problems?); Ability to compensate for most failures and flight conditions (e.g. Adaptive inner loop control); Automatic trajectory execution; On-board assessment of status vs mission completion	Secure, within LOS electronic tether to nearby friendlies Offboard derived vehicle "corridors"; Medium vehicle airspace separation (100's of yds) Threat analysis off-board
3	**Limited Response to Real Time Faults/Events**		RT Health Diag (What is the extent of the problems?) Ability to compensate for limited failures (e.g. Reconfigurable Control) Automatic trajectory execution	Health Status monitored by external supervision Off-board replan; Waypoint plan upload Wide airspace separation requirements (miles)
2	**Pre-loaded Alternative Plans**		RT Health diagnosis (Do I have problems?) Automatic trajectory execution (via waypoints) Preloaded alternative plans (e.g. abort)	External commands - alternative plans, approvals, aborts Reports status on request or on schedule Wide airspace separation requirements (miles)
1	**Execute Preplanned Mission**	Situational awareness via Remote Operator Flight Control and Navigation Sensing	Robotic/Preprogrammed Pre/Post Flight BIT	External control via low level commands Reports status on request Wide airspace separation requirements (miles) No on-board knowledge of other air vehicles - all actions are preplanned
0	**Remotely Piloted Vehicle**	Flight Control (attitude, rates) sensing Nose camera Situational awareness via Remote Pilot	N/A	Remotely Piloted Vehicle status data via telemetry

These models follow the trend of other industries that have attempted to describe level of automation. “In Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles”, SAE international devised a system that progressed from zero to five to describe the automation of the automobile based upon the systems capabilities and the role of the driver, seen in figure 3. While SAE decided to choose a delineation between zero and five vs zero to ten, their taxonomy is also based upon vehicle capabilities.



	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	**You <u>are</u> driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You <u>are not</u> driving** when these automated driving features are engaged – even if you are seated in “the driver's seat”		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/acceleration support to the driver	These features provide steering **AND** brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Figure 3
SAE Levels of Driving Autonomy (SAE International, 2021)

The differences between the taxonomies of these groups should not be surprising. Each has a different purpose for their categorization, and different vehicles that they will be applied to.

However, they all do share an interesting similarity. They all utilize an ordinal scale to describe a perceived progression in automation levels.

This inherent frame work of automation progression is also seen in the approach to automation in manned aircraft certification. According to Advisory Circular 25.1302-1:

> “The design of such automation specific controls per § 25.1302 should enable the flightcrew to … manually intervene in any system function… or revert to manual control. For example, manual intervention might be necessary if a system loses functions, operates abnormally, or fails” (2013, p 35).

While not explicitly stated, this certification standard establishes an approach where automation level is transitory. It reduces automation to only an augmentation of the aircraft and not permanent characteristic. Further it mandates that the pilot must be able to extricate control from the automation, instead of viewing automation as a teammate that could be of assistance. This is the current standard by which manned aircraft are certified, but for UAS this approach to the relationship between operator and automation may need to be reassessed.

Human Factors

The human must be accounted for in the operation of any system. In addition to the ability to collect, process, and interpret data, human operators can provide feedback, acting as control mechanisms capable of performing a wide variety of tasks. However, along with these advantageous capabilities, humans are prone to errors. These errors can be the result of confusion, inattention, fatigue or other causes. The FAA considers the evaluation of human factors to “entail a multidisciplinary effort to generate and compile information about human capabilities and limitations and apply that information … for safe, comfortable, effective human performance" (2005). The study of "the human factor has been widely recognized as critical to aviation safety and effectiveness." (FAA, 2005).

Removing the human from the aircraft does not remove the importance of human factors. Regrettably, this misconception is so common that it is referred to as the *unmanned means no humans* fallacy, and is believed to underlie the neglect of human factors in UAS design (Cooke, 2006). As mentioned in the introduction, according to a Government Accountability Office (GAO) assessment of over 4 years of Department of Defense (DOD) UAS mishap data, human factor issues caused 17 percent of those mishaps (2008). A separate study discovered that human factors were found to be a causal factor for 67% of U.S. Air Force Predator accidents (Williams, 2004). These rates of attribution are made more pressing when considering UAS mishap rates can be as high as 385 per 100,000 flight hours (Cooke, 2006). The prevalence of human factors as causal issues in UAS mishaps are often attributed to UAS system designs that did not adequately consider human abilities, characteristics, and limitations (GAO, 2008; Waraich, et. al., 2013; Hobbs & Lyall, 2016).

In its 2013 *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap* the FAA identified human factors as one area that required additional research. The FAA contended that while "human factors issues in manned aviation are well known … there needs to be further analyses regarding UAS integration into the NAS" (p.30). Specifically, they identified a need for analysis of "how pilots fly UAS, how controllers provide service involving a mix of manned aircraft and UAS, and how pilots and controllers interact with each other" (p. 30). Ultimately, the FAA intends to use the answers to these questions to ensure that standards and operating procedures are in place to enable UAS access to the NAS while maintaining public safety.

One approach to investigating human factors in UAS is to view them as similar to other systems. This approach was taken in *Human Factors Guidelines for Remotely Piloted Aircraft System (RPAS) Remote Pilot Stations (RPS)* (Hobbs & Lyall, 2016). In this effort, the researchers set out to compile a unified collection of design guidelines through the review of existing standards, mishap reports, and human factors literature. However, to manage the scope of their effort, they assumed that UAS "share many of the same human factors considerations that apply in conventionally-piloted aircraft, however the points of difference have implications for [UAS] design" (p. 14). This assumed that the difference in the human factor issues of concern in UAS design are those that derive from the difference between UAS and manned aircraft. By focusing on these differences, Hobbs and Lyall compiled an extensive set of suggested guidelines for UAS design to prevent human-factors caused mishaps. However, of note, while focusing their research on how UAS are different from manned aircraft, this research did not account for differences between UAS.

The approach of treating UAS as similar to manned aircraft is aided through the availability of human factors guidance for manned aircraft. The FAA has published *Human Factors Considerations in the Design and Evaluation of Flight Deck Displays and Controls* (Yeh, et.at. 2016). The document is presented as a compilation of applicable aircraft regulation and best practices in flight-deck design. While acknowledging that human factors issues are interrelated, the report categorizes its content into chapters based upon subject. The categorization enables a quick referencing of issues and provides a topical break down of human factors in aircraft. While this document is not a source of regulation, it does attribute much of its content to regulations and specifications. Further, the document provides a collection of recommendations and best practices to aid designing systems that minimize human factors issues.

Despite Hobbs and Lyall's assertion that the similarity between manned and unmanned aircraft means that they share human factors concerns, many of the recommendations in Yeh's work appear to be inapplicable to UAS. Items such as the general recommendation that the pilot should be able to "manually intervene in any system function, as required by operational conditions, or revert to manual control" (Yeh, et.at. 2016, p.257) may not be possible given the pilot not being on the aircraft. Additionally, while some factors may be common to manned and unmanned aircraft, such as the optimum horizontal and vertical range of field of view (FOV) of the pilot, their effect on operation may not be comparable. One such requirement may be the placement of the Basic-T flight instruments near the middle of this FOV in manned aircraft (Yeh, et.at. 2016, p. 41). For a highly automated UAS system that does not require the pilot to directly control the primary flight controls to maintain heading, airspeed or altitude, this portion of the pilots FOV may be better suited for an item with which they are tasked to monitor.

In *Minimizing Human Factors Mishaps in Unmanned Aircraft Systems* (Waraich, et. al., 2013) the lack of human factors consideration in design is also attributed as a cause of the high UAS mishap rate. However, unlike Hobbs and Lyall's approach that treats UAS as similar to manned aircraft, the authors of this research assumed similarity to computer workstations. A side-by-side comparison between a typical computer workstation and UAS control station is provided in figure 4.

Figure 4
Computer Workstation vs UAS Control Station (Waraich, et. al., 2013)

In a survey of UAS operators Waraich et. al. found a prevalence of commercially available input-output devices (such as displays, mouse, keyboards) and operator comfort equipment (chairs, desks, etc.) in UAS Ground Control Stations (GCS) (2013). They note that research into the human factors of this type of equipment has already been completed in regard to the design of computer work stations. Additionally, the lessons learned have been codified in specification from of the American National Standards Institute (ANSI) Human Factors and Ergonomics Society (HFES). Based upon the similarity of the equipment used in both types of stations, Waraich concludes that the ANSI/HFES 100-2007 (which sets human factors specification for computer workstations) should be applied to UAS ground stations for the purpose of design. Establishing the framework of UAS interface design as similar to that of a computer workstation.

The Waraich and Hobbs research both highlight the importance of human factors in design, however neither really approaches UAS human factors as a unique concept. Both efforts fall into the mode of thinking that UAS are just an evolution of some already existing thing. This approach may be an expedient way to address UAS human factors issues through the implementation of existing standards. Both approaches offer a quick solution, but they do not fully address the human factors issues experienced by UAS pilots.

Flying Qualities

What Engineers Know and How They Know It (Vincenti, 1990) recounts the historical development of the concept of flying qualities. The description of this development begins with the claim that early aircraft designers possessed a poor understanding of how to build aircraft that were easy to fly. It attributes this to the method in which early aircraft were initially designed and tested. In referencing early aircraft engineers, Vincenti states “working as they did almost entirely with unpiloted models with no possibility of control, these men rapidly discovered that they had to have an inherently stable system for success” (p.57). This appreciation for stability in their designs initially blinded designers to the role of the pilot in the aircraft. Designers carried over desirable characteristics of the model aircraft, without appreciating that it is the pilot’s perceptions of controlling the aircraft that determine its ease of operation.

> “Flying qualities [are] taken to mean those analytical and empirical parameters or criteria that can be measured for a given airplane. All such parameters or criteria can be related to the demands the pilot places on the airplane to achieve desired performance. That is, they are open-loop metrics describing pilot-in-the-loop operations” (Klyde, Et Al., 2020, p.6).

In the application of this definition, it is clear that “flying qualities are thus a property of the aircraft, though their identification depends on the perceptions of the pilot” (Vincenti, 1990, p 53). Further, “a pilot’s perception of flying qualities stems in large part from the forces and movements required by the cockpit devices used to move the control surfaces" (Vincenti, 1990, p. 53). John Hodkinson framed this idea of flying qualities in terms of driving a car:

> "It is easy to imagine a car in which the performance potential cannot be realized because the steering is too sensitive, or the brakes require too much effort, or the car steers itself during acceleration, etc. … the desired performance can perhaps be attained only with excessive workload, or perhaps desired performance cannot be attained even with the maximum effort" (1999, p. 1).

Ultimately, aircraft designers learned that it was not only the stability characteristics, but the "forces and movements of the controls, in relation to the perceived response of the device [that] engender in the operator a feeling of ease or difficulty in performing the required tasks" (Vincenti, 1990, p.104).

According to Vincenti, the discovery and definition of flying qualities marked an epistemological transition from the applied science and mathematics of aeronautics to the functional requirements of engineering (p 107). Meaning that engineers were no longer solely focused on designing systems capable of achieving flight, but were also considering the effort (both physical and mental) required to operate the aircraft by the pilot. This presented a new challenge to aircraft engineers who, in considering these qualities, had to transition from the positivist view of aeronautics, defined by derived equations and empirical quantities, to the relativist view that strove to achieve the subjective goal of pilot satisfaction. Through these epistemological elements, engineers were able to construct standards and specifications (objective means) that would produce satisfactory flying qualities (subjective ends).

The application of flying qualities to UAS is not new. Previous research efforts recognized that removing the pilot from the aircraft did not negate the importance of having system qualities that made it easy to operate. One technical approach to the application of flying qualities to UAS is the concept of dynamic scaling. Dynamic scaling attempts to interpolate desired aircraft flying qualities for RPV that do not correspond to the traditional sizes of manned aircraft. Through the correlation of physical characteristics, such as mass and moments of inertia, research demonstrated a way to anticipate desired flying qualities of RPV either larger or smaller than established manned aircraft. Based upon the specific airframe measurement ratios and a sampling of pilot evaluations trend lines are used to predict the desired vehicle characteristics (Peters et al., 1997) (Mettler et al., 1999). While this research addressed the larger variety of vehicle sizes possible with UAS, it's focus was constrained to manual-control line-of-sight operations without automation.

Although the physical differences between aircraft are clearly important to the control of the vehicle, operations beyond line-of-sight are also affected by latency. Research has demonstrated the effect of the C2 datalink and corresponding latency on vehicle control (Baughman & Longeuay, 2015). They found that long range operation of UAS, which often necessitated the use of satellite communications, could often encounter latency in excess of two seconds. They offer:

> "On any aircraft, the latency from pilot input to aircraft response back to pilot input is a large determining factor in the [flying] qualities of the vehicle. If there is a large latency, the pilot can become out of phase with the aircraft response and develop a [pilot induced oscillation] which is undesirable … In a manned platform, the latency is from pilot input to aircraft response, such as that caused by transport time delay in a digital flight control system. In an unmanned platform, the aircraft response has to be downlinked back to the

> ground control station for the pilot to recognize and react to it. This additional step increases the equivalent system time delay" (p.11).

Despite this complication to the application of manned flying qualities to UAS, they conclude that "if the level of autonomy is appropriate for a given task, manned aircraft test techniques can be adapted to evaluate … unmanned systems" (p.19). This conclusion was supported in "Analysis of pilot-induced-oscillation and pilot vehicle system stability using UAS flight experiments" (Mandela & Gu. 2016) where the authors were able to incite Pilot Induced Oscillation (PIO) in RC aircraft by manipulating the C2 link-latency of the controller. These results supported both Baughman and Longeuay's assertion that latency affects the flying qualities of the system, and that manned aircraft standards could be applicable to UAS if latency was accounted for. However, both sets of research only dealt with control of UAS with low or no automation.

The complication of automation on UAS flying qualities is address in "An initial study to categorize unmanned aerial vehicles for flying qualities evaluation" through a shifting of focus. Cotting writes that:

> "Flying qualities to date are focused on piloted aircraft, detailing an aircraft's dynamic response that is required to interface with a pilot. With an unmanned aircraft, the human pilot's requirements for control over the aircraft are no longer applicable" (2009, p1).

Instead Cotting offer's:

> "The pilot's role has been replaced by a flight control system performing a prescribed maneuver. While the mission of the UAV may be similar to that of a manned aircraft, the critical link to a successful mission is no longer the pilot's ability to fly the aircraft. The

> critical link is the payload's ability to perform its task while integrated with the UAS" (2010, p16).

This approach would remove the pilot, and their subjective opinions, from consideration, and focus solely on the definitive performance achieved by the automation in service of the mission sensors. While this approach would seem to appeal to engineers, with a positivist approach to aircraft design, it ignores the various levels of automation that may be present in UAS. While none of the automation scales are definitive, none of them were binary either - with automation as a trait that was either present or not. Additionally, Cotting's all or nothing tactic appears to conflict with Dekker's approach to automation integration (2004), where automation is not a replacement for the pilot but a member of the team. While certain automation levels may assume control of the vehicles flight path, it does not mean that the pilot is no longer an active participant in the operation of the system.

Handling Qualities

The terms flying qualities and handling qualities are often used interchangeably. They both refer to system qualities that affect the ease with which a vehicle can be operated. However, a distinction between the two has emerged in current research. In a recent National Aeronautics and Space Administration (NASA) publication, titled *Defining Handling Qualities of Unmanned Aerial Systems: Phase II Final Report*, Klyde et. al. make a distinction between flying qualities and handling qualities. They focus on flying qualities as the vehicle's response to input from the pilot. This implies that "they are open-loop metrics … by which one attempts to quantify … the airplane" (2020, p.6). While historically this may have been solely a function of an aircraft's physical characteristics, advances such as fly-by wire and digital flight controllers have become more prevalent, allowing engineers to tailor the vehicle response to match the pilot's desired performance. These advances have made the "understanding of [flying qualities] more, not less, essential than it was in the days of the Wright brothers" (Hodgkinson, 2015, p 1).

By contrast, Cooper and Harper offered a definition of handling qualities in their foundational document *The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities.* In it they establish handling qualities as "those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role" (1969, p2). This definition "emphasizes that it includes more than just stability and control characteristics" and that "other factors that influence the handling qualities are the cockpit interface, the aircraft environment, and stress, the effects of which cannot readily be segregated" (1969, p2). With this definition, flying qualities are established as a subset of the larger concept of handling qualities. Flying qualities, or the vehicle's response to inputs, are a factor in the handling qualities, but the human portion of the system cannot be ignored.

Cooper and Harper established common terms in their seminal work that helped frame the concept of handling qualities. They establish that the mission is "the composite of pilot-vehicle functions that must be performed to fulfill operational requirements" or "what it is that the pilot-vehicle combination must be able to accomplish" (1969, p3-4). The definition of mission by Cooper and Harper contrasts with their definition of task which they take to be:

> "only the pilot's task, which includes controlling the aircraft as well as associated functions, not directly related to controlling the aircraft, such as navigation and communication. A task in the sense that it … is defined as the actual work assigned a pilot to be performed in completion of … a designated flight segment" (1969, p 4).

Cooper and Harper went on to better contrast mission and task.

> "Use of task and mission differs then. In that a task represents what the pilot is actually asked to do … while a mission refers to all operational requires the pilot-vehicle combination must be able to accomplish" (1969, p 4).

With these definitions in place, the distinction between flying qualities, which refer to the response of the vehicle to input, and handling qualities, which deal with whole system performance, become more distinct.

In this way, handling qualities also shows commonality with human factors. Handling qualities recognizes that "the pilot is part of a system that is intended to accomplish a mission" (Hodkinson, 2015, p1). While flying quality characteristics of the system may be adequate to achieve desired performance, the system cannot achieve the mission objective without an operator capable of providing the required inputs. Therefore, the human capabilities and limitations that are addressed through human factors research are also applicable to the human operator when considering their effect on mission accomplishment. The slight difference between them often is a question of perspective. While human factors research is often focused on preventing or reducing the impact of human error, handling qualities seek to find the attributes of the system that allow the human operator to achieve satisfactory performance in accomplishment of the mission.

Mission Task Elements

In "Defining Handling Qualities of Unmanned Aerial Systems: Phase II Final Report", the use of Mission Task Elements (MTE) is offered as a way to evaluate the handling qualities of unmanned systems (Klyde Et Al., 2020). They offer MTEs as a way of categorizing and characterizing the mission of an aircraft into specific tasks. This approach is mission-oriented in that the focus is not specifically on either the aircraft or the operator but on the performance required of the operator aircraft system. This effort begins with the acknowledgement of the utility of evaluating the handling qualities of aircraft, and assumes that the same methodology may be applied to UAS. However, they see the impediment to applying handling qualities to UAS as a question of understanding the impacts to MTEs due to the physical differences between UAS and traditional manned aircraft. They offer:

> "Decades of criterial development based on piloted simulation and flight test evaluations were used to create the piloted handling qualities specifications and standards described herein. Thus, there is a strong desire to use this foundational work as a basis for establishing UA requirements. To this end, work is underway … to explore the use of dynamic scaling with existing handling qualities criteria and mission task elements" (Klyde Et Al., 2020, p 19).

Klyde does account for the impacts of autonomy on handling qualities, and stipulates that the handling qualities of a system are directly affected by autonomy level and should be evaluated under the appropriate autonomy level. However, in their approach to evaluation of handling qualities their focus is distinctly on performance. They assert:

> "If a UAS mission is to, for example, station keep over a given location it matters not in terms of handling qualities whether it is remotely piloted or autonomous, the mission requirements will be the same" (2020, p7).

