Distributing

Non-Cooperative Object Information

in

Next Generation

Radar Surveillance Systems

by

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A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Applied Science

in

Systems Design Engineering

Waterloo, Ontario, Canada, 2014

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Radar surveillance systems, in both airspace and maritime domains, are facing increasing challenges in dealing with objects that cannot be detected by traditional transponder-based radar surveillance technologies. These objects, including birds, weather, Unmanned Aircraft Systems (UAS), hot balloons, are labeled as non-cooperative objects. In order to prevent ambiguity and confusion for human operators using the surveillance data non-cooperative objects are commonly treated as unwanted clutter and removed from the displayed data.

However, the omitted information of non-cooperative object can be critical to aircraft safety. With new developments in technology and radar capabilities, it is possible to detect these non-cooperative objects and consider how to distribute relevant information about them to human operators throughout a system. The research goal of this thesis is to identify the human factors challenges in future radar surveillance systems where non-cooperative object information is distributed to both air traffic controllers and pilots.

In order to achieve the goal, the thesis first constructed a model of surveillance information distribution in current ATC operations and a model of surveillance information distribution in the expected future operational environment. The expected future surveillance information distribution model was then carefully examined to identify potential human factors challenges in the non-cooperative object information distribution process. Two of the identified challenges (non-equal time delay and information level of details) were studied in depth through conducting human-in-the-loop experiments and online surveys.

The results of an asynchronous information (non-equal time delay) static simulation environment experiment showed that while a delay in the non-cooperative object information would lead to observable but not statistically significant longer communication time, it does have a significant effect on number of clarification statements – with an increase of time delay, more clarifications were made. A survey of controller and pilot perceptions of maximum acceptable delay showed no significant differences in the average maximum acceptable delay reported by controller (20.5 seconds) and pilot (13.64 seconds) participants. Future research should consider adopting dynamic simulation environment, subject matter experts and shorter delay intervals to identify an acceptable delay threshold.

The survey results also demonstrated that there are more controllers and pilots who have had encounters with UAS in their daily tasks than what was originally expected. The survey also helped identify operational information requirements and availabilities for individual UAS and challenges in sharing non-cooperative object information between controllers and pilots.

These findings are quite valuable as they provide guidance on future radar surveillance systems design in supporting the effective distribution of non-cooperative object information. Future work should complete the analysis of the survey and create more dynamic environment for studying information asynchrony.

Acknowledgements

First and foremost, I would like to express my sincere gratitude and appreciation to my supervisor, Professor Jonathan Histon. I would not have gotten this far without the support and guidance from you. Calling you amazing is an understatement.

I would also like to thank my readers, Professor Carolyn MacGregor and Professor Steven Waslander, and my one-term supervisor, Professor Catherine Burns. I appreciate the comments and help you have given me for my thesis and throughout my graduate studies. It was a great experience working with you.

To my dear friends, Joseph Shum, Wayne Giang, Tom Robinson, Leila Rezai and Betty Chang, I thank you for sharing joyful moments of my life, giving me strength when I need it and putting up with my complaints every now and then. I had a wonderful two years at University of Waterloo because of you. I would also like to extend my appreciation to all my friends for your support.

To all my participants, you made everything possible. Thank you all for your precious input and contribution to our scientific work. Science rocks!

A heartfelt thank you goes out to everyone in HCOM, AIDL, CSL and Use-It Lab. You guys truly make University of Waterloo's Human Factors research group an awesome place to work, learn and have fun.

To my co-workers at ICAO and IBM Canada, I thank you for your help on my research and during my internships. Especially the lovely air traffic controllers and pilots, you sharing your expert knowledge with me have saved me from going crazy about the technical details.

I gratefully acknowledge the support of the National Science and Engineering Research Council of Canada and Raytheon Canada as part of a Collaborative Research and Development.

Lastly, to my parents, I thank you for your understanding and unconditional support throughout the years. Your love and guidance has made me who I am today, and I am always grateful to that. Dedicating my thesis to you might not be able to make up the time I am away from home, but at least you will finally have a book to refer to when you wonder what my research is about again.

Dedication

To Mom and Dad:

I dedicate my first but hopefully not last "book" to you.

Hope it has an answer to every one of your curiosities.

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Chapter 1
Introduction

On January 15, 2009, an Airbus A320-214 with 155 people on board was on its way to Charlotte from New York City when it struck a flock of Canada Geese during its initial climb out. The plane lost both of its engine power and took a forced landing on the Hudson River. The incident is known as the famous "Miracle on the Hudson." In later reports and analysis, it was concluded that "the ingestion of large birds into each engine, which resulted in an almost total loss of thrust in both engines" (NTSB, 2009) is the probable cause of the accident, and the First Officer was the first one who saw the birds approaching, not the air traffic controller.

These large birds were detected by current technology, but were not visible to either the air traffic controller or the pilot. This is an illustrative example of challenges for designing displays for complex radar surveillance systems with multiple types of data. There is a clear need to understand the operators' information needs, and how the information should be displayed in improving, not hindering, their task performance.

1.1 Current Surveillance Systems and Challenges

Radar surveillance systems, in both airspace and maritime domains, are facing increasing challenges in dealing with objects that do not have transponders and/or do not cooperate with human operators (air traffic controllers). These objects, including birds, weather, Unmanned Aircraft Systems (UAS), hot balloons, are recognized as non-cooperative objects. In order to prevent human operators' ambiguity and confusion in the subsequent analysis, the non-cooperative objects are mostly viewed as clutter and/or removed from the displayed data (i.e. US Airways Flight 1549 Accident).

However, the omitted information can be critical to aircraft safety. According to Dolbeer, Wright, Weller and Begier (2012), there are more than 121,000 wildlife strikes records during the past twenty years. From 2006 to 2010, 26 strikes were reported on a daily basis. One might argue that the collisions between birds and aircraft are usually minor. Yet, the experience of US Airways Flight 1549 over the Hudson River, as described at the beginning of the chapter, demonstrates that non-cooperative objects could severely endanger aircraft and the lives of passengers.