This seeming dismissal of the impact of automation forgets the actual thing being measured by handling qualities, and confuses it solely as a measure of performance. This is in conflict with Cooper and Harper's definition of handling qualities as a considering of both "the ease and precision with which a pilot is able to perform the tasks" (1969, p2). While appreciative of the applicability of handling qualities to an autonomous system, Klyde et al.'s approach appears to under-appreciate the impact of automation as simply a reduction of task loading on the operator. However, this does not appear to be the case with AVOs on an autonomous UAS such as Triton.

Workload

The concept of handling qualities poses a unique challenge to aircraft designers. While the flying qualities of a vehicle lend themselves to quantitative, computational analysis, the inclusion of consideration for the human operator in the pilot-vehicle system requires a subjective analysis. This subjective aspect complicates the issue, "for the designer, the quantities set down in performance specifications are themselves objective ends; the quantities prescribed in specifications of [handling qualities] are objective means to an associated subjective end" (Vincenti, 1990, p 100). In essence, the goal of handling qualities is how to design a vehicle using quantitative characteristics that will meet a qualitative goal of pilot opinion.

Cooper and Harper addressed this issue through the development of a handling qualities rating scale, shown by Figure 5. In this scale, aircraft qualities are evaluated using a set of dichotomous questions relating to performance and workload. To increase the applicability of the instrument, the performance metric is delineated in terms of Satisfactory, Adequate, and Controllable, each defined within the individual and specific mission tasked to the pilot-vehicle system. The workload is evaluated through the pilot's perceived compensation. As Cooper and Harper framed it:

> "Pilot compensation … is intended to indicate that the pilot must increase his workload to improve aircraft performance. It relates the pilot's difficulty in completing a task with the precision required for that task. Stated another way, it is the measure of additional effort and attention required to maintain a given level of performance in the face of less

> favorable or deficient characteristics. The total workload is then comprised of the workload due to compensation for aircraft deficiencies plus the workload due to the task" (1969, p 13).

This framing removes evaluation from the actual tasks being performed and places it in the pilot's perception of effort and the resultant impact on mission accomplishment. Effectively, it measures the pilot's perception of how easy is it to fly the aircraft.

While the individual results may be subjective, through the aggregation of multiple evaluations, an average assessment can be achieved through use of the ordinal scale results. Previous manned aircraft assessments have been correlated to aircraft flying characteristics and used to derive specifications for design in documents such as the US Flying Qualities Military Specification, Mil-F-8785B, and the Military Standard Flying Qualities of Piloted Aircraft, Mil-STD-1797.

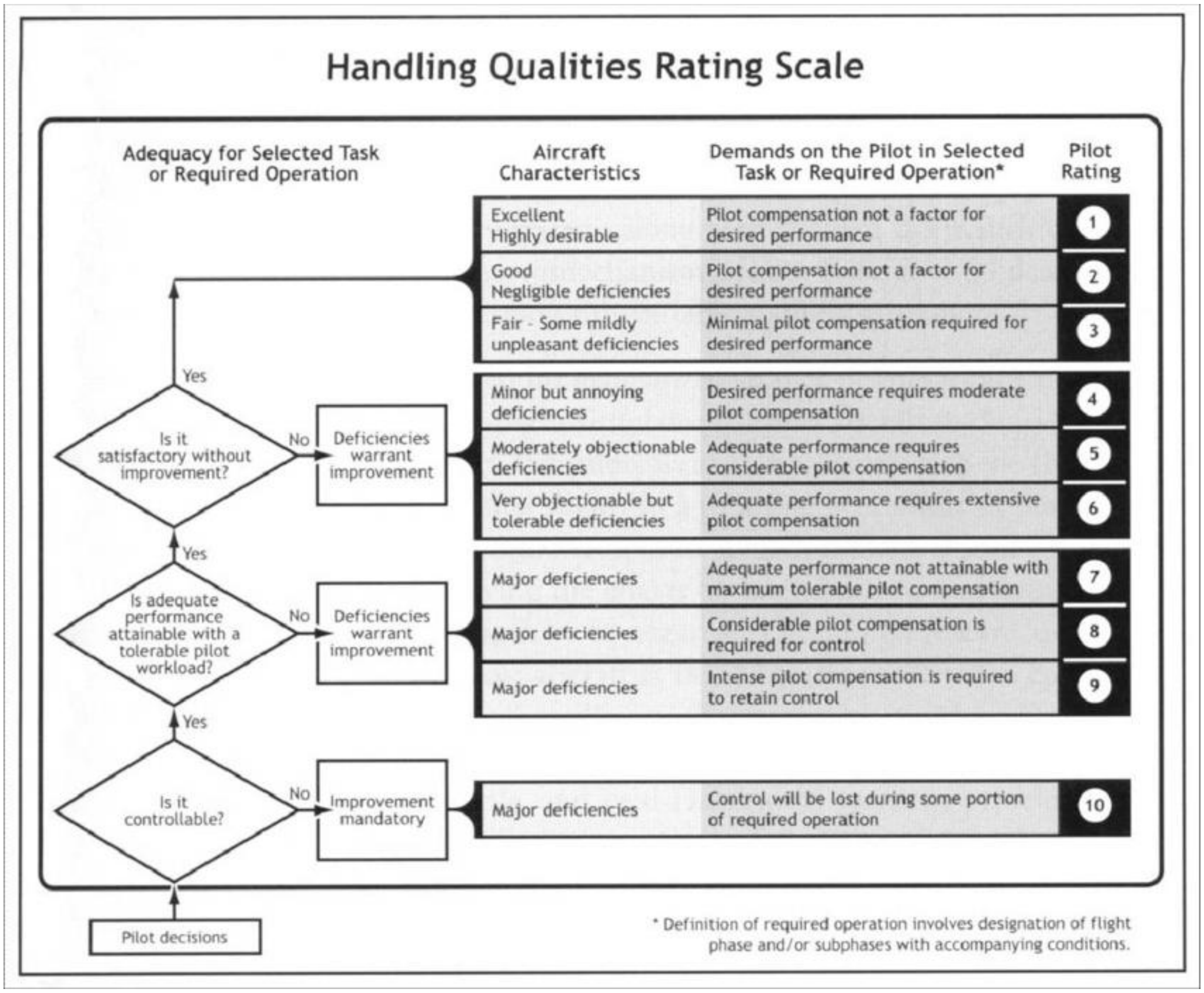


Figure 5

Cooper Harper Rating Scale (Cooper and Harper, 1969, p 12)

Trust

The increased use of automation in UAS may impact the types of qualities of a system that affect pilot opinion. While UA are still affected by the same physical laws that influence manned aircraft, the tasks being asked of the pilot may be substantially different. In 2012, Beth Lyall framed the potential challenges:

> "The types of automated systems that are particularly increasing in UAS, and that still require a lot of work to understand, are those that accomplish the processing and integration of information that would otherwise need to be gathered, processed, and

> integrated by the pilot. Automated systems that focus on information are challenging to design and evaluate, particularly in dynamic, information-rich settings where the complexity of information processing and synthesis requirements makes it difficult to effectively design the system logic as well as the interface. From an operational perspective, automated information processing systems have proven to be very difficult to effectively train for use, monitoring, and management."

These types of systems are removing many of the cognitive and reasoning tasks normally completed by pilots and delegating them to the automation of the UAS. Resultantly, this changes the interaction between the pilot and the machine and transforms the relationship from one of control to one of co-operation.

The interaction between operator and system is discussed in "Trust in Automation: Designing for Appropriate Reliance". In it trust is defined as "the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" (Lee & See, 2004, p51). They assert that "trust helps to overcome the cognitive complexity people face in managing increasingly sophisticated automation" (p 51), and that "poor partnerships between people and automation will become increasingly costly and catastrophic" (p.50). To address this concern, they frame the relationship between operator and system stating "that humans respond socially to technology, and reactions to computers can be similar to reactions to human collaborators" (p.51).

This new dynamic is confirmed by Aubrey Olson, an Air Force officer with experience flying the MQ-9 Predator. In his presentation, *Trust as a UAV Handling Quality*, he frames the new interaction between the pilot and the UAS. In his paradigm, the pilot interacts with the UAS with a tactical intent for the performance of the system. The automation of the UAS reacts to this intent and achieves some outcome (2021). Ultimately, this changes the role of the operator from controller to supervisor and decision maker. However, it also displays a new aspect to the interaction of the system, where the relinquishment of control by the operator creates a reliance on the automation. As predicted by Lee & See (2004), Olson describes the importance this places on the operator's trust in the system, and the relationship that defines that interaction.

This approach of viewing the UAS as a partner could change the way in which the AVO-UAS interaction is approached. It may include the concept of distributed cognition (Hutchins, 1995), where a person's cognition needs to be considered based upon the information and tools available to them. As the information normally available to a pilot physically in an aircraft is removed, how is the information replaced? It also could involve the concept of shared and overlapping situational awareness, where portions of the total situational awareness is maintained by an individual instead of the entire crew (Harris, 2006, pp 60-62). In this way, if the automation is part of the crew, then it may be relied upon to not only maintain situational awareness, but perform cognitive tasks. However, it is abundantly clear, that the increased utilization of automation affects the operator's interaction with the system in a way that was not previously considered with piloted aircraft.

Summary

As previously mentioned, removing the human from the aircraft does not remove them from the system. As UAS proliferate and become a larger portion of aircraft operations, "how we fly them" will become an important aspect of how we maintain safety and efficiency. While there are commonalities between the operation of manned aircraft and UAS, it is clear that many of the differences could have a substantial impact on the way in which the AVO flies the UAS. While previous research efforts have attempted to predict the ways in which AVOs will operate aircraft based upon existing theories, the only way to know for sure will be to ask those with experience in actual operation. Ground Theory methodology is well suited to this task, and will generate theory regarding flying UAS from those that have done it. Through this method, the similarities to manned flight can be confirmed, and the difference can be discovered and explored.

The application of a handling qualities framework is well suited to explore how AVOs fly UAS. With a focus on the operator aircraft system, handling qualities accounts for all of the factors that affect the operation of the system. With this pragmatic frame work, the limitations of applying ill-fitting, previously existing theory is avoided and the focus is placed on achieving adequate performance and operator workload. A decomposition of the handling qualities framework is provided in figure 6.

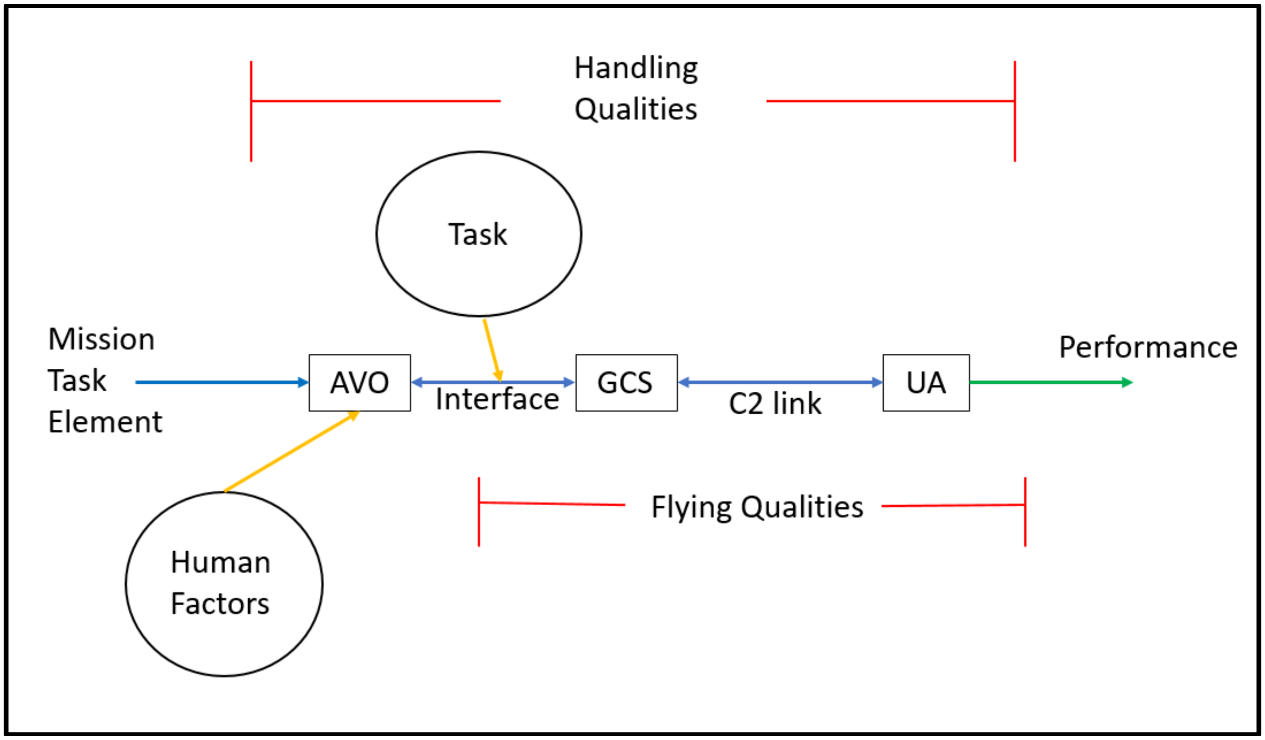


Figure 6
Handling Qualities Decomposition

CHAPTER III

METHODOLOGY

Theoretical Framework

This research is based on the application of the concept of handling qualities. In *The Use of Pilot Rating in The Evaluation of Aircraft Handling Qualities*, Cooper and Harper (1969) offer an evaluation tool to quantify the workload required to perform aviation tasks, and establish a basis from which the subjective quantification of ease of operating an aircraft could be derived. In their work, Cooper and Harper defined handling qualities as “those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role” (p 2). This definition establishes a constructionist approach to handling qualities where

> “Meaning is not discovered but constructed. Meaning does not inhere in the object, merely waiting for someone to come upon it … meanings are constructed by human beings as they engage with the world” (Crotty, 2020, p 42).

In this way, the handling qualities characteristics of the system are dependent on the pilot’s experience in operating the system, not just the design of the aircraft. Further, these experiences are influenced by external factors such as the environment in which it will be operated, the tasks the mission requires the operator to perform, and the level of performance desired. Thus, the handling qualities that may be suitable for a large transport aircraft with large moments of inertia and a desire for precise control may not be sufficient for a tactical aircraft that may need greater maneuverability and desire quick response. Additionally, the ultimate determination of the quality of the system - if it is satisfactory, tolerable, or unacceptable - is based upon the subjective opinion of the operator.

This application of a Constructionist approach stands in contrast to a Positivist, or Objectivist approach that are more traditional in questions of engineering and aircraft design. It holds that “all knowledge, and therefore all meaningful reality as such, is contingent upon human practices, being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context” (Crotty, 2020, p 42).
As stated by Merleau-Ponty, “the world and objects in the world are indeterminate. They may be pregnant with potential meaning, but actual meaning emerges only when consciousness engages with them” (as citied in Crotty, 2020, p 42). In other words, while a system being evaluated has definitive characteristics, it is only the experience of these characteristics in the phenomenon of operating them that determines their quality.

At the same time, despite Constructionism’s reliance on the subjective experience to create meaning, it also stands in contrast to Subjectivism, or Existentialism, that ascribes meaning only to the observer. As stated in Crotty, “the world is always already there. The world and objects in the world may be in themselves meaningless; yet they are our partners in the generation of meaning and need to be taken seriously” (2020, p 44). Ultimately, while the experience of a phenomenon may be subjective, it is not independent of the phenomenon. To apply this to the concept of handling qualities, while a pilot’s opinion of an aircraft is their own, there are objective qualities of the aircraft that will affect that opinion. No amount of subjectivisms can make a transport aircraft well suited to the fighter aircraft mission, or vice versa. Each mission and aircraft have characteristics that make them well suited. While the reality of how well those characteristics match is reliant on the pilot, it is still dependent on the aircraft and mission. “Constructionism does not suppress the object but focuses on it intently… it is meditation with content” (Crotty, 2020, p 52).

This duality of objectivism and subjectivism is reflected in the ontology of Constructionism. "Constructionism is at once realist and relativist" (Crotty, 2020, p 63). The realism was demonstrated by Stanley Fish in an example from baseball. He points out that:

> "Balls and Strikes are certainly socially constructed. They exist as such because of the rules of the game. Yet they are real. Some people are paid as much as $3.5 million to produce them or prevent their production! They are constructions… but they are real, nonetheless" (1996, p 23).

This is as true for baseball as it is for the certification standards and design specifications for aircraft. The pilot experiences the objective characteristics of the aircraft, but their evaluation is inescapably tied to the subjective opinion of the pilot that experiences them. Further, the results of handling qualities evaluations determine if an aircraft is safe and effective for its desired mission, and ultimately if it is airworthy. While based on subjective measures the results have a definitive effect. At the same time, as Crotty points out:

> "We need to recognize that different people may well inhabit different worlds. Their different worlds constitute for them diverse ways of knowing, distinguishable sets of meanings, separate realities… The way things are is really the sense we make of them… at different times and in different places there have been and are very divergent interpretations of the same phenomena" (2020, p 64).

While this approach does not go as far as the Constructivist approach that focuses on each individual experience of reality, it does account for the effect of differences on the shared social or cultural realities between groups.

This Constructionist approach mirrors that embodied in Cooper and Harper's handling qualities. The reality of the quality of an aircraft is a combination of the characteristics of the vehicle (the flying qualities) as well as the experience of the pilot in the completion of required tasks (workload). Additionally, the pilot's experience is not just a reaction to the flying qualities, but is also influenced by the human factors that affect their experience of the phenomenon. In this way, "objectivity and subjectivity need to be brought together and held together indissolubly. Constructionism does precisely that" (Crotty, 2020, p 44). Further, handling qualities accounted for both the realist and relativist aspects of Constructionism by accounting for the difference between the missions of different aircraft and the subsets of phases of the flight.

While the missions that UAS and their operators are asked to perform are often similar to those of manned aircraft, the way in which the AVO interacts with the system can be fundamentally different. Not being in the aircraft can preclude the sensing of the motion and state of the aircraft and environment. Additionally, the utilization of higher level of automation fundamentally changes the role of the operator. Previous research efforts attempted to inform UAS design through the application of existing standards and specification to ensure adequate safety and performance, such as those for manned aircraft (Hobbs & Lyall, 2016) or those for computer workstations (Waraich, et. al., 2013). While these approaches may be expedient, they are limited in that they are a theoretical analysis based upon assumed similarities. However, the strength of the handling qualities approach is that it is focused on the pilot's perception of workload and system performance. According to Cooper and Harper "Theoretical analysis … cannot adequately treat the complex interactions that are now investigated by means of … pilot evaluation" (1969, p 5). The direct measure of the subjective pilot's opinion bypasses any assumptions of similarity, or quantitative proxies for adequate performance, and allows pilot opinion to directly inform what makes the UAS easy to operate.

In *Aircraft Handling Qualities,* Hodkinson asserts that "the best way to collect a pilot's opinion is to ask him or her. A pilot's comments about how an airplane flies are still the best source of information" (1999, p.4). Therefore, this research seeks to build an understanding of the handling qualities of UAS using a grounded theory methodology with semi-structured interviews as the primary source of data. This process will emulate the learning process Vincenti describes for the origin of flying qualities. The objective is to build an understanding of the experience of UAS operators through the compilation and analysis of the perception, awareness, and knowledge of those with experience operating UAS.

The results of this research will be relevant theory that illustrates the interaction between the AVO and the UAS in the accomplishment of their assigned mission. This theory will be based in the role of the AVO, the relevant UAS characteristics, and the tasks they are required to perform in execution of their mission. Establishment of this theory will help inform standards of design and certification that will make UAS operations safer and more effective.

Study Design

Participants

Eleven qualified MQ-4C Triton AVOs were interviewed for this research. The targeted population were AVOs with experience operating the MQ-4C Triton UAS. The AVO population was constrained to a single platform to reduce variability due to UAS mission, training, or organizational differences. The participants came from one of two generic groups: a flight test group, with experience from the Triton Integrated Test Team (ITT); and an operational group, with experience at Unmanned Patrol Squadron 19 (VUP-19). While both groups were qualified and operate in accordance with Naval Air Training and Operating Procedures Standardization

(NATOPS) for the MQ-4C, the ITT is tasked with test and evaluation of the MQ-4C, while VUP-19 is focused on operational employment of the UAS.

Slight differences were noticed during the coding of the responses from the two groups. These differences were not necessarily with their comments about flying Triton, but with the topics in which they chose to discuss when prompted. These differences are not taken as contradictions, but as a byproduct of the nature of the semi-structured interviews. With different objectives, the degree to which the characteristics of the system affected the operator changed. Things that the Triton ITT members found difficult while conducting flight test did not necessarily present the same level of impact to the operational AVOs.

Additionally, the two groups displayed differences in how they operated the aircraft. While both groups operated in accordance with the same flight manual, the test flight operations appeared to be much more controlled than the operational flights by VUP-19. The ITT flight tests are generally shorter in duration, and typically are not as far ranging as the operational flights of VUP-19 that often involve controlling a UA on the other side of the globe. Additionally, weather restrictions, such as a prohibition of flying into visible moisture for flight tests, appear to be a constraint to ITT operations. VUP-19 on the other hand, which supports operational commanders and decision makers, is not as constrained and is more likely to operate in less than ideal conditions. The differences were resolved in the axial coding process, where the differences aided in creating a distinction between handling qualities and artifacts of the challenge of conducting flight test.

The two groups also differed in the focus of their critiques. The flight test side, focused on evaluation of the UAS, tended to be critical of the MQ-4C Triton system and its characteristics. Their comments biased towards citing the short comings of the UAS and system attributes that affected system operation. Conversely, the VUP-19 AVOs tended to be focused on working around UAS issues to facilitate operations. This resulted in more comments about training challenges and AVO workload, which highlighted pilot compensation required for adequate system performance. While a distinction between the groups was noticeable, it wasn't comprehensive. Most of the responses supported and affirmed the commonality between the groups. Nevertheless, the differences between the two did provide an opportunity for a more complete understanding of the handling qualities.

The ITT AVOs involved in flight test appeared more familiar with the classical definition of handling qualities as it applied to manned aircraft. This results in a general approach of dismissiveness in applicability of handling qualities to autonomous UAS, like Triton. However, this dismissiveness did not seem to influence responses about the role of the AVO or the phenomenon of operating Triton.

Participants ranged in experience, from those recently qualified to those with several years operating Triton. All participants had previous manned-flight experience, with at least 1,000 flight hours in multi-crewed Naval manned aircraft. Most participants accumulated that experience in the Maritime Patrol and Reconnaissance Aviation (MPRA) community operating P-3, EP-3, or P-8 aircraft, though two came from other aviation backgrounds. No differences in response was noted between those with an MPRA background and those from other communities.

Some of the participants had experience with other UAS of varying sizes and automation levels. Comments from the participants were not restricted to only discussion of Triton, and references to other UAS are contained in the interviews. A table of interview participant and their background is provided in Table 3.

Table 3

Interview Participant Demographics

Interview	MQ-4C flight hours	Role	MPRA background	Other UAS experience
A	<50	Flight Test	No	Multiple
B	<50	Flight Test	Yes	No
C	>200	Flight Test	Yes	Multiple
D	>200	Flight Test	No	Multiple
E	>200	Flight Test	Yes	Multiple
F	>200	Flight Test	Yes	No
G	50-200	Operational	Yes	No
H	50-200	Operational	Yes	No
I	>200	Operational	Yes	No
J	>200	Operational	Yes	No
K	<50	Operational	Yes	No

Access to participants was coordinated through the pertinent chains of command at the Triton ITT and VUP-19. While each unit was aware that interviews were being conducted, neither were not informed of when the interviews were conducted or what individuals were participating. To prevent any possible harm to the participants, and to remove any undue influence in the responses, the participants are to remain anonymous in accordance with the University of North Dakota Institutional Review Board (IRB) human subjects research requirements. The University of North Dakota IRB procedures were evaluated and approved by the Naval Air Warfare Center Aircraft Division IRB.

Prior to interview, all participants were required to review and sign an Interview Consent form which explained their rights and role in the research. While all of the forms were completed digitally, the researcher has kept and maintained physical copies in a secure location. Participants were not compensated for their time or for participating.

The population of Triton AVOs may not match the population diversity of the general public. It is more likely that the subject population is a closer match to the population diversity of United States military pilots. Three of the eleven respondents were female. To protect the anonymity of the responses the female respondents have not been identified, however no noticeable differences in responses were noted among the female participants. No race, ethnicity, or age demographic information was collected about the participants.

MQ-4C Triton

The MQ-4C Triton UAS is a high-altitude, long-endurance, air vehicle based upon the Air Force's Global Hawk. The max takeoff weight is 32,250lb and the wing span is 130 ft 11in. It is a forward deployed, land-based system that provides persistent maritime intelligence, surveillance, and reconnaissance capability using a multi-sensor mission payload. It is composed of a Mission Control System (MCS), ground segment, and an UA connected through a command and control data link. The MCS contains the hardware, software, and communications equipment required for the control and monitoring of the MQ-4C UA. The MCS is comprised of the Main Operating Base (MOB) and the Forward Operating Base (FOB) (Villiard, 2020). Triton incorporates several improvements over the Global Hawk airframe that enable operation in the harsh maritime weather environment. The aircraft can fly over 24 hours at a time, at altitude over 10 miles, and at an operational range of 8,200 nautical miles (Northrop Grumman, 2022). An image of the MQ-4C Triton is presented in figure 7, and a representative operational overview is provided in figure 8.

Figure 7
MQ-4C Triton (Northrop Grumman, 2022)

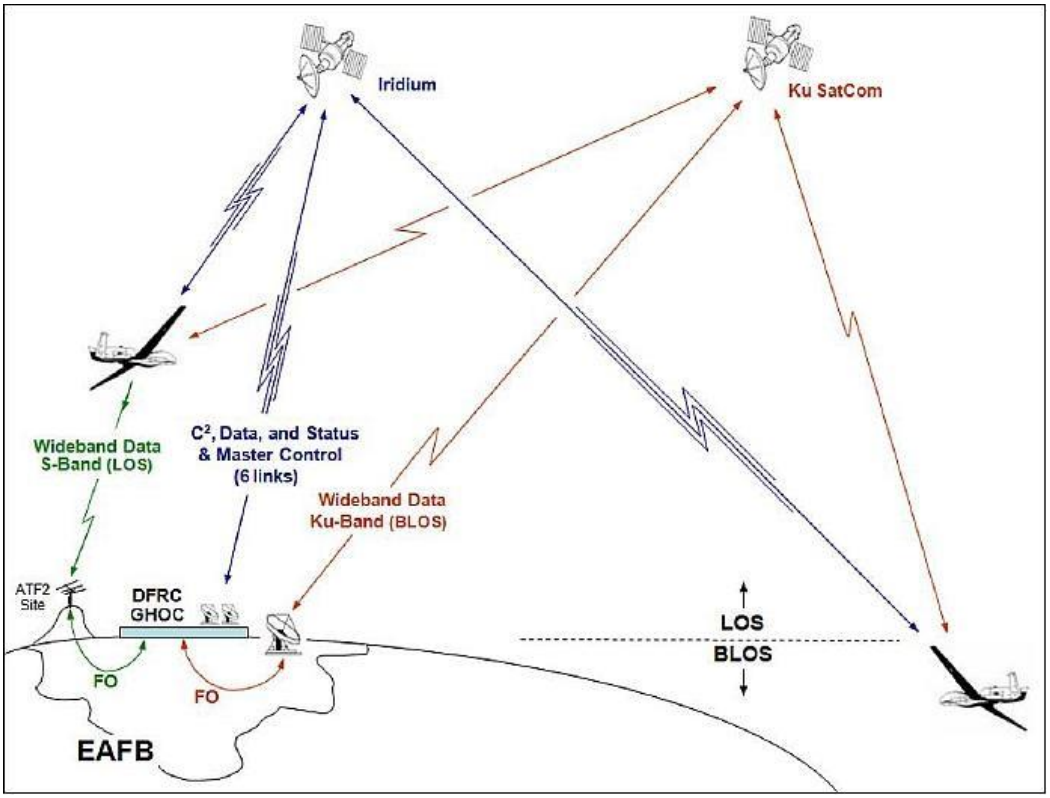


Figure 8
Operational Overview (ESA, 2012)

The connection between the MCS and the UA is maintained through an array of line-of-sight or beyond line-of-sight data links. The line-of-sight links are only possible when there is a clear direct path between the transmission source and the UA. Beyond line-of-sight links are routed through communication satellites, and are constrained to the satellite's communication footprint. The beyond line-of-sight data links enable connection between the GCS to the UA anywhere that can be reached by communication satellite coverage. The data rate of the connection between the UA and the GCS is dependent on the type of link established. Like the Global Hawk, the system can operate autonomously and execute a pre-loaded flight. Additionally, the AVO is capable of monitoring and commanding the system through the use of the data links (NASA, 2019).

The MQ-4C Triton was chosen for this research due to its high level of automation, inclusion of autonomous actions, and ability to operate beyond line-of-sight. These characteristics provided a stark contrast to most manned aircraft. Additionally, the researcher's previous involvement with the platform assisted in gaining access to the MQ-4C AVO population.

Participant Selection

Participants were recruited from the Triton ITT and VUP-19 through email. A contact list with the email information of current AVOs was obtained from the targeted units. The recruitment email was sent from an @NDUS.EDU address to ensure that potential participants understood that the research was separate from their chain-of-command. The contact email made it clear that the identities of the participants and their expressed opinions will be kept confidential, and that all participation was voluntary. Interested subjects were requested to reply to the email with a brief summary of their aviation experience. Of the 52 recruitment emails that were sent out, 11 replies were received. Everyone who replied to the recruitment email was interviewed.

Site/Location

Interviews were conducted over Google Meet, a program that enables video-conferencing through freely available internet-based software. Participants were informed that the interview should take about an hour, and were allowed to schedule the interview for a time that was convenient for them. When coordinating the scheduling of the interview, it was suggested that the participants find a quiet place, with good internet connection, away from public places where they were unlikely to be overheard by non-participants. However, they were allowed to choose their location.

The researcher conducted interviews alone in his office, with the door closed to prevent interruption or from anyone overhearing the conversation. The researcher always had his microphone and camera on during the interview. All of the participants had their microphones on during the interview, and all but two of the participants had their cameras on. The two participants that did not have their cameras on did so due to connectivity concerns. All recruitment materials, consent forms, IRB approval, and communications are on file with the researcher.

Data Collection Method

The data collection effort focused on semi-structured interviews with Triton UAS AVOs. The semi-structured format was used to focus the interviews on the desired areas of inquiry while allowing the discussion to conform to the answers of the participant and to explore and develop terms and concepts that emerged. The goal was to have the participants do the majority of the talking, with the interviewer encouraging as much detail as possible, asking for clarification as necessary, and avoiding too much time off topic. While the interviewer worked from the semi-structured interview guide during the discussion, digression was allowed to discover and explore concepts and themes from the experience of the participant. A copy of the semi-structured interview guide is contained in Appendix A.

Audio and video of the interviews was captured through the Google Meet application. At the completion of the interview, recordings were downloaded and stored on the researcher's password protected laptop, and the recording were removed from the Google server. All interviews were then transcribed from the recorded audio. Interviews A through D were manually transcribed into Microsoft Word by the researcher. Interviews E through K were transcribed using Otter.ai transcription software. The software produced transcripts were reviewed and corrected against the recording by the researcher. Any responses or comments that could identify the participant were removed from the transcripts. The information about the participants provided has been categorized into general ranges to prevent the identification of any one individual participant. Interview transcripts are on file with the researcher. The interviews were scheduled for one hour, and ranged in length from 39 minutes to 1hr 19 minutes.

The interviewer took notes of key points, phrases, and impressions during the interviews. After the interview, the interviewer used the handwritten notes to produce an analytical memo to record thoughts and reflections of the interview. This process helped capture any non-verbal forms of communication or any impressions of emotion or emphasis perceived by the interviewer as well as any initial impressions about the responses. Information from the analytic memo was included with the transcript of the interview for coding and comparative analysis.

The Constant Comparative Method, as described by Glaser and Strauss (1967), was utilized to generate and verify theory. As such, data from interviews was coded and analyzed as soon as possible after it was collected. Analyzed data was used to inform the line of inquiry in future interviews. Before each interview, all data, including previously collected and coded interviews, was reviewed to understand how the new data offered by the interviewee either confirmed or disputed the existing categories or themes. This allowed the interviewer to focus on apparent points of disagreement and seek clarification or amplification to better understand the differences. Saturation was considered to have been achieved when new interviews no longer revealed new understanding on operating UAS. The Axial coding process ultimately determined when saturation had been achieved. As described by Strauss and Corbin "when no new information seems to emerge during coding, that is, when no new properties, dimensions, conditions, actions/interactions, or consequences are seen in the data" (1998, p. 136) saturation is achieved. Saturation was considered achieved for the ITT AVOs after interview F. At that point, the VUP-19 AVOs were targeted for interviews to explore and isolate the influence of the flight test role on the AVO's experience. Saturation was considered achieved for the VUP-19 AVOs after interview K.

In *The Grounded Theory Perspective*, Glaser espouses:

> "All is data is a well-known Glaser dictum. What does it mean? It means exactly what is going on in the research scene is the data, whatever the source, whether interview, observations, documents, in whatever combination. It is not only what is being told, how it is being told and the conditions of its being told, but also all the data surrounding what is being told" (2001, p 145).

Accordingly, all additional sources of data, such as interviewer memos, accident reports, flight manuals, or unit instructions were considered in analysis as they were discovered or presented.

Analysis Techniques

The analysis of collected data began with initial, or open, coding to parse out the data into meaningful segments. The process was completed with the interviewer's analytical memos on hand to provide insight into any underlying meanings that may be present. This step condensed phrases or paragraphs into descriptive codes that summarized what was being expressed. During this open-coding process, there was no limit on the number of codes that could be utilized and focus was on capturing the sentiment of the comments, not correlation to the codes or comments in other interviews. Open codes were recorded in the interview transcripts by using the comment feature of Microsoft Word. Applicable comments were marked and the code was applied as a comment. To remain as authentic as possible to the experience of UAS operators, In Vivo coding was used to the maximum extent practicable (Charmaz, 2014).

The initial coding was followed by a second cycle of Axial coding to form the individual segments into categories. The "categories should not be so abstract as to lose their sensitizing aspect, but yet must be abstract enough to make theory a general guide" (Glaser & Strauss, 1967, p.242.). This process connected the open codes from the initial coding process that expressed similar sentiments. In this way, the commonalities between the interviews could be tied together to reveal the underlying truths of the phenomenon. Moreover, conflicting codes were discovered that highlighted the lines between different aspects or categories. Categorical codes were tracked and maintained on a separate Word document. After transcripts were complete with the initial coding process, the open codes were reviewed in context of the categorical codes. If a code did not fit into an existing category, a new category would be made. Additionally, some codes were fit into more than one category. To facilitate analysis, the interview comments that related to the codes were copied to the applicable categorical section in the Categorical code Word document. By having all of the related comments together a direct comparison of associated categorical comments was possible.

Finally, Conceptual coding, or Theoretical coding, was applied in which the categories discovered in the Axial coding process were related to reveal the core categories that connected them. The purpose of this final coding process was to move from the descriptive results of the individual interviews into generalized theory that addresses the research questions. “A Theoretical code specifies the possible relationships between the categories and moves the analytic story in a theoretical direction” (Charmaz, 2014, p 150).

In accordance with the constant comparison method, this process was iterative with all data being reviewed with the addition of new data. Several sets of axial and conceptual codes were attempted to find a meaningful way in which to organize the open codes produced from the interviews. The process of coding and the selection of coding methods was informed by *The Coding Manual for Qualitative Researchers* (Saldaña, 2021).

Trustworthiness/Validity

One benefit of using the grounded theory methodology is the inherent validity of the data being analyzed. Because the data is acquired from those with firsthand experience of the phenomenon, their opinions and expressions about that experience are inherently true and valid. While an individual experience of a phenomenon may be subjective, the use of multiple sources to confirm or contradict an opinion or idea builds the final constructionist result. The response to a challenge of the internal validity of this research comes in the rigor of the analysis.

In an attempt to contextualize the results, segments of the interviews are provided in the results section. This is done in an attempt to provide a "thick description" of the results (Geertz, 1973). Levitt described the purpose of the thick description as an effort to:

> "Contextualize [the] findings so that readers understand when, where, and under what conditions they were found to hold. Also, [it] will bring results to life by using evocative quotations, exemplars, and details that allow… readers to bring a range of associations to bear on the… findings" (2021, p82).

Interviewees were provided transcripts of their interview and asked to comment if it accurately reflects their experience. They were provided with a draft copy of the results and discussion sections of this report, and asked to comment if they disagreed, had a different interpretation of the findings, or would like to offer additional comments.

Aircraft handling qualities are not consistent across all types of manned aircraft. As such, the characteristics and traits that are tied to good handling qualities may not be similar for all types of UAS. Due to the diversity that exists in UAS types, mission sets, and automation levels, this effort is not intended to generate a single theory for all UAS. To manage the scope of this effort, data was collected for a single UAS platform. Resultantly, the applicability of handling quality theory past this specific UAS and AVO population is uncertain, but may apply in similar platform types.

Researcher Reflexivity

The researcher's previous experience with UAS instilled a view that operating a UAS is fundamentally different than flying a manned aircraft. The confusion and frustration with a system that was not designed to make the AVO’s job easier left a lasting impression. As a test pilot on the MQ-4C UAS at the Triton ITT, the researcher had previous experience with the mission of the platform, but found the act of operating the autonomous UAS to be fundamentally different from operating manned aircraft. However, many of the design considerations of the Ground Control Station (GCS) and Unmanned Air Vehicle (UAV) had utilized manned aircraft handling qualities in their design. This often led to experiences where the systems were awkward or confusing to use, resulting in additional workload to complete tasks. Moreover, time was spent completing tasks that were not required in manned aircraft, and therefore had no established criteria for what was adequate.

The researcher acknowledges the influences of his previous experience on this work. On the one hand, familiarity with the subject matter was beneficial in interpreting the lingo and jargon used by those operating Triton. The military and aviation are both famous (or infamous) for the use of acronyms, metaphors, and idioms that may confuse those not familiar. Additionally, he may have an increased empathy toward Triton AVOs having previously performed the roles and tasks they are assigned. This background provided some insight into their experience that was useful in analysis. Furthermore, the connected history promoted the interviewees’ willingness to disclose their unguarded opinions and thoughts with someone that has had a shared experience. However, he is aware that his experience has left him with impressions as to the handling qualities of UAS. In conducting interviews and in analyzing the data, he tried to listen and perceive the opinions that did not agree with his preconceived notions. Ultimately, his experience should inform the work, but the data should be the source of results.

CHAPTER IV

RESULTS

The responses from the interviews with the MQ-4C Triton AVOs were coded, sorted into themes, and arranged into categories. The discussion of the results is arranged by these categories in an attempt to present the concepts in the responses in a meaningful way that develops theory. The categories are not intended to imply a separation or segregation of the concepts they include. On the contrary, the ways in which the categories are related and the themes that interconnect between them reveal nearly as much as the themes that have been chosen for this analysis. The three themes presented are: Role of the AVO, Role of automation, Role of the interface. The titles of the subsections come from the codes used to correlate the interview responses. Some of these titles come from the in vivo codes that utilize the phrases used by the AVOs. They are not intended to be definitive, but descriptive of the concepts that emerged through the interviews.