In addition to the dangers presented by birds, there is also an increasing demand to use unmanned aircraft systems (UAS) in commercial applications. Since the introduction of UAS, the main focus has been on military applications. Yet, driven by the huge profit opportunities in the UAS market, it is inevitable that the sky will eventually open up to UAS. Airline companies, research institutions, governments and other organizations are already planning to introduce UASs to the airspace (Dalamagkidis, Valavanis, & Piegl, 2008a, 2008b); this interest is also reflected in recent policy discussions in the United States that have been driven by privacy fears due to the expanding use of UAS by law-enforcement agencies.

The expanded use of UAS will require an integration of their operations into airspace actively managed by an air traffic controller ("controlled airspace"). However, due to the fundamental differences between UAS and manned aircraft (Dalamagkidis et al., 2008a), it is unclear how UAS operations in controlled airspace would affect the pilots and controllers' communication and task performance. For example, there is a need to understand better how UAS operations will be different from traditional flight operations, and if and how those differences affect the information requirements for air traffic controllers and pilots.

1.2 New Technologies and Potential Opportunities

Recently, a number of new surveillance capabilities (i.e. Automatic Dependent Surveillance-Broadcast equipped UAS) have been developed, and radar manufacturers are continuously working to improve existing capabilities. Applying this technology to UAS creates new opportunities to improve the quality and timeliness of surveillance information used for real-time decision-making, enhances the performance of air traffic management systems, and could help facilitate the integration of UAS into controlled airspace.

Other advances in surveillance and communication operational concepts are creating opportunities to expand the distribution of ground-based surveillance data about UAS to include both pilots and controllers. For instance, System Wide Information Management (SWIM) (Eurocontrol. SESAR Consortium, 2007; NASA, 2008) is a concept for an information subscription and distribution system that would allow users from different locations to access the same information. It greatly reduces the information transmission time and the complexity of the system.

1.3 Challenges in Information Distribution

The improvement of technologies and capabilities not only present opportunities, but also bring potential human factors challenges.

First, the new technologies create potential challenges in punctual and accurate information sharing. The future air traffic management platforms, such as SWIM, would be able to facilitate information sharing among multiple users. However, for users accessing the same information from different physical locations, it is unclear what would happen if the information flow were disrupted. It is unclear how the users would react to the information disruption and the potential for differential information delays, with users collaborating while having access to the same information at different points in time. There could be substantial impact on the effectiveness of information sharing, leading to potential confusion and communication frustration.

Secondly, it is not yet clear how UAS activities should be effectively managed. Incidents reported to NASA's Aviation Safety & Reporting system (ASRS) highlight concerns about what information about nearby UAS is available to pilots and/or controllers, and what information about the nearby UAS they need (ASRS CALLBACK Issue 397, 2013). This raises the issue of what information about a UAS, and at what level of detail, should be displayed to the other human operators (pilots and controllers) in the aviation system.

Guided by the two major concerns, the goal of the research presented in the thesis is to identify the potential human factors challenges in the future environment where non-cooperative information is distributed to both controllers and pilots, understand how the challenges affect human operators' performance, and provide guidance for future radar surveillance systems design.

The specific objectives of the thesis and the approach to accomplish them are shown as follows:

Objective 1: *Create a surveillance information distribution model of current ATC environment capturing current challenges in handling non-cooperative object surveillance data*.

In order to achieve the objective, a literature review on past publications of bird-strike forecasting systems, hazardous weather warning systems and UAS detection and integration technologies was performed. A current surveillance information distribution model was built on the basis of the review findings and it is presented in Chapter 3. Yet, with the development and introduction of new technologies, services and operational concepts, there was a need to expand and adapt the old model to be representative of the anticipated future environment. As such, it leads to the second objective of the thesis;

Objective 2: *Create a surveillance information distribution model of future ATC environments incorporating emerging technologies relevant to handling non-cooperative object surveillance data*.

Literature reviews on recent research about advanced radar capabilities and new infrastructure design were performed. They provided a better understanding of the future ATC environment and were used to create a future information distribution model presented in Chapter 3. The model illustrates a different non-cooperative information distribution process compared with the current model. This difference provided a basis for identifying research needs and opportunities on relevant human factors challenges.

Objective 3: *Identify potential human factor challenges in distributing non-cooperative information in the future operational environment.*

In order to identify the human factors challenges, the future surveillance information distribution model was critically examined to identify high impact consequences of changes in information distribution on the human operators in the system. A literature review on related human factors challenges in communication, information sharing and information perception was conducted in support of the identification of challenges. The identified challenges led to additional objectives specific to each challenge.

Objective 4: *Determine how non-equal time delays (HF challenge 1) in the distribution of non-cooperative object radar surveillance information affects the communication between controller and pilot.*

An initial experiment was designed and performed as a stepping-stone towards understanding the potential effects of asynchronous information on controller-pilot communication. The amount of the delay time was manipulated to identify the correlation between information asynchrony and operators' task performance. An online survey of pilots and controllers was also used to understand the challenges in sharing non-cooperative object information between controllers and pilots.

Objective 5: *Gather information requirements from air traffic controllers and pilots on individual UAS operations (HF challenge 2).*

The same online survey study mentioned in Objective 4 was also used to accomplish the fifth objective. Certified air traffic controllers and pilots were invited to participate in the study and share their insights on UAS operation in the controlled airspace.

1.4 Thesis Organization

The remainder of the thesis is organized as follows:

- **Chapter 2: Literature Review** contains a review of previous work on systems handling non-cooperative objects, advanced radar capabilities, and systems architecture and infrastructure design for distributing surveillance data. Related human factors challenges are briefly discussed. Parts of Objectives 1 and 2 will be achieved in this chapter.