Role of the AVO

Aircraft Command

In manned aircraft with multiple pilots or control stations, the individual exercising control of the aircraft may change several times during the flight. However, for each flight, a Pilot-In-Command (PIC) must be established. According to Federal Aviation Regulations, the PIC "is directly responsible for, and is the final authority as to, the operation of that aircraft" (14 CFR § 91.3, 2022). For Naval flight operations, this position is designated as the Aircraft Commander. Despite the difference in terms, both positions are held by a single individual who has decision-making authority on that aircraft; an individual who has ultimate responsibility for operation of that aircraft. Though not explicitly stipulated, the PIC, or aircraft commander, has always been physically located on the aircraft. However, despite this traditional location of the Aircraft Commander, Triton AVOs assume this responsibility for the operation of their UAS. According to one AVO:

> "Your role and responsibilities are going to be … basically the same as they would be if you were flying a manned aircraft. If you're the pilot in command… then your role is safety. You know, just safe operation of the aircraft to accomplish your mission…. those responsibilities don't change whether you're controlling a manned aircraft or, or if you're controlling an unmanned aircraft" (interview F).

This was supported by another AVO who offered that the:

> "responsibilities are not much different than … it was in the manned aircraft, it is safety of flight, and in our community, it is putting the aircraft in the right place at the right time for sensor collection, and exercising that aircraft to the max extent possible" (interview H).

This assumption of responsibility by the Triton AVOs is supported by the Department of the Navy's General Flight and Operating Instructions Manual (CNAF M-3710.7), which asserts "the positional authority of the UAC is analogous to that of an 'aircraft commander' of a manned aircraft" (2016). Ultimately establishing that despite the AVO not being physically located on the air vehicle, they are still responsible for the safe execution of the mission assigned.

This is an important point in establishing the relationship of the AVO to the UAS. Despite the physical distance between the AVO and the UA, the potential of losing communication between the two, autonomous action by the system, the AVO (as aircraft commander) retains responsibility to complete the assigned mission through operation of the UAS. While this may seem trivial, it is an essential cornerstone in applying the concept of handling qualities to the system. As with manned aircraft, the AVO and UAS work as a team to complete the mission, and despite not being located on the UA the AVO is just as responsible for mission completion as a manned aircraft pilot.

Aviate, Navigate, Communicate

With the establishment of the AVO's responsibility for the operation of the vehicle, to apply the concept of handling qualities, it must be established what mission task elements the AVO and UAS team are being asked to complete. When posed with this question one AVO offered:

> "It's still the same, like aviate, navigate, communicate is still the role of the pilot, you know, just the basic safety of the aircraft. Putting it where it's supposed to be. That's, that's still the job of the [AVO]" (interview G).

Another AVO offered:

> "I mean all the classic aviate, navigate, communicate stuff is still there from manned aircraft… It's just that a portion, the aviate piece has a different flavor, because I am not worried about maintaining a good instrument scan as much as I was, and keeping everything trimmed up so that altitude wasn't wandering, or drifting left or right, or that kind of thing. Because… the computer does it for you." (interview C).

In their experience, they see the objectives of the manned and unmanned systems as being the same. However, as one AVO points out, how these tasks are completed is different. They offered:

> "You're going to have to control the altitude with an aircraft, whether it's unmanned or manned, you're going to have to monitor its navigation, you're gonna have to coordinate

> with air traffic control. So, I guess technically, like, the way I see it, all those tasks are going to be are going to be the same, you're just going to execute them differently… the execution… is different” (F).

This statement shows that the required performance of the Triton AVO-UAS system is the same as for a manned aircraft, but points out that what is being asked of the AVO is different. This is important in establishing the conditions under which the system may be evaluated. The Mission Task Elements (MTE) previously established for manned vehicles with a similar mission may still apply; however, the division of labor between the UAS and the AVO in the completion of those MTE is different.

Different “Monkey Skills”

With the mission task elements of Triton being similar to those of manned aircraft, it would be tempting to jump to the conclusion that the handling qualities may be similar as well. However, according the to AVOs this does not appear to be the case. In talking about the handling qualities of the Triton UAS, an AVO provided the following insight:

> “How do you assess handling qualities when the pilot is not in the loop?... I am sending a command, and that is very very different” (interview D).

This is reinforced with other comments highlighting the difference between the AVOs’ previous experience flying manned aircraft and operating Triton:

> “How much it looks like an airplane and how you control it are kind of dissonant in my mind. Because I mean, it looks just like a small P-8, but you don't control it even remotely like that” (interview G).

> "I don't think actually operating the drone really relied on my previous experience in an aircraft… as far as actually operating it, it's just no different than clicking buttons on a screen, so it really doesn't translate too much to the actual flying." (interview K)
>
> "Flying [Triton] is not hard. You click on the keyboard or mouse and you fly to the points" (interview B).
>
> "As far as actually flying the aircraft, you're really just letting it fly itself. Like you're a systems monitor" (Interview E).

This opinion was reinforced by responses to a question about how they describe operating Triton to non-UAS pilots the following responses were offered:

> "That is really the discussion I have with a lot of these guys. Like, hey all that cool stuff you learned flying T-34 or T-6s, that is great, but it's not super translatable here" (interview C).
>
> "I tell them it is not like flying an airplane. And it's not even as cool as what you think of when you think of flying a drone - because they're like, oh, there's like a joystick, right? So, I mean, your [Primary Flight Display] looks the same and that is about where the similarities end" (interview G).
>
> "It looks very similar to the P-8s but other than that, like, you click a box you type the altitude you hit Enter, like, that's how you climb. So, you definitely, I don't I don't personally feel like a pilot when I'm flying it. That doesn't mean I dislike it. But it's, I would not describe it as being a pilot to another pilot" (interview G).

Another AVO offered this regarding the operation of the UAS:

> "That is the big thing. It's that difference. Some of the easy stuff became hard, and in exchange some of the hard stuff became really really easy. Like just the basic monkey

> skills, just flying the plane is way easier. But the management, and keeping track of the plane is a bit harder." (interview C)

Ultimately, The AVO and UAS are still a system that work together to complete a mission. Many of the MTEs are the same. However, the role of the AVO is changed by the way they interact with the system. The tasks required of the AVO to complete the MTEs are different from those that are typically encountered in manned aircraft. Instead of spending effort controlling the flight path of the vehicle, the AVO is now responsible for different and new tasks that require attention and effort.

In the end, when assessing what characteristics of an autonomous UAS, like Triton, affect the effort required to operate it, it is not enough to look at just the required performance of the system. The evaluation must consider the workload required by the operator. When direct manipulation of the flight controls is no longer the primary task being completed by the AVO, those characteristics become less important in determining the workload. Resultantly, to adequately evaluate the handling qualities of these types of UAS, the tasks that present high workloads to AVOs should be considered when evaluating handling qualities.

Role of Automation

Benefit of Automation

Automation is not unique to UAS; however, its implementation may be. One of the defining characteristics of an UAS is that the operator is not located on the air vehicle. This necessitates a connection between the AVO and the UA. Commonly this connection is made via radio link where data can be transmitted and received. However, due to the limitations of the propagation of radio waves and the great distances that can exist between the AVO and the UA, there can be a delay between when a signal is sent and when that signal is received. That delay is referred to as latency. According to one AVO:

> "You have latency. You have some latency down for your feedback and in sending the commands in. You click on it, send it, there is latency going up. So, I think that is definitely a piece of the handling qualities is the latency of the links. The links you are using that day could influence the handling quality experience" (B).

While there is no solution for removing latency when operating UA from long distances, automation can be used to alleviate some of the challenges it presents.

In comparing the operating of Triton as opposed to Remotely Piloted Aircraft (RPA) one AVO offered:

> "Those ultra-fine flight control movements, I find it is better to have the keyboard and mouse. Because it takes the man out-of-the-loop, it takes the link latency out-of-the-loop. It pushes all of the processing onto the on-board autopilot, which is doing however many hertz calculations per seconds" (interview C)
>
> "Guys like me that came from manned aircraft find it really really annoying to sit in the RPA station because the latency is just so bad. Even a half second latency when you are trying to fly off of remote video, you notice it… is what we found. And some of these things can have 6 seconds latency. And in that case, that is why I just like key board and mouse. I am going to tell it to land, and here is the runway, and boom [the automation] figures it out. Let the HAL 9000 do it" (interview C).
>
> "Every ground control station design I've looked at where they have tried to give me [direct control], we've pushed back and said 'No, no, no … we don't want them, we don't need them'. Latency in the system makes that really stupid. And you talk to the

> RQ-1 guys who were … They like to make that distinction ‘oh we’re remotely piloted, we’re not a UAS we are an RPA’. And you talk to them about it and you are like ‘Ya, you guys make it work with all of that stuff, but why?’ Look at how much work you are doing to have your stupid stick and throttle there to manually land this thing. I get it 20 years ago you needed that, but now you don’t” (interview C).

This view of the effect of latency on UAS where the pilot has direct control (often referred to as RPA) confirms previous research on the issue which showed that increased latency has a negative impact on the handling characteristics of UAS (Baughman & Longeuay, 2015), (Mandel & Gu, 2016). Ultimately, the shifting of control of the vehicle from the AVO to the automation on the UA ameliorates the impact of command and control datalink latency and, in the case of Triton, provides for a lower workload for the AVO.

In addition to addressing the issue of latency on control, the automation of the UAS also allows for the vehicle to address an interruption in the link between the GCS and UA. Referred to as lost link, this situation results in a loss of the ability for the AVO to send commands to the UA, and an inability to receive data from the UA. While this loss of connection separates the AVO from the UA, with the autonomous characteristic of Triton, it does not prevent the UA from continuing safe operation.

> “If we lose [link], the aircraft, will go loss link and there's a pre-planned condition for the aircraft to come back safely” (interview H).

On Triton a loss link results in a Contingency 1 (CONT-1) condition, and occurs when the link is lost for more than a specified time. Once this occurs, the UA autonomously initiates navigation, based upon the current mission plan, along the CONT-1 route. This routing will guide the UA back to a specified airfield for a normal approach and landing. This response is considered autonomous vs automatic because the vehicle is able to initiate the response on its own when it senses the loss-link condition. During this contingency the UA is only responding in a preplanned way based upon what it has been instructed to do through the mission plan. It is not devising a best course of action, but is instead triggering a preplanned response. However, because the system is able to initiate this change in objective without input from the pilot, it is considered autonomous.

> “The nice thing about [Triton]. They’ve got a mission plan and even if the thing loses link it knows what to do” (interview A).
>
> “The fact that I click a takeoff button execute and it does everything for you. Or when I click taxi …. just click taxi and hit execute, and it taxis, and you know it stays on the line…. When I'm taxing a manned airplane and I'm trying to look down and run checklists. It's like texting on your phone while you're driving. I mean, you're trying to text and trying to use the, you know, just feel of what the car is doing to stay on center line. So, it's the same thing. Like, the fact that it does all that is, you know, I can take my eyes off of the screen plenty and not have to worry about it, because it's just going to do what it's programmed to do” (interview F).
>
> “There's a lot of automation which makes your life easier. Obviously, I mean, the plane flies itself if you do nothing to it, which is fantastic” (interview J).

These comments reflect the benefit and change in dynamic that comes from operating an autonomous system. Where the responsibility of control of the vehicle lays strictly with the pilot in a manned aircraft, the inclusion of automation and autonomous decision making have shifted some of that responsibility to the UA. This shifting appears to have several impacts. First, it addresses the latency inherent in long-distance remote operations. Second, it mitigates the impact for drops of the command-and-control data link. Instead of the vehicle becoming uncontrolled, the autonomous UA continues along as programed. Third, it reduces some of the workload on the AVO.

Is it Doing What I Expect it to do?

While the automation of Triton reduces the task loading on the AVO for flight path control, it does not remove their responsibility for the safe operation of the UAS. Despite not being in control of the flight path, the AVO is still responsible for the navigation of the system. This changes the tasks of the AVO from those of control to those of being a monitor.

> "I see the role of the AVO specifically as more of a monitor… When you go through your training pipe line as an AVO you are instructed … You're told that the system knows best. So, keep an eye on it, make sure it is doing what it is supposed to be doing, and then if something goes wrong then you are there to intervene and help out with whatever the problem may be" (interview A).
>
> "Cause that is really what you are doing, you are monitoring the system with Triton.... for Triton, the robot can do the whole mission by itself. If you send it off, or give it a go to, or give it a lock, you need to be much more in tune with what the system is doing" (interview B).
>
> "Sometimes you don't know exactly what [UAS] are going to do, because they may make this little juke turn or climb and descent before they do what you want them to do because somewhere in its algorithm that is how it told it to do it – or it calculated that that was the best way. So, there is that suspicion all of the time about it" (interview C).

> "It's the same thing with a student… you are monitoring the student – 'Are you doing what I expect you to be doing?' It's the same with the system, is it doing what I expect it to be doing" (interview B).

While monitoring may seem like low workload, any instructor pilot can attest to the amount a vigilance and anticipation needed. Not only must the AVO know where the UA should be, they must constantly assess the adequacy of where the vehicle is, and be able to decide if and how they should intervene to correct. Ultimately, the task for the AVO is not directly controlling the vehicle to the appropriate location, but monitoring the state of the UA and constantly determining if they should intervene.

Staying Ahead of the Robot

In addition to CONT-1, Triton has a total of five possible contingences where the UA autonomously changes its objective. When the trigger criteria are met, the UA selects and initiates a preplanned response. These contingencies may be overridden by the AVO, if a link is established, but the capability allows for the vehicle to make appropriate responses to emergency situations in the event of a loss link. Additionally, the UA will initiate these other contingency conditions regardless of if the vehicle has an established C2 link. The UA does not wait for a command from the AVO to act. It can, of its own accord, decide to follow a contingency course of action, which places a difficult burden on the AVO.

> "I think one of the bigger things that I tell people is that it's very much a mental game, don't come to this and think it is easy, just because you're no longer physically flying the aircraft. It's a mental game, that means you have to be ahead of the aircraft much more to understand what the aircraft is going to do" (interview I).

> "We will go in there … and make sure we understand the mission. Understand what the mission plan is - to include contingencies. Contingency 1, Contingency 2 stuff, which is the [return to base] and obviously the Contingency 3 … both engine-out and engine-operating. So, we want to make sure we are studying that and are well versed in that, especially in the terminal area for Takeoff. We have to make sure we know where that aircraft is going to… It is a big thing, we have to definitely know the mission plan" (interview D).
>
> "When it comes to contingencies … you still have to account for where the contingency routes are going to bring you in… like, Hey, Cont-1 is gonna take you back through the storm. You're still allowed to take off, but you're still trying to do your due diligence as the aircraft commander and not fly through that if you can" (interview G).

This aspect of operating Triton is one of the largest differences with manned aircraft, and a new task requirement for the AVO. With the system capable of acting without AVO command, the AVO must then anticipate the vehicles action in the event of a contingency. This increases the task of the AVO from just monitoring the current performance of the system, to one of anticipating the reaction of the automation during each moment of the flight.

In a manned aircraft, automation is designed to allow for reversion to lower levels when the system encounters a fault or emergency. If the automation is not performing as desired, the pilot can assume higher levels of control, and then address the situation appropriately. For Triton, the opposite is true. In the event of a contingency condition, the UA reverts to a higher automation level, taking command as well as control over the vehicle.

> "The way you rescue yourself in a manned aircraft is you just click everything off and fly the plane. And then you figure out what happened afterwards… In Triton, we don't

> have that option. Like if you don't understand what the aircraft logic and the automation is doing. You don't have any, you don't have any recourse to just be a pilot and fly the plane. So, I think that is a big difference” (interview I).

This compounds the burden on the AVO. Not only must they be aware of what the vehicle is doing, and have enough insight to understand what the vehicle will do in a contingency condition, they also have fewer tools to provide correction. It is clear that this implementation of automation creates new task requires on the AVO, shifting from the manual tasks of controlling the vehicle to the mental tasks of monitoring and anticipating the responses of the UA.

Adaptability – Need for Intervention

While automation changes the tasks of the AVO, it does not completely remove the need for AVO intervention. Despite the loaded mission plan and the autonomous contingency logic, the AVO may still need to intervene to adapt to unexpected conditions or changes to the mission.

> “If we can do the preplanned mission that’s the best – to stay on that on tracked condition. But, if we have to deviate with override steering commands as necessary, we can do that” (interview D).
>
> “Until something goes wrong, or until something in the situation changes, like maybe you have a cloud deck or maybe your airspace gets cut down and you have to stay in a smaller box, or maybe the units on the ground have to work in a different space. And that is the change, that is where the autonomy piece is not quite there yet” (interview C).
>
> “You have to figure out lots of different workarounds. Like, there's a huge [weather] system blocking your main tracks, you can take the secondary track, but your C1 route goes back through that big weather system. So, there's not a lot of flexibility when it

> comes to our routing. Just because they are so time consuming to create, we don't have just an unlimited amount of routes” (interview G).
>
> “The engineers that built [Triton] can't … account for every single circumstance that you come into, and that's why you need a human to be in the loop... To be able to make those decisions” (interview F).
>
> “Immediately after takeoff [if you] have an engine failure. Regardless, it's going to be going to that next waypoint. So, that's kind of when you have to determine whether it's, it's safer to let it continue. Does it have the energy, altitude, airspeed, etc., to make that turn back around to land... So, you kind of have to make that determination pretty quickly, whether you're going to put it in the water or let it, let it land, if it has the energy to do that” (interview K).

Ultimately, the AVO is still relied upon to make the decision for the best course of action.

While the mission plans account for some contingency conditions, there is no way to plan for every possible event. In these inevitable instances, the AVO intervention is what allows the system to adequately perform in dynamic situations. It can be tempting for AVOs to override the mission plan and take control over the flight path of the vehicle. However, that is not always the best course of action.

> “Probably the worst thing that we do as AVOs is put ourselves in the loop. A lot of times the logic is there, the system will just do its thing if you just get out of the way and let it do it” (interview B).
>
> “The plane is smarter than you, it flies better than you, it can probably handle EPs better than you – Let’s put these increased levels of autonomy in it, where not only will the

> aircraft fly the mission plan that you gave it, but if it detects this fault… I just have command by negation from my GCS" (interview C).
>
> "It is when you try to manipulate the aircraft during important transitions is when it could get outside normal flight profiles" (interview H).

Unlike with manned aircraft where automation reversion assures that the pilot can assume control, in Triton, AVO intervention is limited to working with the automation through changes to the commanded objectives. As one AVO commented:

> "In a manned aircraft you just quickly disconnect everything and fly the aircraft. Here you don't have that" (interview B).

Where the mission plans loaded into the UA are evaluated before flight to assure adequate performance, once the AVO intervenes adequate performance becomes less certain.

> "On a mission plan, those are self-explanatory, and you just have to keep up with every single possible contingency that the aircraft can go. When you're off mission plan, then that's when things start to possibly be more varsity as to what you are going to do" (interview H).
>
> "[If] we have a standoff… you can't crank it over to … 30 degrees [angle of bank] and turn it like you could in [a manned aircraft]. It's going to take a little bit longer. So, that part of it was definitely a little bit strange and took some getting used to" (interview K).
>
> "If you have overrides on. Some of those contingencies will clear overrides some will not. Like a Cont-3 clears everything, Cont-1 doesn't clear everything. Cont-2 will clear if you are in endurance mode, it will speed the aircraft up. So, just knowing all that flight logic is quite a challenge at times" (interview D).

The limited options the AVO has when intervening with the system makes it much more difficult to decide if or how they should intervene. While Triton's automation provides many advantages, it also complicates the response to dynamic situations by adding another source of commands that the AVO must anticipate. Additionally, without the ability to take control, it also creates new challenges to the AVOs who must work through the constraints of the automation to achieve adequate performance and ensure safe operation.

Flying Qualities

Traditional manned aircraft flying qualities center around the classic modes of an aircraft, or the aerodynamic response of the vehicle to an input or disturbance. Automation and fly-by-wire systems have long supplemented or replaced theses basic aerodynamic responses in modern aircraft, allowing engineers to precisely control the vehicle response to input. As the ability of the engineers to precisely control the flying qualities of aircraft has increased, the importance of understanding what qualities are desired has increased as well (Hodkinson, 2015, p1). While automation to assist with control of a piloted aircraft has become common, the requirement to revert to manual pilot control has always necessitated a consideration of traditional flying qualities (or at least the apparent flying qualities) by aircraft designers. However, this necessity to regard the traditional flying qualities does not seem to affect the AVO's experience when operating UAS. According to one AVO:

> "UAVs have all of these classical flight modes, like they are going to Phugoid. Like every plane, it's got a short period – pitch pointing mode. They all have it. But, how much does it matter to you as the operator. Most of the time it really doesn't. Because

> you can have the computer damp it out, you can have the computer fix it. You can tell it to go over there and the plane is gonna do it" (interview C).

In other words, in a system where the pilot does not directly control the flight path, the response of the system to flight path controls is not pertinent. While the ability of the automation to achieve the required performance to suitably achieve the mission test elements is still relevant, that concern is a performance limitation and not one of operator workload.

This is not to imply that flying qualities as a concept is not applicable to Triton. Using Klyde's definition of flying qualities as the open-loop system response to a pilot's input, it is plain to see that since AVOs still make inputs to the system, and the vehicle responds to those inputs, Triton has flying qualities. However, instead of making inputs that control the flight path of the vehicle, Triton AVOs make command inputs that change the objectives of the automation. While thinking of the response of automation to a command input as open-loop may seem erroneous, it is only a small step removed from the advanced fly-by wire systems found in many modern aircraft: systems that long-ago disconnected pilots from direct manipulation of flight control surfaces, and instead translated pilot inputs into targeted vehicle states. It should be of no surprise that as the tasks required of operators change with higher levels of automation, the inputs from the AVO to the UAS should change as well. As such, while the classic air vehicle flying qualities may not be pertinent to Triton, other system characteristics and attributes may take their place.

Intuitive

One of the characteristics of the UAS that appears to influence the AVOs' assessments is the intuitiveness of the system. In this sense, intuitive is taken to mean how closely the system's response matches the pilot's intent. One AVO offered:

> "If your controls laws are more intuitive to how a manned aircraft would react that would make more sense to you as a pilot" (interview B).

While a software's response to a command should always be consistent, the complex operating modes of the UA can sometimes cause a misalignment between the AVOs intent and the UA response. This was mentioned several times by AVOs regarding the vehicle's response to 'goto' commands.

On a mission planned route, Triton will navigate via a series of waypoints, following along from one to the next until it reaches the end. In doing so, it will imitate manned aircraft navigation by leading the turn when approaching a waypoint where a turn is required. This results in the aircraft never actually reaching the way point but flying by the way point such that it is aligned on course to the next point at the conclusion of the turn. However, the UA response is different when executing a 'goto' command by the AVO.

If given a 'goto' command by the AVO, the vehicle does not actually turn directly to the waypoint. Instead it establishes a course inbound to the way point from the location it received the command, and turns to rejoin that course. Additionally, as it approaches the designated goto way point, the vehicles flight logic will treat the waypoint differently. Instead of flying by the way point, the vehicle will fly over the waypoint extending past the ground track it would have flown without the goto command. This difference between fly-by and fly-over is seen in Figure 9.

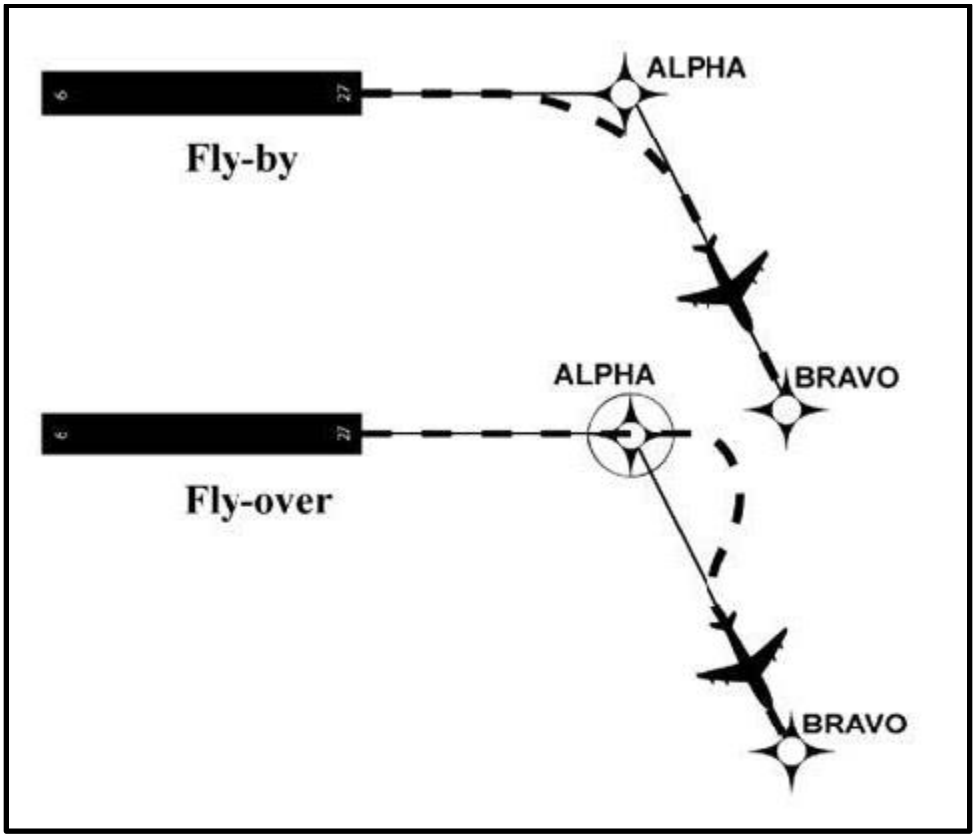


Figure 9
Fly-by vs Fly-over (Aeronautical Information Manual, 2011)

While this change in flight logic does not appear to put the aircraft in direct danger, the UA doesn’t execute the command in the same way a pilot would execute the maneuver, and seemingly the way the AVO intends for the vehicle to respond. To address this misalignment in vehicle response, AVOs have developed a workaround they call a double clutch.

> “Knowing if it is going to be a fly through waypoint or fly over point / fly by definitely matters… There is a double clutch to the turns where it is going to continue to turn to get back on the line you were on when you initiate the turn, so that is a technique and a work around, like that double clutch on the turning. To control exactly where it is going to go when you are off of the mission plan” (interview B).

> "Okay, now you're clear direct to, whatever point. Well, I'm not gonna overfly that point… I'm going to lead my turn into my next point. But the engineers that designed it didn't. I don't think they got enough input from pilots. And so, in their heads, they're like, Okay, well, if you're going and doing a heading, and you want to now go to a waypoint, you have to fly over the waypoint. Well now, it way overshoots. And that's when you start running into problems where you could, like end up in a denied area" (interview F).
>
> "If they send me direct to a waypoint… depending on where I am in the world, like if I need to hit that waypoint, and stay real close to the direct path between that waypoint and the next one, then I will either add like basically a right click on the navigation screen and add a waypoint in. And so, that's sort of, in between where I am and the waypoint I'm trying to go to, and send it to that waypoint first. So, it hits that then it goes to the next one, and it'll do a turn early. You know, or I will just keep steering it myself. So, I will send it direct, and then double clutch" (interview F).

While the double clutch appears to be a satisfactory workaround for this issue, it is an increase in workload on the AVO. Additionally, it is required only when the AVO has elected to intervene with the vehicle, a condition that is already at an elevated workload

Another example of this misalignment between AVO intent and UA response occurs with a climb command while the UA is in Endurance mode.

> "When I started flying UAS, all of the instructors said there is going to be a time when you look up and say 'where is it going?' You really gotta know the flight logic. Just like, as a professional test pilot you got to know the flight control system, you really got to know the flight logic on this one" (interview D).

> “If you want to climb and you are in endurance mode, yeah, it's going to descend to get to its nominal airspeed first and then climb. Well, in a manned airplane, we don't… we don't do it that way. We set power and start climbing” (interview F).
>
> “If you're in endurance mode, and you come out of endurance mode, then it should just do a level speed change. So, I will do that first and then command a climb just so that to prevent it from descending… I'm just going to try to manipulate the airplane to do what I think it should do” (interview F).
>
> “It will speed up to climb… If we have traffic and need to climb immediately, and we are in endurance mode, I know that I can trick the aircraft by giving it a discrete airspeed, and then give it the climb 2,000 ft above for it to climb right away... Because the last thing I want when [converging with another aircraft] is have the aircraft try to accelerate because it will start to descend [in response to the climb command], and then two minutes later when it is on scheduled speed start a climb... By that time, you had a midair” (interview D).

The hazard associated with the vehicle’s initial response is clearly seen. It is not reasonable to assume that a system’s response to increase altitude should initially be to do the opposite, descend. However, like with the ‘goto’ waypoint command, AVOs have identified this hazard and are able to compensate to achieve desired performance.

While adequate performance is possible, the compensation required by the AVO increases the physical and mental workload, increasing the possibility of mishap or incident. As one AVO put it:

> “a complacent AVO would be easily surprised at what the robot does when something changes” (interview H).

Importantly, both cases are not caused by a failure of the automation, but by a misalignment between the course of action intended by the AVO and the response of the system which results in a non-intuitive action. Clearly, this misalignment between user's intention and system response affects the ease of operating the system, and indicates that the attribute of intuitiveness contributes to Triton's flying qualities.

Predictability

Where the intuitiveness of the system reflects the matching between the intention of the AVO and the response of the vehicle, the predictability of the vehicle relates to the consistency of the response to the AVO's intention. This comes about when there are variations in the performance of the UA to a command. The AVOs offered the following comments regarding the predictability of the system:

> "The phrase we use is that this thing is the world's worst flight lead. Because part of the effect of taking the pilot a little further out of the loop and just saying 'hey here is what I want airplane, you do it' is sometimes it will determine that instead of turning right to get somewhere, it is one degree shorter to turn left" (interview D).

> "You say hey, go to this waypoint on the map, which is great. [However], you still, if you have a lock in, it is just going to grab all of the attributes of that waypoint and send it to the airplane. So, you have to go back to the Primary Flight Display and say 'no no, I want you at this altitude' 'not 50,000, I need you at 39,000… and because you graphically said 'go to this way point' on the map, it bashes everything and blows off your lock. It goes there, and the next thing you know ATC is telling you your 10,000 ft above your altitude. Like crap. There are so many little gotchas'" (interview D).

> “If you send it off, or give it a go to, or give it a lock, you need to be much more in tune with what the system is doing. Understanding how you may have influenced the mission plan” (Interview B).

Again, the issue seen here is not that the vehicle is performing erroneously, it is that the intended command of AVO does not match the command the UA received. This confusion could have many causes. Whether it is due to a lack of awareness on the part of the AVO, confusion on the commands being sent, or misunderstanding on how the UA may prioritize multiple commands; the system attributes can contribute to causing or alleviating these confusions. Unlike with intuitiveness, this is not an issue with implementation, but a problem of accurate communication between the AVO and the system. Ultimately, for AVO’s tasked with monitoring the response of the system, confusion about the current objective of the vehicle increases the workload on the AVO. As one AVO summarized:

> “As long as you were out of the loop, the unpredictable doesn't matter. Once you are in the loop, you've made it harder due to the unpredictability. Your task load has increased” (interview E).

In addition to the confusion that can be caused by a misalignment of AVO intent and UA execution, the predictability of the system is also related to the trust the AVO has in regard to the system.

> “The biggest thing, is putting in your input and monitor your feedback. You have to look at things like event history. You’ve got to make sure that your command is accepted. So, all those things – trust but verify” (interview D).

> “You can trust the system to perform tasks, [but] then you can hinder it so that it can’t actually be successful without understanding that that is what you have actually done” (interview B).
>
> “I think it is the knowledge of the system. If I told it to do something, and it doesn’t do what I expect, now I am hanging on the tail trying to figure out what it is doing and why it didn’t do what I expected it to do. So, it is almost a double put you behind the aircraft when that happens” (interview B).
>
> “I have a high degree of trust in what is being reported from the aircraft. I haven’t had the aircraft lie to me and tell me false information. That is not the way it works. So, if I can read the information I have a lot of faith in it and that it reflects reality.
>
> I have almost no faith or trust in the aircraft itself” (interview B).

While the pilot may have a clear understanding of what they want the vehicle to do, a lack of trust in the vehicle’s response to those intentions causes uncertainty with the AVO, and the workload is increased as the AVO must now pay closer attention to the vehicle’s response to ensure that it matches what was intended.

Flexibility

In addition to inappropriate or uncertain responses to pilot intention, the AVO can also be constrained through an inability to actually get the vehicle to do what is required. While the mission plan can navigate the UA to preplanned locations, when the AVO is required to adapt to the current conditions, they can be constrained in what they are actually able to get the UA to do. AVOs frequently mentioned this in regard to using commanded heading changes to navigate the vehicle. While the AVO can command an assigned heading, they cannot manipulate the rate at which the vehicle turns to that heading.

> “The turn rate, because you can't change your angle of bank, and you really can't change your airspeed… the turn radius is completely unpredictable… Because, by their design, you can take it off the mission plan, where it has all the calculations that go into how to turn. But now that you've taken it off of the mission plan, which you may need for traffic avoidance, or for the mission or for whatever, you now have no way to… increase your turn radius or decrease your speed to decrease your turn radius. And it's completely out of your awareness of like what it's going to be and how you can maneuver it. So, I thought that was a real difficulty” (interview E).
>
> “For turning I am limited to 15 degrees angle of bank, at altitude. We have had 150 knot crosswind before in R4008. Boy, and when you are dealing with some override steering commands, doing some ‘handling qualities.’ I tell you what, you turn down wind… 14 miles later you are out of the airspace. So those things make it a challenge” (interview D).
>
> “We do have turned radius charts that you could look up before you make those turns… When we're in a track, and we're trying to get close to standoff line, we might actually make those calculations. But you know, when you're just off the cuff, like, Hey, can I turn inside of this? That's, that's pretty hard. Pretty hard to judge, because the wind, like I mentioned, it has a huge effect. And you may not have noticed that you now have a 49-knot tailwind, because you're just not really thinking about looking in that specific spot” (interview G).

> “ATC calls me, we're at 43,000 feet, which is not unusual height for some of the current commuters. And they gave us a turn for traffic. And I was like, Well, can you confirm, and they're like, ‘You need to turn now’. And I was like, okay, so I commanded a [override steering]. And then I had to let them know that we were gonna go outside of the airspace by performing that turn… It really highlighted for me that I have an aircraft where … it's really difficult to maneuver” (interview E).

Ultimately, this system characteristic is the ability of the AVO to get the desired response out of the vehicle. Again, while it may be related to UA performance, it should not be confused with the ability of the aircraft to perform a maneuver. Instead this attribute is tied to the AVO’s ability to command the vehicle to get the desired responses.

The Role of automation in Triton is a defining characteristic in the experience of an AVO. It enables the aircraft to operate over-the-horizon without the negative impacts of signal latency or reliability. Subsequently, it requires the tasks of the AVO to shift from vehicle controller to system monitor. With this shift, the system attributes and characteristics that determine the ease of operating the vehicle change as well. As one AVO put it:

> “Some of the easy stuff became hard, and in exchange some of the hard stuff became really really easy” (interview C).

While the workload required for flight path control is reduced, the AVO’s workload for monitoring the vehicle, deciding to intervene, and achieving desire performance has increased. To adequately evaluate the handling qualities of these types of UAS, the attributes of the system automation that affect these high workload tasks must be considered.

Role of the Interface

Loss of Environmental Cues

One of the defining characteristics of an UAS is that the pilot is not in the aircraft. While the operator's ability to directly observe the UA varies between UAS, for Triton the AVO can often be on the other side of the world, well beyond the line-of-sight. This distance removes the cues that manned aircraft pilots perceive while flying in the aircraft.

> "You are not in the aircraft and you can't feel what is happening as you command inputs to the UAS" (interview A).
>
> "Let's say you had some sort of engine issue or something, there's no feel or sound… you can't start saying, huh, it is running a little rough, right. So, not having those visual, you know, physiological and aural cues can definitely be different" (interview I).
>
> "Any UAS, really, I mean, the big thing that I'm sure most everybody else's told you that already is that you don't have any inherent like physical, I forget that the seat of the pants type feel that I forget what that big word is… proprioceptive. Yeah, you don't have that seat of the pants feeling of what the airplane is doing. So, the [UAS] has to… or all the engineering folks that go through the whole systems process to build this thing, they have to have a very intuitive method of presenting to you what the airplane is doing, its status, where it's going, what it's doing" (Interview F).

These absent data sources, available to manned aircraft pilots, can come from multiple senses: proprioception, smell, sound, or just through looking out the window. No matter where these cues come from, by removing the operator from the aircraft, the operator's awareness of the aircraft and its environment is reduced. Ultimately, this loss of awareness by the AVO results in challenges to operating the system.

Data Availability

One way in which the Triton system has attempted to address the loss of environmental cues available to the AVO is to increase the amount of data available from the UA. The Triton GCS allows the AVO to pull thorough telemetry data regarding the status of specific systems by requesting a detailed status. The UA replies to requests for this telemetry data with a snapshot of the system parameters that it monitors. This process provides a much more in-depth view of the system than would typically be available in a manned aircraft.

> "The amount of telemetry that we get back from the UAS is extremely beneficial. I can throw up any number of flight critical parameters that I am interested in, and it puts it right up there next to the UAS as you are watching it fly. That is really cool" (interview A).
>
> "A lot of stuff that I could just look at it, or just feel it, or sense it, or smell it. Now I have that small pipe line that is coming back… with tons and tons of data. Which is great cause who knows when I am going to need that piece [of data]" (interview C).
>
> "You can run detailed status on any number of systems and the detail status screen pulls up anywhere from 50 to 100 lines or more of information about any given system and its current status. And you can run those instantly, and the real benefit at least in UAS is you've got a desktop and, I mean it's not really a text editor but it, it's a scrolling window, right, so you can see all of these hundreds of lines of information" (interview A).

Having access to this data is an extremely important piece in maintaining awareness of the status of the system. Especially, in light of the AVOs role moving toward monitoring. As one AVO commented:

> "You can't monitor a thing if you can't see a parameter" (interview C).

This point was highlighted by another AVO who described the utility of the detailed status feature during an emergency.

> "In the case of the engine vibration… one of the main things you have to do, especially as an aviator, is you have to decide whether or not to shut down the single engine you have on the aircraft. And one of the key metrics is how badly is the engine vibrating. So, you can run multiple detailed statuses… You have a date and time stamp at the top of each of those one hundred lines. So, depending on how many you run, if you want to go back like 'oh I want to go back and look at two cycles ago' you… go down and look at the value" (interview A).

By providing access to all of the telemetry data the system is collecting, the AVO can interpret the status of the UA and decide on the appropriate course of action. In this way, Triton substitutes the information physically sensed by the pilot in the aircraft, with data collected from the UA. However, this approach can be problematic.