- **Chapter 3: Surveillance Information Distribution Model & Human Factors Challenges** presents two models for current and future ATC operations respectively. Four human factors challenges are identified in the future surveillance information distribution model. The challenges of information asynchrony and information level of details are discussed in details in Chapter 4 and 5. The remainder of Objectives 1 and 2, and Objective 3 will be achieved in this chapter.

- **Chapter 4: Initial Study of Information Asynchrony** presents an experiment investigating the effect of asynchronized information on controller-pilot communication (*HF challenge 1*). The chapter describes the methodology and design of the experiment, reports the results and discusses the implications of the study. Objective 4 will be achieved in this chapter.

- **Chapter 5: Survey on Information Level of Detail** presents a survey study investigating operators' UAS information requirements and availability (*HF challenge 2*) and challenges in sharing non-cooperative object information between controllers and pilots (*HF challenge 1)*. Detailed design process, structure of the survey and survey implementation are described. Results of the survey are reported and analyzed based on the structure. Objective 5 will be achieved in this chapter.

- **Chapter 6: Conclusion & Implications** summarizes the findings of this thesis and proposes areas for further research.

Chapter 2
Literature Review

This chapter provides a review of previous research work in distributing non-cooperative object information in current radar surveillance systems. Work in several areas was reviewed: (2.1) advanced radar capabilities, (2.2) current technologies and systems in handling non-cooperative objects, including birds, weather and UAS, (2.3) infrastructure service for information centralization, and (2.4) potential human factors challenges in radar surveillance systems.

In the remainder of this chapter, each of the areas above is discussed. The literature review was conducted by reviewing past publications, technical reports, and news reports. The sources include the UAS / Europe Air Traffic Management Research & Development Seminars, Human Factors and Ergonomics Society (HFES) proceedings and journals, Institute of Electrical and Electronics Engineers (IEEE) proceedings, and FAA publications.

2.1 Advanced Radar Capabilities

There are two types of air traffic control surveillance systems– primary surveillance radar and secondary surveillance radar. Primary surveillance radar (PSR) returns both cooperative and non-cooperative target information based on the objects' energy reflection, whereas secondary surveillance radar (SSR) requires the object to be equipped with an on-board transponder so that it can receive and reply signals (Trim, 1990).

In the famous US Airways Flight 1549 Hudson River Accident, the accident report shows that there were radar data from the EWR and JFK airports indicating the airplane's designated path "intersected a string of unidentified primary targets" (NTSB, 2009). The radar system in this accident, ASR-9, is capable of providing limited primary surveillance data and sufficient secondary surveillance data. Yet, the LGA departure controller chose to filter these "uncorrelated" primary returns in order to focus on the more important targets (NTSB, 2009).

As demonstrated by the Hudson River Accident, current radar surveillance capabilities are advanced in a way that they enable effective cooperative target tracking and communication. One of the most widely used radar surveillance systems in the United States in Terminal Radar Approach Control (TRACON) facilities – the Standard Terminal Automation Replacement Systems (STARS) –

is capable of tracking up to 1,350 airborne aircraft (cooperative objects) simultaneously in a terminal area and displaying 6 levels of weather (non-cooperative objects) data in color.

Beyond radar technologies, data link is also becoming one of the widely used technologies. Automatic Dependent Surveillance-Broadcast (ADS-B) and Traffic Information Service-Broadcast (TIS-B) are two great examples of data link technology. While ADS-B uses transponders to broadcast aircraft position, TIS-B collects SSR information and sends it out to aircraft with the capabilities of receiving ADS-B information. Although these technologies are more accurate in reporting positions, ADS-B has been identified as flawed in its security mechanism (Costin & Francillon, 2012). In addition, for aircraft that are not equipped with transponders, such technologies are not effective. Therefore, there is still a need for enhanced radar surveillance technology that would accurately detect and transmit non-cooperative object information to both controllers and pilots.

2.2 Technologies and Systems for Handling Non-cooperative Objects

In order to better understand the requirements of distributing information on non-cooperative objects in radar surveillance systems, previous work on bird strikes monitoring and reporting systems, weather surveillance systems, and the integration of UAS into controlled airspace was reviewed.

2.2.1 Birds

Bird-strike has always been one of the hot research topics in airspace safety due to its potential catastrophic damage to the aircraft in close encounter accidents/incidents. The wildlife-strike database in the FAA has collected over 120,000 strikes during the past two decades. From 1988 to 2010, wildlife strikes had killed more than 229 people and destroyed over 210 aircraft worldwide, and the threat is increasing (Dolbeer et al., 2012). In early studies of world-wide bird flock risks to aircraft, Allan, Bell, and Jackson (1999) pointed out the lack of a complete and accurate bird strike database at that time, and predicted that having a complete bird strike database would help to make the monitoring of bird movement much easier. Over the past decades, a number of models and systems have been developed as tools to monitor bird activities, predict potential bird migrations, and set alarms when potential hazards are spotted. These models and systems are discussed in the remainder of this section.

The US Bird Avoidance Model (US BAM) is a quantitative model based on the strike records in the FAA wildlife strike database and is used for assessment of potential hazards (Zakrajsek &

Bissonette, 2002). It uses Geographic Information System (GIS) technology for "analysis and correlation of bird habitat, migration, and breeding characteristics to produce a bird-strike risk surface" (Kelly, 2005). In 2005, US BAM was integrated with the Avian Hazard Advisory System (AHAS) (Kelly, 2005).

AHAS is the main bird-strike risk management tool used by United States Air Force (Kelly, 2005). It integrates information from Next Generation Weather Radar (NEXRAD), weather forecasts and known bird distributions (Kelly, Merritt, Donalds, & White, 1999). The system itself provides 24-hour bird migration forecast, 24-hour soaring activities forecast and near real time bird activities forecast. Its nowcast has an update rate of one hour (Ruhe, 2005). An important advantage of AHAS is that it provides a near real-time monitoring and frequent updating of current bird activities, and the information is posted via the Internet at hourly intervals. However, this approach is too restrictive when it comes to military training, because the flight schedules are made according to the forecast of bird activities with a possible error ranging from a few hours to a month (Kelly, Merritt, White, Smith, & Howera, 2000). Moreover, as operational environment becomes increasingly complex, the update rate is still too long and introduces too much uncertainty for real time bird avoidance maneuvers.