Data Overload

While access to the data contained in the detailed status messages from the UA can help the AVO increase their awareness of the state of the vehicle, the presentation of that data can cause issues. On one hand, the additional data can backfill for the lost sensed data available to a pilot on the aircraft. However, challenges arise in absorbing that telemetry data and turning it into useful decision-making information. This problem was summarized by one AVO:

> "How do I get [information] to the operator in a manner that is meaningful and timely? So that they recognize it and take appropriate action" (interview C).

It is not enough to have the data available, it must be observed, deciphered, and comprehended into information for the AVO to make an appropriate decision.

With the challenge arising from a loss of data available to the AVO, ironically, a common complaint among AVOs arose from the amount of data available.

> “If you look at like an Airbus, or like a 737, like they can display to you one hertz data, but like they don't… So, there's a reason that they don't want to display that much information to you because it's overwhelming. It's not something that you take into account. And it's not needed… UAS you have to be intentional about what you're going to show the operator. Now, it's great if you really need to diagnose something to have more information. But just because you can doesn't mean you should, just because it's too much information to process” (interview E).
>
> “I think Triton does overwhelm you with information when you're like taking detailed statuses, and you're trying to scroll through it and try to figure out where the pertinent pieces of information are. So, I think it overwhelms you with information that is not really useful to you” (interview F).
>
> “The problem is not how do I get information, it is how do I display it and put it into a digestible format. I‘ve got six quad redundant micro-processors and a thousand different sensors that are constantly feeding me all these parameters - my brain cannot physically digest all of those. Even if you could think of a cool way to display all of those and get all those values on one computer screen at one time, my brain couldn’t digest them. So, a lot of it is figuring out what is important, and how do I get what is important, and how do I have what is important in a way that is useful and meaningful to me” (interview C).

Ultimately, while additional data sources from the UA can help the AVO understand the state of the vehicle, and make good decisions, it is not as simple as flooding the AVO with all available data. One AVO summed this up as:

> "It's this interesting balance between not enough information and information overload when you go looking for it" (interview I).

This concept follows the principle of information need.

> "How much information does a pilot need? The short answer is just enough. Too little information leaves the pilot flying, and making decisions in the blind… Too much information can lead to a cluttered flight deck… Searching for the needed information among all of the extraneous information can lead to poor performance on critical, time-sensitive tasks" (Martinussen & Hunter 2017, p 192-193).

While Martinussen and Hunter were describing design principles for manned aircraft displays, the same principles apply to providing information to the AVO. While more data is needed to replace the lost environmental cues, too much data can overwhelm the AVO and be detrimental. The objective for the designers becomes providing the needed data at the right time, and determining what those are.

Engineering Speak

Another issue found in Triton is the way the data is presented to the AVO. Utilization of system telemetry data provides access to increased awareness of the status of the UA; however, the way in which the technical telemetry data is presented to the AVO can be problematic.

> "Have you heard of the detailed status pages? Okay, those are atrocious. And very hard to read as a non-engineer" (interview G).

> "The data we're pulling is essentially, more than anything I would say it's, it's formatted like engineering data… it's just a list of a whole bunch… of numbers" (interview I).
>
> "Like even the fact that when you do a detailed status, and you have things that say like, you know, something equals false. You know, just like, the ground safety pin is removed, or the ground safety pin is installed - instead of [showing] ground safety pin [in or out] … it's …some engineering terms equals false. Like there's a circuit in there, then you put [the safety pin] in, and [the message displayed to the AVO] is this closed relay circuit two equals false... You know, it's great for the guy that built the circuit, but not good for the AVO" (interview F).
>
> "[The difficulty] is coming at it from a pilot perspective when it was coded by engineers who don't fly airplanes" (interview B).
>
> "Like I need things like oil pressure and you know, stuff like that. I don't need like hexadecimal type code or engineering speak type things... The information you do need is very difficult to understand, like the verbiage that they use is not immediately understood by the AVO" (interview F).

The availability of data to the AVO does not ensure that the they will be able to take it in. The utility of the data is not just that the AVO has access, but that they can comprehend the data, and use it to make decisions. While the additional information may provide additional understanding of the state of the UA, if it is not presented in a method that intuitively make sense to the AVO, the effort it takes to translate the message adds to the AVO's mental workload and increases the likelihood of it being misinterpreted. Ultimately, to reduce the workload of the AVO, the data displayed should be formatted to communicate in a digestible manner, easily understood by the AVO.

Data Integration

In addition to the method in which the data is presented to the AVOs, the location of the data can be problematic. Compared to manned aircraft, the AVO work environment is not as constrained in where data may be displayed. Consisting mainly of software generated displays, most data is presented in windows that can be moved or adjusted to some degree. This allows for customization by the AVO.

> "It is pretty good because you can customize it, and I need a lot of customizability because each person has different preferences. And you can standardize it as much as you want… maybe someone likes their links in the upper left, and somebody else likes the moving map up there because they are left handed. So, it is a computer, let me move it around" (interview C).

> "I like the idea of just having my [primary flight display] and the engine display… underneath the [primary flight display]. So, I like to just kind of go up and down, up and down, instead of having it like further over to the side to the left... So, I just tried to go with what I thought would be the simple, would be the quickest cross check of things, if there's an emergency or something that would be the least time consuming… Hey, I don't want to have to work that hard. Yeah, so if I just put these windows this way, that's what I found, at least for me, was the most efficient way to cross check" (interview D).

However, while the display windows allow the AVO to customize and group data to meet their preferences, this approach does not enable the integration of data into a single display.

> "I have to parse through multiple menus, especially to get… different pieces of information from different displays or different menus. Or if I have to do separate pings

> or queries, so that I am just getting a snapshot in time rather than a running time history. Those are all things that make it harder to do that" (interview C).
>
> "They will give you one or two of those on a display. And then if you want a third parameter, well now I've got to bring up a separate window that is distinct… and I've got to parse 20 lines of text to find the one that I need, and it's not popped out or celebrated in any way. Which makes it tougher" (interview C).
>
> "We had a third screen on the left side, which was your comms screen, and it wasn't integrated in the first two… even though to me, they're like very critical to what's going on in the front" (interview E).

This is prominently seen when data presented to the AVO comes from different sources, such as with the Traffic Collision Avoidance System (TCAS).

> "None of that [TCAS] traffic is displayed on the [MTD]. So, now you are having to look at three different displays when you are tracking to see where the aircraft is going" (interview D).
>
> "TCAS has to be oriented to the nose of the aircraft. Well, you can fly Triton in any orientation that you want. So, I try to line everything up, with my [MTD], Primary Flight Display up… And I am not having to second guess, having TCAS one way and my PFD in some other orientation, and eliminating any doubt about where the traffic is" (interview D).
>
> "When they started throwing in an [Aircraft Conflict Avoidance Display] in there for TCAS and things, and doing this other interface…. Integration is a concerted effort, and getting rid of these stove pipe designs would go a long way to helping people understand the system" (interview D).

> “It makes training so difficult for folks. It is almost like they stove piped all of these interfaces, and then they bring them together and are like ‘hey, deal with it’” (interview D).

It is also seen with the display of weather information:

> “Definitely an issue we have is that there is no weather overlay on the system. So, avoiding thunderstorms or working around weather of the day is challenging. If you pull up an external weather feed, you are still doing the mind juxtaposition of am I actually 25 miles from the thunderstorm or not” (interview B).
>
> “Another big struggle that we have is whether we have a moving map or we call it [Mission Tactical Display]. But it provides no weather overlay. And the aircraft is very sensitive to weather or any type of weather phenomena... And that is obviously very difficult when now you are as an aircraft commander are going to have to use third party assets to try to operate the aircraft around the weather” (interview H).

While the ability to group information is useful to the AVOs, the fact that the information is not integrated into the existing situational awareness displays creates an additional mental workload for the AVO.

Traditional Displays

In addition to the supplementary data and flexibility in configuration provided to the AVO, many of the GCS displays mimic those of manned aircraft. While it is not certain if these displays were chosen based upon their functionality or because they complied with existing specifications, many AVOs found the commonality between manned aircraft displays and the Triton displays beneficial.

> "They try to replicate an aircraft cockpit, but tailor it …for this airplane specifically, but in general, it's, you know, it's not it's not hugely different… you have a window that tells you your attitude, tells you your speed, something like a PFD" (interview F).
>
> "Attitude indicator and an HSI look pretty normal, because, you know, tapes on either side for airspeed and altitude. So, all that looks like you know, copy paste from aircraft" (interview I).

Despite the reasoning why the interfaces were chosen, this group of AVOs with manned flight experience, appear to appreciate the utilization of a familiar display format.

> "I do like that the PFD looks just like a standard airplane because that makes it easier to read for someone who's already been flying. So that system design I think is good" (interview G).
>
> "I think that just having that screen to kind of keep familiarity with how a cockpit usually looks is visually more appealing to us" (interview K).

While the AVOs appear to appreciate the utilization of a familiar data display, the usage of those displays seems to be different for Triton.

On a manned aircraft, the PFD is the primary reference instrument. On Triton, with the AVO no longer responsible for flight path control, the utilization of the PFD appears to have been reduced.

> "You know it's not altitude, airspeed, and heading primary anymore, because I can just say altitude, airspeed, heading and boom – I know it's got it" (interview C).
>
> "[I use] the PFD and the altitude and airspeed as a secondary instrument to figure out what commands I needed to give it… where when I'm flying manned aircraft, I'm looking at the PFD primary" (interview D).

> "The fact that we have our route displayed on the MTD, but not the PFD, means that we end up relying on the North Up MTD moving map display quite a bit" (interview I).
>
> "I actually didn't really care about the PFD… where in a manned aircraft the PFD is like the thing I always want to look at… in a UAS I don't even look at that" (interview E).
>
> "The aircraft when it comes to monitoring your gauges… the scan on monitoring the aircraft is like nothing else that we've had to ever operate. Nothing like a manned aircraft… where there's strict placement and strict things that the FAA, and aviation as a whole, place information in front of you…. [Triton] is different, you have to adjust your scan. So, that's very, very different from being manned" (interview H).

Clearly, with the shifting role of the AVO, the data required by the AVO has changed. The things that were of primary importance to a pilot tasked with flight path control do not exactly match with what is desired by an AVO so many of the assumptions and specifications about what information is necessary or important for a pilot do not hold for AVOs. This was also seen with the turn and slip indicator.

> "The [Chief of Naval Air Forces instruction] 3710 said that you can't fly an aircraft unless it has a turn and slip indicator… So, we had to go to CNAF… and said we need to take this out for UASs because we don't have one" (interview D).

While a turn and slip indicator is a required piece of equipment considered essential for manned flight, Triton is able to safely operate without one. Ultimately, while traditional manned flight displays may be a familiar way to display information to AVOs, the utility of the displays should be evaluated by their relevance to the role of the AVO.

Link Information

Triton relies on Command and Control (C2) data links to connect the GCS and the UA. These links enable the UA to send down information regarding the state of the vehicle and allow the GCS to transmit commands from the AVO. These links are fundamental to the operation of the UAS, and are a key difference between manned and unmanned aviation. In addition to the effect the links have on the flying qualities of the vehicle, this defining characteristic of UAS operation also affects the data that needs to be displayed to the AVO.

> "I need to know what my C2 link says because that's almost like a flight control. Like without my C2 links. I can't control the radios, depending on how beyond line of sight is working. I can't give it commands. I can't really affect anything. I might not even have situational awareness on where the vehicle is. So, the C2 links… I don't look at those as radios. I look at those as flight controls… Knowing the health, like knowing where they're routed through… what is talking to the jet becomes one of the most like, it's flight controls. Like, to me, it's like one of the most safety of flight, critical things I need situational awareness of" (interview E).
>
> "I mean, the things we're always worried about… is the link to the aircraft, because that's how you do everything" (interview G).

While awareness of the C2 link is paramount in the operation of Triton, the task of managing these links is not one that has traditionally existed in manned aviation.

> "It's the managing the links, bringing all your networks up. Cause obviously your links are your life blood as a highly networked system. So, it is understanding what your links are that day and any issues you are having – actively monitoring that…. You talk to our

> manned counterparts and you talk about data-link rates and their eyes glaze over, but that is really important for an AVO" (interview B).
>
> "[Managing C2 links] was a concern that I didn't have on a manned aircraft, right. Even trying to stream video, it was kind of like, what you see is what ya got. If it clogs the pipe – It's like ok. We will just reset the system and get it going again. Well, I can't really do that on my UAV, especially if my C2 data is going down the same link" (interview C).

This new imperative creates a demand on the GCS interface that did not previously exist in manned aircraft.

> "There's no FAA standard on like, this is how you, you know, whatever, like there's no Part61… There wasn't a lot of way to get that information… and not having an understanding of software and not understanding how the comm links talk to each other and ping the hardware like that made it really difficult [to learn to operate Triton]" (interview E).

To meet this new challenge, Triton presents the AVO with multiple methods of monitoring the link status. The most prevalent are the stale data meter, the latest round-trip time, and the active link display on the PFD. These indications are positioned on the PFD as to not be hidden from the AVO's view, and are designed to alert the AVO in the event of a loss link event.

> "The round-trip time, which is the primary indication if the link is going stale, when that thing starts going stale it turns from green to yellow to red. That is part of your normal scan. If you see green it only takes a fraction of a second to, as an aviator, to verify that your link is perfectly fine. And if you don't catch it, the thing beeps at you." (interview A).

In addition to the indications on the PFD, the AVO also has link information available in the comms manager. In the comms manager, AVOs are able to display the Link Configuration tab. This graphical display indicates how the GCS is connected to the UA using color coded lines that graphically connect between the operating base and the UA. In addition to what link is active, the display also shows what links may be available if the current link is lost.

> "I like to have a link manager window open over to the side so that I can always tell how many links I have available, which links I have back" (interview C).
>
> "It's a very easy picture, just like green lines from the UA to whichever [narrow band assembly] you're using. So those are really straightforward" (interview G).

These two sources of link status are beneficial to the AVO and allow for a quick and easy assessment of if the GCS is connected to the UA. However, many AVOs expressed a need for more information about the C2 link than just if a link is established.

One aspect of the connection to the UA that AVOs wanted to easily assess was what link was established.

> "You look at like 'what link [am I connected through] - well I'm on a wideband link – [but] which one is it?', and you have to dig through menus deep to figure out like actually it's on CDL right now. You could make an argument like 'does that really matter?' And like some of these things are range limited, so CDL only has a couple hundred-mile range, and I am going to fly out of that range, and it is going to be lost-link while it fails over and switches down. And so, I just think you have to name them and have the nomenclature good. And be able to see it at a glance, to know what links I have hooked up and which ones are idling and available" (interview C).

> "We really need to know what the hell link we are on. I can't be going to the comms manager and delving down. It needs to be in your primary field of view. It used to say 'IP NBA 1' or IP whatever your slot was, I said [to the design engineers], what the [AVO] wants to know is if I am Wideband, INMARSAT, UHF. Can you tell me that? And they look at me and said, well we didn't know you needed that information" (interview D).

AVOs have developed a workaround to determine the current link by referencing data rate and latency.

> "By understanding that we're at 600, vice 1100, with this just flowing data that's constantly there, we are able to tell which link we are based off of what the latency is showing at the time... it's raw data that we're trying to take in, and we're trying to utilize to facilitate our life" (interview H).

That workaround enables the AVO to understand which system is currently connected as the C2 link, however it does not tell them which system is available as a fail over.

> "While we will essentially have a wideband SATCOM link on military satellites, and then an Inmarsat link on the commercial Inmarsat network, I can see that they're both connected, …but I cannot see what the bandwidth or latency is on the one that I'm not using, I can ask [support personnel] to check it and look on their computer and see. I can just see that yes, it's still connected in the background" (interview I).

While the AVO can easily see that a fail over link is available in the event of a loss of the primary link, but they are left unaware of what link is providing that back up.

Understanding which system is providing the C2 link is important to the AVO. For one, there are data limits to what is provided by each different system.

> “I've done flights …where we basically [only] have enough data for [telemetry]… so we have to pick like one sensor at a time to run because you don't have the bandwidth” (interview I).

A shift between data links can not only affect how much data can come down, but also the way in which it is received.

> “People that are operating on UHF line-of-sight link, it is a serial data link so there is no quality of service. So, there is no pecking order for commands, so it will block any kind of contact information from TCAS or ADS-B. For me personally, I always takeoff with an IP link…Because I like to see the picture. I like to see the traffic” (interview C).

Because of the different transmission methods, the availability of information may be affected. Additionally, because some of the systems operate through direct line-of-sight connection and others utilize satellite communications, some links may have different areas in which they will be blocked due to location or geometry.

> “A lot of times in the terminal area, or, you know, in critical phases of flight like takeoff and landing with low altitude, we might drop link, just because of line-of-sight… depending on where the satellite actually is. The other day we actually took a link hit, literally while the plane was on the takeoff roll, it's like, this is [the worst] time to not have link with the jet. And then once it took off… a link was back and it was fine. But that potential that we might lose a satellite link in a critical phase of flight, it's definitely an interesting situation” (interview I).

In addition to knowing the system providing the link, AVOs also have a strong desire to understand where and when that link may not be available. Due to the positioning of antennas on the UA, line-of-sight constraints, areas of interference, and limitations of satellite footprints, no one system is able to always provide a reliable link. However, the ability to anticipate these losses of connection is important to the AVO.

> "We have had UAVs that we know – at this distance it is going to drop link – Ok, Ok, don't get near there… if I have a quartering tail shot axis between the antenna and the aircraft, I am going to have really crappy link quality. So, I need to try to avoid this area, or when I am at a certain distance I need to make sure that I am constantly turning to maintain a nose on aspect. That sort of thing" (interview C).
>
> "We might have a pretty good idea of somewhere around this latitude longitude, we're going to start dropping link, because of the satellite footprint that we're on… We know in the terminal area, hey, some of the 20-degree angle bank turns that we'll make right after takeoff for departure. We always drop link in those, so we expect it. But that's just like tribal knowledge. It's not actually displayed anywhere. And there's no predictor" (interview I).
>
> "We know that there are certain parts of the airfield where that link takes a hit, and we know about it, and there are certain parts of the operating area, depending on what satellite you're communicating with, one of the bands is really sensitive in the test track. On those few flights I have been on, one of them the Aircraft Commander stepped out to go to the bathroom and we made a left hand turn and we started losing link … and the aircraft commander wasn't in the control station with me. That was a little scary for me." (interview A).

Experienced AVOs seem to recognize and anticipate when a link loss is caused by the positioning of the UA. However, the system does nothing to alert other AVOs of these known potential link drops. Ultimately, the ability of the AVO to command the UA is reliant on the C2 link. Therefore, it is not enough that AVO is aware that a link is established. They must also maintain awareness of the details of this link that will impact what data is available from the UA and any risks to the status of the C2 link.

> “Understanding the link, especially the IP links, is tough for people. I think they need to represent them a little bit better” (interview D).

The challenge of providing awareness of the status of the C2 link is novel for UAS designers. Unlike other displays that can leverage over 100 years of manned flight experience and lessons learned, these vital displays have no previous standard from which to inform their design. Despite that challenge, awareness of the C2 link and its limitations is an import trait for the safe operation of these vehicles.

Alerting

In addition to providing information about the vehicle, the GCS interface also has the task of alerting the AVO. Alerting systems are common and required in manned aircraft, however in UAS their role takes on greater importance.

> “Whenever a malfunction comes up, like there's a lot of things I think we do proprioceptively. When we have a malfunction on a manned aircraft, like if I see an engine thing, or I see like an RPM [change] and I don't hear it - I'm like Okay… [or] if I see a temperature going up, and so there's no smoke? Like, there's a couple other things that we use to try to diagnose a problem that you don't have when you're not in the plane” (interview E).

The alerting system of manned aircraft are often a supplemented by the sensations the pilot is naturally taking in, on an UAS the alerting system is the sole means by which the AVO may be made aware of an issue.

In addition to the lack of environmental cues supplementing the alerting data, the low task loading of AVO in monitoring the system can cause the AVO to become less engaged in the state of the UA.

> "You have an instrument scan, but it's not as time consuming as a regular plane. I mean, I'm trying to look at it every so often, but it's not like a constant… Because I know that it's doing fine for the most part" (interview G).
>
> "People can really forget that they are flying an airplane. It can feel in a lot of ways like 'I am just sitting here at a computer', messing around. And they can lose sight of that, and so they will send commands and all of a sudden the airplane will start descending – and you are like 'hey dude, aren't you supposed to be at 30,000 ft, why is it descending through 25 now?', and they'll be like 'oh no, I forgot to put that lock on'" (interview C).
>
> "When you have that much automation, it really is hard to stay in the loop with it, because you're just not engaged. So, the, the stimuli that you really need to get in a loop has to be like pretty dramatic" (interview E).

This possible detachment places an increased demand on the alerting system of an UAS to capture the AVO's attention and raise their awareness so that they can follow the appropriate course of action.

Like with the data overload previously discussed, this does not necessarily mean that the AVO should be bombarded with too much alerting. Simply presenting the AVO with data does not necessarily increase their awareness of the situation.

> "A challenge when you do have emergencies is more… how the emergencies are presented. So, I don't know, if you've seen them, but we have these little things called Chiclets that are all the faults that pop up. So, you may have 20 or so that pop up for one

> electrical fault. But it's going to say these 10 things - voltages out of tolerance - when really, it's because you've lost one specific thing" (interview G).
>
> "Other scenarios that we've seen, like a generator shutting itself off or being tripped offline, for some reason, there might be 25-30 faults. The plane does not tell you what the root cause actually is, of your 25-30 different electrical faults. Some of them might be you know, buses and batteries and voltages out of tolerance, some of them might be associated failures of things that now just got tripped off because they no longer had electrical power. So, you might be looking at indications from other systems now that have also generated faults" (interview I).
>
> "You have a major subsystem failure and it trips 30 cautions and warnings, like what are you supposed to do with that? .... That is the biggest bane, the human factors engineering and the interfaces make it so bloody difficult, especially when things go wrong" (interview D).
>
> "If you get compounding malfunction or cascading faults, that quickly becomes a can of worms" (interview H).

Obviously, a flood of alerts does not necessarily help the AVO understand the root cause of the malfunction, and correspondingly what corrective action should be taken. This difficulty is compounded with indications that do not help identify the actual problem.

> "In an emergency situation, you know, in manned aircraft... it'll say, like, low oil pressure engine number one or something. But in [Triton], it's like ENG 431 fault. And it's like, what the heck does that mean?" (interview F).
>
> "I gotta look up in a Rosetta Stone called the NATOPS, to figure out what this Engine 21 is…. It's maddening. It has caused a mishap. It was B-6 that they lost out at Point

> Mugu. Exactly because of human factors, because they didn't understand what was going on, and the airplane hang stung them on a lot of things" (interview D).

One AVO described compensating for the alerting system through the use of memorization:

> "If you can memorize the critical ones, you hone in for those" (interview D).

However, another AVO pointed out the limits to memorization:

> "I actually have to go either have them remembered, which is only practical to a point, because I'll forget some of them. And then [possibly] remember inaccurate information. So, then I'm going back to the [NATOPS] to figure out okay, what did normal look like? How far away am I from normal? What were my limits?" (Interview I).

Ultimately, pilot compensation can only do so much to cover for the system design.

While the alerting system for Triton has an additional burden in alerting and informing the AVO, it must also balance against overwhelming AVOs as they are brought back into the loop. As one AVO described:

> "If everything is going smoothly, we've spent a lot of time sitting, monitoring, so workload is very, very low, if things are normal. If we do start getting faults though, workload can become very, very high very, very quickly" (interview I).

The design of the alerting system for UAS should address the additional challenges faced by UAS while focusing on the needs of the AVO.

The needs of an AVO may be different during an emergency than what is needed by a manned aircraft pilot. In a system like Triton, where reversion to manual control is not possible, the tasks of the AVO are different. Instead of controlling the vehicle's flight path, or determining if manual control should be assumed, the Triton AVO's main goal is to decide what course of action should be taken. One AVO summarized the purpose of the alerting system:

> “It is a decision-making tool for the pilot – I can continue the mission, I can’t continue the mission, I got to land, [because] the aircraft’s safety is in jeopardy, [or] I need to land as soon as possible” (interview D).

To that end, the desired characteristics of the alerting system should be those that serve that purpose.

Feedback

Another highlighted difference for the Triton display system is its role in providing feedback to the AVO. Unlike in a manned aircraft, where control inputs can be immediately perceived, the systems response to AVO commands are not inherently observable by the AVO.

> “It is like instrument flying, cause you are always looking at the displays. I have no proprioceptive feedback. You are kind of blind as far as any kind of visual” (interview D).

> “You're not cued in enough when things change with the state of the airplane…. Like when things are changing when the aircraft's changing altitudes and leveling off or doing certain things, you know, it's if you're not specifically like looking at the altitude at the time, then you're not going to necessarily notice” (interview F).

This loss of cueing occurs not just with the state of the vehicle in response to commands, but also if the UA received or accepted them.

> “The biggest thing, is putting in your input and monitor your feedback. You have to look at things like event history. You’ve got to make sure that your command is accepted… There have been times when the aircraft has rejected commands, and it is not, it’s not like a big alert that goes off that it rejects it. It just gives you a little line in text that it has rejected it” (interview D).

This acknowledgement from the UA is essential for the AVO to understand the state of the vehicle and to be able to anticipate the actions of the automation.

Part of the necessity of the feedback is the lack of control by the AVO. While still in command of the vehicle, the AVOs are reliant on the automation of the UA to execute those commands. In this way, the availability of feedback allows the AVO to anticipate vehicle actions and then be reassured when those actions are perceived.

> “All of those seat-of-the-pants things that you don’t get that make it a lot easier in a manned aircraft. You are coming in on Final and you look outside and feel like, yeah, I am pretty much on a three-degree glide slope, I feel good. On the UAS you are look – oh did the RADALT come on, is it now changing to this mode. So, there are more things to monitor as it is coming in that give us confidence that the system is doing what it is supposed to be doing” (interview B).

> “I think most pilots would probably agree when I say, it gives us a little comfort when we give their aircraft a command to see that the nose is dropping, along with that decreasing airspeed, it just gives us maybe a warm, fuzzy, right, it's thinking positive feedback over just seeing a number that's decreasing, like, knowing that the aircraft is actually like corresponding with or you're telling it to do it visually, seeing that, instead of just a number, I think is, is helpful” (interview K).

One specific instance AVO’s mentioned, in which they actively seek out this feedback, comes if the aircraft loses thrust and enters a Contingency 3 condition. In this scenario, with the loss of thrust, the aircraft may attempt to glide to a landing along the Contingency 3 routing.

> “Contingency three, after, shortly after takeoff, so not much different than the Sully, right? Because we have the aircraft, it will transition to a Contingency 3 emergency

> landing. But again, depending on your altitude and where you're at and your flight characteristics, just because you were attached to Contingency 3 logic doesn't mean you're gonna make the field. Yeah. And so, it's the AVOs responsibility to either make a play for the field or put the put the aircraft in the drink and avoiding populated airspace" (interview H).

In this situation, it is the AVO's responsibility as the UAC to determine the best course of action.

> "The system will just do its thing if you just get out of the way and let it do it. So, I have high confidence that it will fly those points, it will hit exactly waypoint 45, it is going to hit GHAWK, it's going to try to come in and land. If I hit my C3 altitude where it is supposed to be, I know I am going to make it" (interview B).

At that point, the AVO's task is to resolve if the UA has enough altitude to glide back to the runway. If it can make it back to the runway, the vehicle should be allowed to do so, if not, it needs to be directed away from populate areas.

> "But there is no predictor. Even if you tell me with 98% probability it is going to make the runway, like with a graphic on the map to show me. It's not there. It's all mental gymnastics that the pilot has to do in an emergency" (interview D).

This is where the indirect feedback from the system can be crucial to the AVO's decision making. AVOs have found that the vehicle is likely to deploy spoilers to maintain glide path if it has extra altitude in a Contingency 3 condition. Recognizing this condition, the AVOs are able to observe spoiler deployment as feedback from the system.

> "You see a little spoiler come up, and you are like OK I am good. The system is going to do its thing – I should get out of the way" (interview B).

> “If you have the spoilers out, that's probably a good indication to say the plane thinks you have extra energy. If they’re stowed, all it's telling us is it's doing all it can” (interview I).
>
> “We look for spoilers. If the spoilers come up a little bit and the engine is out, I think the airplane thinks its gonna make it. The challenge is that there is nothing that is going to show me, predictive, on the map” (interview D).

Even though the spoiler indication was likely not intended to inform decision making during a Contingency 3 condition, by the system providing that feedback it allows the AVOs to complete their task, making good decisions. As one AVO put it:

> “With an experienced AVO, you can take indirect data quickly and make a decision” (interview H).

In due course, by the AVO predicting vehicle behavior, and the UA providing feedback that confirmed the AVO’s expectation, the AVO is imparted with trust that the system will perform as expected.

While the vehicle performing expected actions is a source of trust in the UAS, incomplete feedback can be a source of uncertainty and frustration.

> “Sometimes it just says declined, or some negative response and you are like, huh, what did I do wrong? I don’t know… So, you start over, and you do it again. Then maybe the third time it shows success, so it’s like, what the hell. It’s frustrating because you are taking all of this time… monkeying with the system. But you don’t have confidence that it is going to take” (interview B).

In this instance the system provided notification of the rejection, but did not inform the AVO why the command was rejected. This incomplete feedback creates uncertainty, and while the

AVO may understand the current state of the vehicle, they are left with a loss of confidence in the result of future commands.

Clearly, the operation of Triton is affected by the interaction of the AVO with the UAS. Like with manned aircraft, the AVO needs to understand the state of the vehicle and the environment to make command decisions about the best course of action. Additionally, due to the limitations of their attention, they need to be made aware when conditions change that require their perception. However, the AVO not being on the aircraft and the level of automation creates distinct differences from manned aircraft. Similar to the role of the AVO and the role of the automation, the role of the interface shows that the operation of Triton functions in a comparable manner to traditional manned aircraft, but with distinct differences that prevent the direct application of manned aircraft standards. The question becomes in what ways are the handling qualities of Triton similar to traditional aircraft and in what ways are they different.

CHAPTER V

DISCUSSION

The interview responses from the Triton AVOs provided themes regarding their experience in operating Triton. These themes are built on the commonalities between those responses, and they form the Constructionist reality of that experience. This shared reality is the basis from which future predictions about the phenomenon of autonomous UAS operation is established. However, while the themes that connect these shared experiences are the bedrock of these predictions, the interconnection between the themes reveal many of the traits from which the theory about UAS handling qualities can be inductively reasoned.

The discussion of these interconnections, and theories that they produce, do not fall along clean lines of demarcation. Unlike other quantitative methods of research, the results of a grounded-theory exploration are descriptions of the phenomenon examined and not simple yes-no answers. The goal of this effort is to generate theory, and not to find conclusive answers. Complex and multifaceted phenomenon, such as the operation of an UAS, defy simple partitioning. Attempts to do so weaken the description in an attempt at order. However, faced with the need to communicate these theories in a meaningful manner, an order of presentation has been selected.

The discussion section structure begins with an affirmation of the handling qualities framework used to conduct the research. It proceeds to discuss the results of the segmented aspects of handling qualities (flying qualities, interface, human factors). The developed theory is then extrapolated to highlight conclusions about system characteristics that fundamentally differ from current manned aircraft traits. Finally, the impact of the results to a taxonomy of UAS and the validity of the use of grounded theory in the exploration of engineering are covered.

Utility of Handling Qualities

The first finding of this research is that the framework of handling qualities applies to UAS. This is not a result that is inherently evident. The traditional methods of evaluating the handling qualities of aircraft often rely on measures of interaction regarding the modes of the aircraft and the physical manipulation of the flight controls. This leads to an easy muddling of the concepts of handling qualities, flying qualities, and the characteristics that are used to quantify them. Indeed, many of the AVOs interviewed seemed dismissive of the applicability of handling qualities to their experience with Triton. As discussed in the *different 'monkey skills'* section of the results, AVOs are well aware of the inapplicability of traditional handling qualities metrics to Triton. However, as the higher automation levels seen in autonomous UAS reduce the relevance of traditional handling qualities characteristics, it is easy to misconstrue that it removes the applicability of handling qualities. Nevertheless, by focusing strictly on the definitions of handling qualities, set forth by Cooper and Harper, this effort breaks from the constraints of traditional manned aircraft metrics when evaluating UAS.

This research shows that the inclusion of higher levels of automation does not reduce the importance of handling qualities, but changes the attributes of the system that impact those qualities. Just because the AVO does not manipulate traditional flight controls, it does not mean that the AVO does not have tasks to perform that result in a workload. As noted by Cooper and Harper, workload is composed of both the mental and physical effort required by the AVO to complete tasks (1969, p 6). Where the physical tasks required of the AVO may be less than for a piloted aircraft, the mental workload is clearly increased. The resultant total workload required of the AVO can impact the performance of the system, and influence the AVO's evaluation of the effort required to complete tasks.

This conclusion is supported by repeated comments from AVOs regarding characteristics of the system that made their tasks more or less difficult. Comments that indicated that certain tasks were hard or difficult, highlighted the attributes of the system that may be improved to make the tasks of the AVO more manageable. Moreover, several comments distinctly called out workarounds required by the AVO to achieve adequate performance by the system. These attributes often focused not on the physical interactions with the system, but the mental workload required to understand and anticipate the actions of the automation. This need to operate the system in a manner in which it was not intended places additional burdens on the AVO, and is a clear indication of how the system could be addressed to make the job of the AVO easier. While this research falls short of specifying a comprehensive list of system attributes that quantify these qualities, the conclusion that these qualities do exist is an important first step in their definition and eventual use for design and certification.

Command

In spite of the AVO not being in the air vehicle, they still assume responsibility for its operation. The common refrain from Triton AVOs was that, regardless of the autonomous attributes of the system, they were still in command as they would be for a piloted aircraft. While the description of the role of the AVO often included the term monitor, this should not be taken to assume that they are a passive participant. By being removed from control of the vehicle, the mental aspects of the AVO tasks increase. Not only must they have the same understanding of the state of the vehicle and objective of the mission, they must now also understand how the UA intends to act. Additionally, in having fewer available inputs into the system, the importance of those inputs and the impact of the decision to intervene greatly increase.

With Triton much of the mission and many of the mission task elements are the same as for piloted aircraft. The need to aviate, navigate, and communicate did not change with the removal of the operator from the aircraft. Ultimately, the necessity for an AVO to be responsible for these aspects of operation are the same as with manned aircraft, and the skills of communication, crew coordination, familiarity with ATC procedures, and risk assessment are all still applicable. This is supported by the AVO comments in the *aviate, navigate, communicate* section of the results that described the operation of Triton as being similar to piloting a manned aircraft. These comments were not referring to the tasks required of the AVO, but to the objectives that were required of the AVO-UAS system. Despite the AVO losing the ability to directly control the aircraft, they still retain the responsibility for command and require the skills and training to execute that duty responsibly. In the end, there is more to flying aircraft than simply manipulating the controls. The skills that are developed in manned aircraft to assume command still need to be instilled in future UAS operators.

AVO Tasks

Another conclusion from this research is that while there are similarities between the role of a pilot and a Triton AVO, their tasks are different. Unlike the applicability of handling qualities, this result is readily apparent. The use of qualified pilots in the position of AVO is an acknowledgement that many of the skills possessed by manned-aircraft pilots are applicable to the operation of UAS. However, the higher levels of automation that enable the use of a mouse and keyboard instead of a stick and rudder, fundamentally differentiate the interaction between a pilot and their aircraft, and an AVO with Triton. Despite the similarities in responsibility and mission task elements, the experience of Triton AVOs shows that their tasks are fundamentally different from those of a pilot.

The conclusion of this difference may not be true for all UAS. Specifically, the inability of the AVO on Triton to take direct control of the UAS fundamentally changes the tasks that the AVO may be asked to perform. Automation is prevalent through manned and unmanned aviation. The need to understand and anticipate the action of automatic controls is important whenever it is present. However, for the Triton AVO, the inability to assume control of the vehicle from the automation changes this relationship. In a manned aircraft, or even a UAS with the appropriate inceptors, the operator can revert to a lower level of automation to quickly change the course or action of the vehicle, on Triton that is not an option. Equipped with only a mouse and keyboard, the only actions of intervention available to the Triton AVO is to command a change in the objective of the automation. The inability to assume control removes the burden of ensuring that the AVO is capable and ready to control the vehicle, but also places much greater importance on their understanding of the actions of the automation in response to those commands. As one Triton AVO put it:

> “This is 100% a mental game. There's no muscle memory, there's no coordination, you know, gauging exactly where you need to flare like that sort of thing for aircraft handling is no longer a factor” (interview I).

These new tasks required of the AVO, for an autonomous UAS like Triton, fundamentally change the characteristics that define the handling qualities of the system.

Flying Qualities

One major factor in the handling qualities of any aircraft is the vehicle’s response to inputs. Klyde defined these vehicle characteristics as the flying qualities of the aircraft (2020). In aircraft capable of manual control, these characteristics are often quantified through metrics such as the aircraft’s modes and the force gradient on the controls. However, in vehicles, like Triton, where the AVO is not capable of controlling the vehicle, these traditional metrics do not influence the AVO’s completion of tasks, and therefore do not influence the handling qualities. Nevertheless, while the traditional aircraft flying qualities are not applicable to the handling quality of the aircraft, that does not mean that the vehicle’s response to inputs is no longer important.

The results of this research show that the flying qualities of Triton are still relevant to the handling qualities of the system. However, instead of being influenced by the qualities that define the control of the vehicle, they are defined by the system’s response to the commands sent by the AVO. This difference results in a change in what vehicle characteristics are relevant to the AVO’s perception of workload. This research doesn’t identify exact metrics that can quantify these qualities. However, through the responses of the AVOs some system attributes can be identified that affect the AVO’s completion of their required tasks.

The three system attributes identified are intuitiveness, predictability, and flexibility. Intuitiveness relates to the matching of the AVO’s expectation to the aircraft’s actual response. This was clearly identified in several cases of AVO intervention, such as commanding a climb from endurance mode or a goto command to a waypoint. As the AVOs command the UAS, they have an expectation of how the UAS should respond. This response appears to be predicated on how the pilot-trained AVO would control the vehicle if they had the ability to do so. When the vehicle does not respond in the manner desired or expected by the AVO, this creates the potential for mishap or incident with the UA, and creates a new burden on the AVO. When there is a discrepancy between AVO expectation and UA execution, the AVO must determine what the UA is doing and if further commands are required to correct its response. Many AVOs detailed these non-intuitive responses and described the workarounds they implement to ensure that the vehicle responds in the way that they require. These workarounds appear to be analogous to the control shaping techniques used to affect traditional flying qualities.

Predictability relates to the matching of the AVO's intended command to what command is actually executed by the UA. Unlike intuitiveness, where the AVO is surprised by the response to the command, predictability relates to a miscommunication between the AVO and the UA. AVOs mentioned these occurrences relating to override commands, where the objective sent to the UA may not be clear to the AVO. In an occurrence that appears similar to modal confusion, AVOs described this occurrence as unintended consequence that can occur when issuing override commands. While the AVO may have wanted the UA to navigate to a waypoint by sending a goto command, the vehicle may also interpret the goto as a corresponding command to climb or descend to the altitude prescribed in the waypoint's definition. This ability for confusion between the AVO and UA can result in deviations in the intended flight path of the vehicle, creating a hazard to navigation and additional mental workload for the AVO.