Similarly in Europe, there are also a couple of different bird strike forecast models and systems (Ruhe, 2005). For instance, BIRDTAM is a bird migration observation and warning system developed by the German Military Geophysical Service (Ruhe, 1999). The system provides a regular bird strike forecast (daily forecast for 24 hours, and twice a week forecast for 3 days) for low-level military missions and instant warnings to relevant personnel (Ruhe, 1999). Even though its data gathering and processing is automatic, there is still additional need for human analysis and interpretation (Ruhe, 2005).

In addition to the forecasting systems used for a broader range of area like AHAS and BIRDTAM, some risk analysis systems are designed specifically for the need of the terminal area. For example, the Lévy Flight Model could effectively provide information including "bird mass, flight speed, flight direction and its position in relation to the runway"(Ning, Wang, & Chen, 2013).

These bird-strike databases and forecasting systems are great sources for providing valuable information on bird migration patterns and high-risk bird activities. However, there is a disconnection between en-route and airport bird strike forecast. There also lacks a real-time bird-strike warning system and emergency reaction mechanism would enable prompt information sharing between the pilots and air traffic controllers regarding the potential hazards.

2.2.2 Weather

Hazardous weather is another category of non-cooperative objects. According to the statistics published by the FAA, weather is responsible for about 70 percent of the delays in the NAS (Kulesa, 2003). Moreover, it contributes to enormous economic loss, aircraft damage, passenger injuries and unexpected operating costs (Kulesa, 2003). Among all the weather conditions, convective weather is the most damaging and dangerous one. The common convective weather conditions include hail, lightening, tornadoes, thunderstorms, heavy precipitation, icing and wind shear.

The Next Generation Weather Radar (NEXRAD) is a weather information network that uses advanced weather surveillance radar in the United States. It collects important weather information and translates it into a mosaic map for human operators in the system. Since its deployment, NEXRAD has greatly improved the accuracy of remote sensing and warning of the environment (Klazura & Imy, 1993).

A couple of examples of NEXRAD information applications that greatly benefit aviation safety are the Integrated Terminal Weather System (ITWS) and Corridor Integrated Weather System (CIWS). ITWS was initiated by the FAA to address the airport terminal area weather issues. It merges data and information from FAA and several National Weather Service (NWS) sensors (including NEXRAD) to provide accurate weather forecasts for terminal operations (Evans & Ducot, 1994). Its information consumers include air traffic controllers, supervisors, pilots and airline dispatch (MIT Lincoln Lab, 2013). Similarly to ITWS, CIWS also has an access to a wide variety of sensors, and the information is distributed to controllers, pilots and airline dispatch. In addition, it provides accurate and swift 3-D weather information and forecasts, and information is used for pilot avoidance of storms model construction (Evans & Ducot, 2006).

NEXRAD images are now also available in cockpit. However, it is possible that the pilots could misinterpret the information due to lack of knowledge and experience (Vincent, Blickensderfer, Thomas, Smith, & Lanicci, 2013). As clarified by the National Transportation Safety Board (2012), there could be an extreme latency (15-20 minutes) in the weather information displayed in the cockpit. Without knowing the limitation, pilots could have incorrect perception and assumptions of the situation.

Another limitation of NEXRAD is information discrepancy. Although both pilots and controllers have access to NEXRAD information, they may not be seeing the same thing (Brown, 2007). It could be caused by information delay, information pre-process and unreliable detecting capabilities, which could result in poor situation awareness and communication.

2.2.3 Unmanned Aircraft Systems

2.2.3.1 Current Situation

Unmanned aircraft systems (UAS) are becoming an increasingly important class of aircraft in the airspace. The success of using UAS in military applications demonstrated its great advantages and potential. Meanwhile, more focus has also been given to UAS in civil aviation, such as traffic surveillance, post-disaster assessment, and scientific research. However, the use of UAS in civil aviation is currently very limited by the strict rules of the Federal Aviation Administration (FAA) (Dalamagkidis et al., 2008a). This is mainly because the FAA believes that UAS technology is still not mature enough to be incorporated into current National Airspace System (NAS) (Babbitt, 2009), and the FAA needs to ensure that the development and employment of UASs will not jeopardize the current users in the NAS.

In 2011, the FAA announced plans to gradually open the U.S. sky for UASs and integrate UASs within the NAS (Griner, 2011). As an initial step, the FAA certified two UAS models to operate along the Alaska coast for civil aviation purposes (The Associated Press, 2013). Recently, the FAA released its five-year roadmap for UAS regulations (FAA, 2013). Yet, as described in next two subsections, a seamless integration still requires a lot of work to be done.

2.2.3.2 Integration Challenges

The integration of UAS is facing two main challenges: the capability of Sense and Avoid, and communications.

The biggest concern of UAS comes from its fundamental difference in sense-and-avoid capability from traditional manned aircraft. Sense and avoid refers to aircraft’s capability of reliably detecting and avoiding intruding aircraft. Some of the major research trends include 1) creating a platform/concept to support overall situation awareness where data from different sources will be merged, and 2) equipping the UAS with on-board transponders to enable Detect-Sense-and-Avoid (DSA) capabilities (Tirri, Fasano, Accardo, Moccia, & Lellis, 2012).

As part of the first research trend, the National Aeronautics and Space Administration (NASA) introduced a Sense and Avoid (SAA) concept that enables self-separation and collision avoidance (Consiglio, Chamberlain, Munoz, & Hoffler, 2012). Pérez-Batlle, Pastor and Prats (2012) also proposed a set of pre-planned separation maneuvers that would improve both air traffic controllers and UAS pilots' situation awareness. The researchers also explored the options of using ground-based radar to provide UAS sense and avoid information. These concepts are promising and worth more exploration; in the meantime, researchers should keep in mind how these pre-set concepts affect pilots and controllers' workload.