Flexibility relates to the AVO's ability to command the UA to respond in the needed fashion. The AVO is unable to directly control the path of the vehicle, but still must be able to adjust the objective of the UA to position the vehicle where it is needed for the mission or to avoid areas of hazard. This requirement is limited by the preestablished available commands. Where a pilot can set an unlimited variety of angles of bank for their aircraft to precisely manage their flight path, the Triton AVO is limited to commanding a heading and accepting the resulting flight path from the 15-degree angle of bank turn the UA provides. This issue can be compounded through delays in command transmission due to latency, and uncertain effects from winds. This reliance on the limited number of commands that can be sent to the UA forces the AVO to be diligent in anticipating the response and monitoring the progress of the execution, again adding to the mental workload.

Seemingly, these flying quality characteristics appears to relate to a question of team work between the AVO and the UAS, either expressing the intent of the AVO, communication of that intention to the UA, or anticipating the intended response from the UA. This matches neatly with comments from the Triton AVOs that describe their tasks in terms of monitoring the system. This monitoring is not in expectation that the system will malfunction, but monitoring of the system's actions against the intended and anticipated response. Clearly, these characteristics are different from manned aircraft, but they do contribute to the AVO's workload and evaluation of the system. Ultimately, the flying qualities relevant to the handling qualities of Triton are related to factors affecting communication and coordination of intention between the AVO and the UAS.

Interface

With the non-typical flying qualities of Triton, the pertinent qualities for the system interface are different as well. On its face, this conclusion appears to be obvious. With the use of a mouse-and-keyboard to interact with the system, Triton is distinctly different from piloted aircraft. Nevertheless, one of the defining characteristics of Triton is its use of high levels of automation and autonomy. The automation that controls the vehicle from the UA, and the autonomous functions that enable the safe operation in the event of a lost link, enable the utilization of a mouse and keyboard to interact with the GCS. This is in line with the research of Pankok & Bass (2017), who showed that interface type was dependent on the tasks performed. Additionally, this appears to dispute the work of Waraich (2013), who saw the control interface as the driving system characteristic. Ultimately, it is apparent that the AVOs' interactions with automation of the UAS drive their opinion of the system. While this does not remove the inceptors from consideration in handling qualities, it does confirm that inceptor type is a choice in support of the qualities of the system, instead of the defining characteristic. Resultantly, while the mouse-and-keyboard inceptors are the apparent distinction of Triton, the difference in interaction is tied to the implementation of high automation levels and lack of manual control.

One of the goals for the interface of an aircraft is to facilitate the operator's interaction with the flying qualities. For a pilot controlling an aircraft by manipulating flight controls, this may be achieved through the display by providing a reference to a state of the vehicle: attitude, airspeed, altitude, flight path, etc. By displaying the states to the pilot, the pilot is able to provide feedback to the system through the flight controls to achieve a desired end state. The need for this information to be displayed to the pilot is codified in 14 CFR § 23.1321, and is standardized in the basic T arrangement (2022). However, in the case of Triton, the AVO is unable to assume closed-loop control the aircraft. Instead open-loop commands are sent to the vehicle, and all closed-loop control is performed by the UA. With these different modes of interaction, there are different requirements for information from the vehicle.

Where many of the Triton AVOs expressed a need for or appreciation for the PFD, which provides the Basic T display, the way in which they utilize the system appears to be different. Where a pilot may use the PFD to inform control inputs, the Triton AVO uses the system to monitor the performance of the automation. Did the system hike up the nose gear as it should prior to Takeoff? Is the vehicle starting to turn in the direction expected? Is it pitching up in response to a need to climb? The AVO is not specifically trying to gauge what action or input is required, but to ensure that the UA is matching their expectation. These displays are providing feedback to the AVO, in confirmation of the action of the automation or indication that intervention is required. Ultimately, the AVO is adapting the displays provided, designed to inform for feedback control, to match the need to compare AVO intention with UA execution.

This is further demonstrated by the AVO's utilization of indicated spoiler deployment during an engine loss emergency. During an engine failure, the autonomous response of the UA navigates the aircraft towards the designated approach and landing waypoints. While the autonomous action provides command and control input to address the emergency, the AVO's task is to determine if the aircraft has enough energy to reach the final waypoint or if it needs to be diverted away to avoid risk to the population on the ground. Traditional aircraft displays, which would be vital to a pilot controlling the aircraft, do not provide the AVO with the needed information to complete their task. However, the AVOs have discovered that the system does provide them with the data to inform their decision. Specifically, when the vehicle assesses its progress in achieving the engine failure flight path, it will deploy spoilers if it calculates that it has enough energy to reach the landing waypoint. This calculation is far from conclusive, but the AVOs have adapted to observe the system's deployment of the spoilers as an indication of its assessed energy. They then use that information to perform their task; either letting the UA continue, or intervening.

Ultimately, what the AVOs need in the operation of Triton, is not the required manned aircraft displays. The AVOs need displays that directly relate to the tasks they are assigned to perform. Specifically, they need displays that aid in monitoring the performance of the system.

While the AVOs have adapted to the current system design, it is clear that those tasks could be made easier if the information that is needed or desired by the AVO was presented directly. Resultantly, the interface for UAS should not be constrained by traditional piloted aircraft interface standards, but should be approached with the goal of assisting the communication and coordination of intention between the AVO and the UAS.

It should be noted that this result does not preclude the use of traditional aircraft displays. The population of AVOs interviewed for this research all had a significant background in piloting manned aircraft prior to becoming an AVO. With thousands of hours of experience utilizing traditional displays, it can be assumed that they became familiar and comfortable with the format and function of the information that the traditional displays provide. This familiarity may bias the experience of the AVOs towards an expectation of the traditional displays, or produce a discomfort if they were absent. Ultimately, the experience and background of the AVOs may influence how they interact with the information from traditional displays. This result may impact the design for systems that are intended for AVOs based upon whether they are expected to have previous pilot experience.

Human Factors

The experience of flying a Triton UAS is distinctly different for an AVO than the experience of a pilot flying a manned aircraft. However, while the tasks required of the AVO, and the interaction with the vehicle are distinctly different, there is a commonality in the application of human factors to the operator. This research indicates that many of the human factors issues that led to the standards seen in manned aircraft are still applicable to Triton. Throughout the AVOs' responses there are confirmations of the influence of situational awareness, engagement, task loading, and the influence of the application or disregarding of design principles to address these concerns. The proximity compatibility principle is clearly demonstrated by the AVOs grouping related data, and their frustration with data that is not integrated. The principle of predictive aiding is seen in the AVOs difficulty with accounting for winds in using heading override commands, and the principle of discriminability is seen in the dissatisfaction with warning and cautions codes. Evidently, while the job of the AVO is different, it is still being performed by a human.

This result appears to complement the work of Hobbs, A., & Lyall, B. (2016), who approached the issue of UAS human factors from the perspective of an assumed similarity to manned aircraft. Their approach accounted for the perceived differences in the systems, but assumed that the unaffected design traits were the same. However, the results of this research are slightly different. Where Hobbs & Lyall observed the similarity between manned aircraft and UAS, this research shows the similarity between the operators. This is highlighted again by the utility of the PFD. Where the AVO perceives the PFD in the same way as a pilot, the utility and the need for that information by the AVO is different, so the requirement of and specification for that system may be different.

Ultimately, UAS designers should apply primary principles in determining how to display information to AVOs. Simply relying on the traditions of manned aircraft displays may not adequately serve the AVO’s need for information when operating a highly automated UAS. Thankfully, the designers do not have to start with a blank sheet of paper. The understood principles of design and human traits of the operators both appear to be applicable to the operation of UAS.

Automation as Copilot

One of the most significant implications of this research is its framing of the interaction between the AVO and the UAS. A traditional approach to the operation of an aircraft posits the pilot operating the aircraft as a craftsman with a tool. An aircraft may be a complicated tool, but the operation is reduced to a functional interaction. The pilot provides the input, and the vehicle responds. However, this construct does not fully capture the relationship between Triton AVOs and their UAS. In its place, Triton AVOs tended to describe their interactions with the UAS in terms of a relationship or as though they were interacting with a crewmember. One AVO commented:

> "The airplane can't fly unless we give it the inputs to takeoff. Back and forth might be a little rigid. I would say it is… more of like a harmonious interaction between pilot and system, but our role is more monitoring than manipulating controls… If we go flying, it is still the result of me doing something. If it is just me sitting in front of a computer clicking a mouse, then ok. That doesn't sound cool to most pilots but that's what our job is" (interview A).

Another AVO framed it in terms of an instructor pilot with a student:

> "It's the same thing with a student… you are monitoring the student, are you doing what I expect you to be doing? It's the same with the system, is it doing what I expect it to be doing" (interview B).

This modeling of a relationship between the AVO and UAS could suggest the focus of design principles that should be applied. Instead of strictly applying principles of design for displays or inceptors, the principles of good communication and crew resource management may be pertinent.

A design focus that approached the interaction between the AVO and the UAS as crewmembers may better inform the metrics by which the system's qualities are evaluated. It would shift from those characteristics that quantize the aircraft's response to commands to those that enable good communication and coordination. This view reflects research by Dekker (2004), who suggested "developing the anthropomorphic aspects attributed to automation further, making it into a team player." Where the question for the designer should be "how do [the pilot and automation] get along together" (p194). Ultimately, when approaching design for these autonomous systems, the interaction between the AVO and UAS should be framed as a team, instead of operator and system.

Trust

Framing the interaction between the AVO and UAS in terms of crewmembers also helps understand the emerging issue of trust in operating UAS. The more trust the AVO has in the system's automation, the less effort they need to spend monitoring its performance. In a similar manor to an instructor pilot's trust in their student, the more confidence the instructor feels in the student's ability, the less time and effort the instructor needs to expend monitoring the actions of the student. Ultimately, the more trust the AVO has in the system, the lower the workload required to monitor the system, and the more capacity to complete other tasks. Designers could employ this understanding to build systems that encouraged this trust in the system. While the tools required to quantize trust are not readily available, the use of the UAS flying qualities could be a starting point.

This research characterized the flying qualities of Triton as involving the communication and coordination of intention between the AVO and the UAS. The AVOs expressed confidence in the system's technical abilities to perform required maneuvers. The uncertainty arose in the ability to communicate the required objective, the interpretation of that objective, and the execution of that objective. The workload for the AVO comes in the monitoring of that process. Resultantly, the attributes of the system that provide feedback to the AVO that the system is following the intent of the AVO and allows the AVO to understand the intent of the automation should reduce the burden required to monitor the system. Ultimately, the more trust the AVO has in the system, the easier it will be to operate.

UAS Taxonomy

Despites the FAA's assumption of responsibility for safe operation of UAS in the NAS, they have yet to provide specific guidance for UAS designs as to the specifications and standards that would be considered acceptable. To compound this issue, the FAA has also failed to provide any distinction between UAS. While the size, speed, and purpose of UAS vary greatly, currently the FAA treats all systems the same when it comes to certification. The DOD does offer a categorization for UAS that considers the different capabilities and operating conditions. However, even that classification system fails to account for the role that handling qualities should play in classification taxonomy.

As demonstrated by this research, the handling qualities for Triton vary greatly from manned aircraft and remotely piloted UAS, where the pilot controls the vehicle. This variance dictates that the characteristics that are required to ensure adequate performance for Triton are different from the ones that have been established for piloted aircraft. These different desired characteristics dictate that the specifications established to ensure adequate performance must be tailored to address the specific required attributes of each vehicle type.

The FAA recognizes these differences through the use of a taxonomy of aircraft type and category. While fixed-wing and rotary-wing aircraft are both manned, piloted aircraft, they possess distinctly different handling qualities, brought upon by differing control methods and interfaces. Resultantly, they are certified through separate sets of regulations and standards. In this way, the FAA ensures that each aircraft is safe according to the specific concerns for each aircraft type. Ultimately, the same is required for UAS, and as a result a proper taxonomy must be adopted that accounts for the variety of automation levels and interfaces of UAS.

Grounded Theory

One last result of this research is the validation of the use of grounded theory to generate pertinent results. Although this research is far from definitive on the handling qualities of UAS, it does demonstrate the utility of this qualitative methodology in the development of theory. There have been multiple previous research efforts attempting to address the human factors and handling qualities of UAS. They have taken multiple, different approaches as to how to make UAS safer and more effective. However, the commonality between them was their attempt to apply existing theory to a new phenomenon.

This direct examination of the phenomenon of operating UAS through those with experience, provides inherently valid theory that can now guide future research efforts. This method bypasses the trap of assuming what operating Triton is similar to, and directly addresses the issue by discovering what it is. In this way, the convoluted interpolations of existing theory can be avoided, and the true objective can be directly addressed. Ultimately, the goal of the research is to make UAS safer and easier to fly, and there is no better way to start that process than to ask what about it is difficult.

While the issue of handling qualities appears to be distinctly suited for the grounded theory methodology, it could easily be adapted to most types of engineering. While the field of engineering is typically regarded as quantitative in nature with a distinctly positivist view of the world, most engineering is, at its core, a user-focused enterprise. There are no models or calculations that can better capture a user's experience than the first-hand involvement in that experience. Ultimately, grounded theory methodology has demonstrated its utility in this research, and appears well suited to the exploration of other engineering applications.

CHAPTER VI

CONCLUSION

The results of this research mark the beginning of an effort to define desired handling qualities for UAS. The narrow focus of the population explored inherently limits the results to a single UAS type and potentially single platform. It is expected, that as with manned aircraft, the qualities that make an autonomous UAS, like Triton, easy or difficult to operate, will be different than those for an RPA or radio controlled vehicle, with different levels of automation and types of interface. As with manned aircraft, it is also likely that the mission the system is designed to perform will have an impact on the desired handling qualities. Inevitably, the effort performed here will need to be reproduced with other UAS types, and the specifications that inform and control the certification of these systems will need to reflect the differences found in the results.

The concept of flying qualities is still relevant to autonomous UAS. In Triton, the implementation of automated control and autonomous actions removes the need for manual control by the AVO. Resultantly, this has decreased the relevance of the classic flying qualities to the AVO. The effect of classic flying qualities, such as short-period, roll-mode, and stick-force gradients, no longer influence the AVOs interaction with the UAS. However, this does not mean that the AVO is completely removed from interactions with the vehicle. The AVO is not simply an observer. They are relied upon to act in ensuring the best course of action for the UAS, and responsible for the safe and effective operation of the system. While they no longer directly control the vehicle, they are still in command. Yet, this shifts the interaction of the AVO with the system. Ultimately, the characteristics of Triton that affect the operator’s evaluation of the system are fundamentally different than piloted aircraft, but they do still exist and are pertinent to future design and certification.

The theory generated by this research is not sufficient to inform the certification of systems as safe for operation. The results are only theory. Further research is required to sustain these results with quantitative measurement. It is possible that this process may follow the same path documented by Vincenti (1990) in his description of the development of flying qualities for piloted aircraft. The theory provided here is a first step in that process and informs the direction of those further efforts. Future researchers can use this developed theory as a guide to direct them to meaningful conclusions that will improve future UAS designs.

Inevitably, the need to make autonomous UAS easier to operate will take on a greater urgency as AVOs are asked to take command of multiple UA platforms, and as manned aircraft pilots are tasked with the simultaneous command of UAS while piloting their aircraft. These new demands will take advantage of the low task-loading required during normal autonomous operations, but have the potential to overwhelm the AVO when things go wrong. In these situations, the AVO will not have the luxury of an undivided attention that can parse through large volumes of data and interpret cumbersome data displays. To unlock the potential of these platforms the AVO must be able to work as a team with the vehicle to assess its current state and intentions, and then to provide updated guidance if necessary. The framework of handling qualities presented here, and the grounded theory methodology used to explore it, can provide the theory needed to address those emergent issues.

Appendix A
Semi-Structured Interview Guide

Introduction:

Thank you for agreeing to participate in this interview. The purpose of this research study is to explore how pilots interact with Unmanned Aircraft Systems (UAS) and what system qualities affect that interaction. The interview will focus on your experience operating UAS. There are no right or wrong answers to these questions, and you will not be evaluated or measured based upon your replies.

The interview should take approximately one hour depending on how much information you would like to share. With your permission, I would like to record the interview because I don't want to miss any of your comments. All responses will be kept confidential. This means that your de-identified interview responses will only be shared with research team members and we will ensure that any information we include in our report does not identify you as the respondent. Your identity and contact information will be maintained on a password-protected personal laptop computer. Categorical data about participants (age range, gender, experience level, etc.) may be used to provide insights and show connections, however no personal identifying information will be disseminated or published.

You do not have to participate in this research. You can stop your participation at any time. You may refuse to participate or choose to discontinue participation at any time without losing any benefits to which you are otherwise entitled.

Are there any questions about what I have just explained?

May I start recording?

Appendix A
Semi-Structured Interview Guide

Note that this guide only represents the main themes to be discussed with the participants and as such does not include the various prompts that may also be used (examples given for each question). Non-leading and general prompts will also be used, such as "Can you please tell me a little bit more about that?" and "What does that look like for you".

Establishing Rapport / Background

-Before we begin, could you tell me a little bit about yourself and your background?

Opportunity to collect demographic and categorical information. May include specific probing questions to complete categorical data.

What are the perceptions of pilots of their role in UAS operations?

-Can you tell me about what it is like to fly your UAS?

Prompt: What is your role in the operation of the UAS?

Prompt: What tasks do you spend time on while flying the UAS?

Prompt: How would you describe being a UAS pilot to someone who is just about to start training?

What difficulties do pilots experience when operating UAS?

-What do you find challenging or difficult about flying a UAS?

Prompt: Are there any challenges specific to flight characteristics of the air vehicle?

Prompt: Are there any challenges specific to the command and control link?

Prompt: Are there any challenges specific to the interface with the ground segment?

Prompt: Are there any challenges specific to not being on the air vehicle?

Prompt: Are there any challenges that you did not anticipate before you began flying UAS?

How do pilots perceive the effect of UAS design on operating a UAS?

-Can you talk a bit about how the design of your UAS, and any impact or influence that has on its operation?

Prompt: What about the design makes your job as a pilot easier?

Prompt: What about the design make your job more difficult?

Prompt: Are there parts of the system that seem superfluous or unnecessary?

What, if any, strategies or techniques do pilots use to overcome system limitations?

-Do you have any techniques or work-arounds that you use to help make flying your UAS easier or to overcome any shortfalls in the system?

Prompt: Are there ways in which you use the system that are other than it was intended?

Prompt: Do you rely, or often use, tools or resources outside of the UAS to assist with operating the aircraft?

What are the experiences of pilots in interacting with those external to the UAS during operations?

-What is it like interacting with the National Airspace System, ATC, and other aircraft?

Prompt: How does the current structure do in supporting UAS?

Prompt: Does the current structure let you complete your operational goals? If not, how are you constrained?

Conclusion

-Is there anything else that you can think of that would be pertinent to know about flying UAS?

Turn off the recorder.

Thank you for your time and the information you shared. I may contact you again in the near future for clarification on your answers or to ask you to expand on a comment. Your participation will still be voluntary and the additional information you provide will still be confidential. If you have any additional comments or would like to make additions to your answers please feel free to contact me. Your continued participation is welcomed. I will make a transcription of this interview with my notes. If you would like a copy please let me know.

You can reach me at Michael.M.McLean@ndus.edu

Thank you again for your time.

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