Current DSA technologies fall into two main categories – cooperative and non-cooperative technologies. Cooperative technologies include the Traffic alert and Collision Avoidance System (TCAS), Automatic Dependent Surveillance-Broadcast (ADS-B) and Traffic Advisory System. Most of these technologies are already being widely used in human-in-the-loop manned aircraft. However, before applying them to UAS, they need to be verified that they also meet the specific requirements of UAS operation. Non-cooperative technologies, on the other hand, consist of radar, laser, sonar, electro-optical, infrared and acoustic, and do not require a human operator in the loop. The limitation of non-cooperative technologies is the ranging capabilities and resolution requirements (Hottman, Hansen, & Berry, 2009).

A fair amount of effort has also been put into modeling what size of UAS vehicles would require DSA capabilities. For example, Weibel and Hansman (2006) previously considered the risks of both midair collisions and subsequent ground impact as a function of UAS size. Multiple approaches have been used for calculating and mitigating potential collision hazards between two UASs, including using probabilistic trajectory models and Monte Carlo simulations (Kim, Park, & Tahk, 2007), using the geometric relations between two UASs to calculate the point of closest approach (Park, Oh, & Tahk, 2008), and relying on cooperative predictive control algorithm to avoid static obstacles (Boivin, Desbiens, & Gagnon, 2008). For small UAS particularly, Tirri et al. (2012) pointed out that adopting particle filtering could achieve multi-sensor data fusion for getting a more accurate estimate of the collision threat.

The second main challenge – communications – is essential as well, as UAS need to constantly transmit large amounts of data to ground stations. Communication presents a challenge on currently assigned radio frequencies due to bandwidth limitations (Griswold, 2008). Research has been focused on validating new UAS spectrum and data link communications. For instance, Jain and Templin (2011) proposed to use dual-band design where L-band and C-band are being considered instead of using the single-band design. McHenry et al. (2010) introduced a Dynamic Spectrum Access (DSA) concept where the radio frequency spectrum is monitored, and available spectrum is identified and allocated based on pre-programmed rules. In the meantime, NASA has been funding a Communications Subproject to analyze and obtain appropriate frequency spectrum allocations for safe operations of UAS (NASA, 2013).

2.2.3.3 Other Concerns and Next Steps

Other than the technical challenges, there are a few other concerns in UAS integration. One of them is the different behaviors of different types of UAS. Some large UAS will operate in a manner very similar to manned aircraft in current operations; on-board transponders and real-time two-way communication links between controllers and operators will provide the basic capabilities of surveillance and communication with the UAS. However, for small and medium size UAS that do not have the same on-board capabilities, additional limitations in communicating and implementing control instructions may create the need for controllers to treat some UAS in a manner similar to birds, weather, or other non-controllable objects. The significant research efforts placed on having a UAS operator be responsible for multiple UAS may exacerbate this need (Cummings, 2004).

At the same time, air traffic control systems around the world are being transformed with new technological capabilities and new operational concepts. New communication frameworks such as System Wide Information Management (Meserole & Moore, 2007) are creating opportunities to rethink the distribution of surveillance information. In particular, “who needs to know what, and when do they need to know it” about UAS operating in close proximity to other aircraft is the main challenge.

As part of assessing the potential and challenges of distributing ground-based surveillance data about non-cooperative objects, such as UAS, Yuan et al. (2012) previously proposed the future surveillance information distribution model described in Chapter 3. The model was used to identify four human factors challenges that might be created by sharing surveillance data gathered from ground-based systems, such as primary or secondary radar, with both controllers and pilots. These challenges, described more fully in Chapter 3, were: impact of time delays between information available to pilots and that available to controllers (Yuan, Histon, Burns, Waslander, & Dizaji, 2013), appropriate level of detail (e.g. information requirements) of surveillance data presented to pilots and/or controllers for decision making, the potential for dissonance, or inconsistent and contradictory warnings from two or more alerting systems due to multiple sources of surveillance data, and the effect of target not being continuously detected on operators' information perception.

2.3 Infrastructure Service for Information Centralization

In addition to developing new technologies and radar capabilities, infrastructure services are also an important component in successfully distributing non-cooperative object information. One of the new infrastructure designs is System Wide Information Management (SWIM). SWIM is an information subscribe-and-distribute service, facilitating shared situation awareness among different applications and operators in the system (Meserole & Moore, 2007). It is adopted by both Single European Sky ATM Research (SESAR) and Next Generation Air Transportation System (NextGen) (Ulfbratt & McConville, 2008).

More specifically, SWIM provides 5 core services: interfaces, registry services, message broker services, information assurance and system management (Stephens, 2006). Each of the services covers a unique part of the information exchange process in SWIM. Stephens (2006) conducted a thorough review of SWIM security architecture and concluded that information exchange will only occur "when it is authorized and when the information can be sufficiently protected by the system."

During the past couple of years, SWIM has gradually transitioned from a concept design to implementation. Besada and fellow researchers (2012) deployed ADS-B in an air-inclusive SWIM environment. The results are quite promising and showed that such an implementation of ADS-B can "fulfill the most demanding surveillance accuracy requirements." Other work has been trying to establish a general SWIM model that is usable for various simulation analyses. For instance, Balakrishnan et al. (2012) proposed a simulation model of SWIM that can be used to evaluate its capability in facilitating increasing performance demands from the users. Similar models could be used to analyze the effectiveness of distributing UAS information in the surveillance system.

SWIM is now in the phase of Segment 2 implementation, which provides enterprise messaging capabilities. It has been used in the Network Enabled Operations program where simulated UAS flights were generated for research of UAS integration into the National Airspace System.

SWIM provides a promising future of information sharing within the complex ATC systems. In Chapter 3, it is specifically discussed and envisioned as the core infrastructure design for future radar surveillance systems.

2.4 Related Human Factors Challenges in Surveillance Systems

During the past couple of decades, researchers have also looked beyond the technologies and into the human component in the surveillance systems. They have previously identified a fair number of potential human factor challenges, which would have a great impact on the air traffic controllers and pilots in the system. Some of the major issues that are of particular interest to this thesis project include situation awareness, display clutter and information latency.

2.4.1 Situation Awareness

Situation awareness (SA), as defined by Endsley (1988), is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." SA is a relatively well-researched and documented area. Related studies have dived into fields of commercial pilot information requirements (Endsley, Farley, Jones, Midkiff, & Hansman, 1998), automated flight control and its reliability (Hollands & Wickens, 1999; Mouloua, Gilson, & Hancock, 2003), multimodal displays for UAS pilots (Arrabito et al., 2010; Ruff, Calhoun, Draper, Fontejon, & Guilfoos, 2004; Tvaryanas, 2004), and pilot interface design (Quigley, Goodrich, & Beard, 2004).

Automation can improve as well as hinder operators' performance and perception of information; as the automation increases to a certain level, there is less interaction between the operators and the system, which in turn reduces their awareness of the situation. Multimodal displays and interface design (visual, auditory and tactile information) is another very promising area, especially for UAS controls. In the longer term, this research should also take vigilance decrement and operator fatigue (Arrabito et al., 2010) into account. Meanwhile, given the current transformation of ATC systems, it is also critical to understand how system design potentially affects operators shared situation awareness and information requirements on non-cooperative objects (FAA, 2013; Langan-Fox, Sankey, & Canty, 2009).

Most of current research on UAS related situation awareness mainly focuses on enhancing UAS see-and-avoid capabilities. In other words, advanced UAS see-and-avoid capabilities can supplement

UAS pilots' loss of visual cues in order to perform avoidance maneuvers as manned aircraft (Melega, Lazarus, Lone, & Savvaris, 2013). For instance, McAree and Chen (2012) proposed artificial situation awareness where a manned aircraft's future trajectory is projected. UAS pilots can then see the projections and make corresponding maneuvers.

In terms of UAS information display regulations, currently there is insufficient or no guidance on how it should be displayed and what information should be displayed to controllers in the system. NASA did briefly give an example of UAS traffic display to manned aircraft in a presentation (Johnson et al., 2012). There is, however, no written documentation on this matter.

2.4.2 Display Clutter

Display clutter is another important human factors issue closely related to operators' information perception and decision-making. Future concepts of air traffic management require advanced technologies to support operators' situation awareness and performance, but they may also bring up new challenges of presenting too much information to the operators, which would in turn cloud the operators' information perception and decision-making. As indicated by different sources of research, cluttered displays would hinder the pilots' detection of command changes and traffic (Ververs & Wickens, 1998), and extremely cluttered displays would cause higher workload and less stable performance (Kim et al., 2011).

While there is plenty of research done examining the effect of visual clutter, it is more important to understand how the systems/displays should be designed to minimize the negative effect of clutter and provide the operators with sufficient information. Doyon-Poulin, Robert and Ouellette (2012) conducted a thorough literature review on visual clutter and identified three key indicators of visual clutter as "the amount of information, the relevancy of the information and the presentation or organization of the information." Based on this categorization, they also proposed three design solutions to de-clutter: minimizing the quantity of the information, highlighting task-related information, and mapping the relationship between different information. Color-coding can reduce the complexity of ATC display to a certain degree (Ahlstrom & Arend, 2005; Yuditsky, Sollenberger, Della Rooco, Friedman-Berg, & Manning, 2002).

2.4.3 Information Latency

Effective communication is built on top of accurate and prompt information sharing. Ambiguity, errors, and miscommunications between pilots and controllers are all potential causes of accidents (Morrow, Lee, & Rodvold, 1993). An important factor affecting communications is the presence of time delays (Morrow et al., 1993).

Information delay could create challenges around communicating target locations and confusion generated by the presence of time delays. National Transportation Safety Board (NTSB) issued safety alerts on this matter about the use of NEXRAD mosaic image by pilots (National Transportation Safety Board, 2012). Day, Holt and Russell (1999) studied the effects of delayed visual feedback and found that it produced oscillations in control movements and targeting exercises. Outside of the air traffic control domain, Kraut, Gergle and Fussell (2002) have examined the effect of time delays in a contrived jigsaw puzzle collaboration task with a shared visual display. Introducing a delay of as little as 3 seconds in the task was reported to impact performance and “in many cases rendered the shared visual space useless” (Gergle, Kraut, & Fussell, 2006).

Besides information delay, there are potential challenges about communication itself as well. Rantanen, McCarley and Xu (2002) looked into the communication delay and identified that a delay on the pilots’ side in responding to controllers’ instruction (pilot delay) has a significant effect on controller performance, whereas the delay of transmitting controllers’ instructions to the cockpit (audio delay) does not affect pilots’ performance accuracy.

Ultimately, controller-pilot communications are important for maintaining consistent and accurate mental models of the traffic situation for both the pilot and the controller (Mogford, 1997). The shared mental model between pilots and controllers will include weather, traffic, intent and effective states (Farley & Hansman, 1999). Farley and Hansman (1999) experimentally studied the effects of increased sharing of weather and traffic data between pilots and controllers; however, this previous work assumed that information sharing would be instantaneous and did not examine the effects of differing time delays in access to shared information.

New technologies and concepts, such as SWIM, are creating opportunities to broader information sharing between pilots and controllers (Ulfbratt & McConville, 2008). Thus, it is fundamental for future radar surveillance systems to address the challenges created by non-cooperative objects information latency in order to improve operators’ shared situation awareness and communication.

2.5 Chapter Summary

This chapter examined four aspects of radar surveillance systems– advanced radar capabilities, current technologies and systems for handling non-cooperative objects, infrastructure services for information distribution and related human factors challenges in current surveillance systems. Current technologies can, to a certain degree, provide near-real time warnings of potential hazards caused by non-cooperative objects. Past research of ATC has identified potential human factors challenges, including situation awareness, display clutter and information latency. With the emerging new capabilities and technologies (i.e. ADS-B, SWIM), these issues should be carefully studied and addressed in order to improve the overall efficiency and safety of future surveillance systems. How the implications are tied with distributing non-cooperative information in future surveillance systems is discussed in Chapter 3.

Chapter 3
Surveillance Information Distribution Models & Human Factors Challenges

In order to better understand the information flow of radar surveillance systems and identify associated human factors challenges, the first part of the chapter presents the process of developing existing and future surveillance information distribution models based on previous literature review. The second half of the chapter discusses the identification of human factors challenges based on the model of expected future information distribution.

3.1 Surveillance information distribution models

Chapter 2 discussed the current operations in radar surveillance systems. The understanding of those systems was used to develop a surveillance information distribution model, which captures how cooperative and non-cooperative surveillance data are currently distributed. The advanced technologies and concepts that will be used in future ATC identified in Chapter 2 were incorporated into a second surveillance information distribution model, the model of expected future operational environment. This model was then used as basis for identifying human factors challenges of distributing non-cooperative object information that might be expected to be present if the advanced technologies are deployed.

3.1.1 Current Surveillance Information Distribution Model

Based on the discussion in Chapter 2, the current surveillance information distribution model in current air traffic control operations is shown in Figure 3-1. Key aspects captured in the model include the fact that pilots do not have direct access to radar data (neither non-cooperative nor cooperative object information), and they negotiate and respond to clearance modifications from air traffic controllers when a potential hazard is identified. Pilots have the potential of directly observing non-cooperative objects and cooperative objects outside the aircraft. Due to the scope of the thesis, pilots' visual detection of cooperative objects was not depicted in the model and considered in the thesis. There are many limitations of visual detection, and it is especially difficult depending on aircraft geometry and behavior, nighttime and weather conditions. Even if the weather were clear, aircraft speeds and competing task obligations of the pilots, would also limit their awareness of the non-cooperative objects.

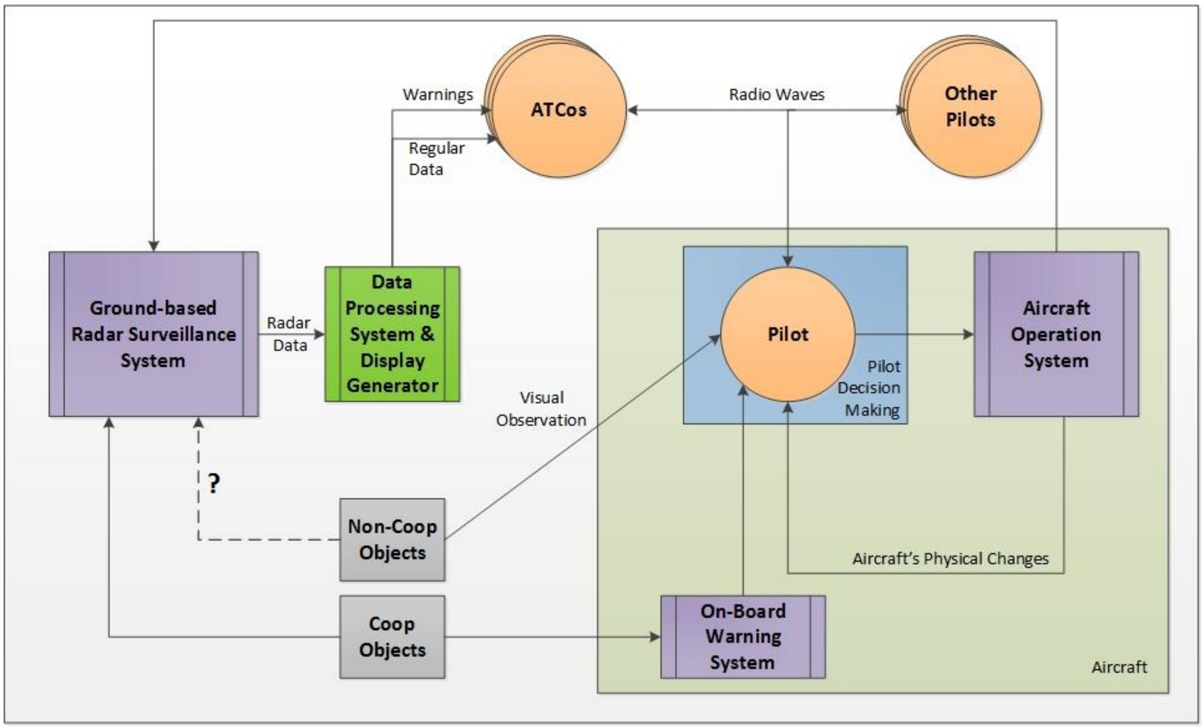

Figure 3-1. Current Surveillance Information Distribution Model

3.1.2 Model of Expected Future Surveillance Information Distribution

As discussed in Chapter 2, although the deployment of any enhanced surveillance technology is several years away, a number of new concepts and techniques for bird strike avoidance, aircraft tracking and system integration have been developed in several undergoing projects. These projects have the potential to eventually change the surveillance data distribution shown in Figure 3-1. It will be important to assess and understand how these changes might affect human operators' performance. In order to identify expected human factors challenges, the current surveillance information distribution model has been expanded based on anticipated enhancements and new technologies that are in development.

A new surveillance information distribution model incorporating the core ideas behind the System Wide Information Management (SWIM) architecture was developed and is presented in Figure 3-2.

The model can be used to better understand the collaboration needs and impacts of new information sources on the relationship between controllers and pilots.

As shown in Figure 3-2, the ground-based radar surveillance system is responsible for detecting non-cooperative and cooperative objects, and transmitting the radar data to SWIM, which publishes the data to a data fusion and process center. The processed data are subscribed by SWIM from the data fusion and processing center and subsequently published through distinct and different information channels to different users (e.g. pilots and controllers).

As demonstrated, the non-cooperative information is displayed to pilots and controllers, introducing additional collaboration and sharing information considerations. Information derived from surveillance objects can be used as inputs into automated avoidance systems that are granted authority to maneuver an aircraft without requiring coordination with pilot or controller.

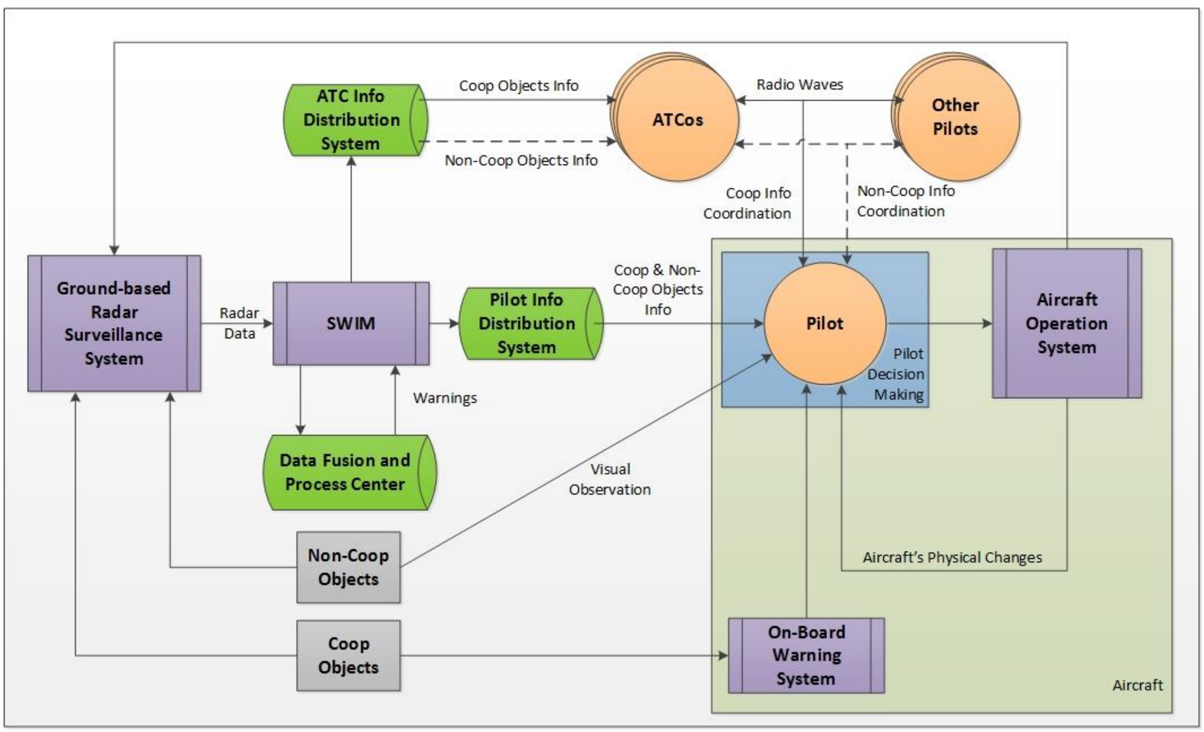

Figure 3-2. Model of Expected Future Surveillance Information Distribution

The key difference between current and future surveillance information distribution models is pilots' access to cooperative and non-cooperative object radar surveillance data facilitated by SWIM.

It enables pilot-controller information sharing on non-cooperative objects and could potentially improve operators' situation awareness.

3.2 Identification of Human Factors Challenges

The projected future environment creates opportunities to distribute enhanced surveillance data on non-cooperative objects; however, there are also challenges that will need to be overcome and key questions that need answering. Key human factors challenges were identified by studying the non-cooperative information distribution process in future operational environment and reviewing past literature on related human factors issues.

3.2.1 Potential for Asynchronous Information for Air Traffic Controllers and Pilots

The first area identified was the potential for asynchronous information to be shared between controllers and pilots. As illustrated in Figure 3-2, with the SWIM architecture the information on a non-cooperative target is published to SWIM and then to pilots and controllers. It is possible to hypothesize a scenario where a pilot receives the UAS warnings from the pilot information distribution system (Figure 3-2), and they need to confirm with a controller about the intention, speed and controlling status of the UAS.

However, since the controller is receiving the information through a different distribution system (air traffic controllers' information distribution system which is displayed as ATCos information distribution system in Figure 3-2), there may be different inherent time delays and, potentially, differences in presentation and awareness of the information. The asynchronocity could be caused by several factors, including hardware design (i.e. the means for transferring the information), software design (i.e. system process speed), human operation (i.e. controllers' or pilots' current workload and tasks) and human cognitive complexity in processing the information. The cognitive complexity, as defined by Scott (1962), is "the number of independent dimensions-worth of concepts the individual brings to bear in describing a particular domain of phenomena." In the field of air traffic control, the cognitive complexity refers to the "measure of the difficulty that a particular traffic situation will present to an air traffic controller" (Meckiff, Chone, & Nicolaon, 1998). Human operators' cognitive complexity increases with the growth of traffic situation difficulty, which might contribute to a more sever asynchronous information perception.

Given that pilots and controllers might not have the same, up-to-date information, it is expected that the communication will be passive and ambiguous, i.e. pilots and controllers would not have the same sense of situation in one conversation. As identified by Mosier et al. (2013), different information is one of the resulting factors of conflicts, which would disrupt communication on traffic flow. Even when operators have access to the same information, there might be a time delay in when the information becomes available resulting in reaction delays. This is seen in current operations where differences in weather presentation (as derived from aircraft weather radar radars and as derived from ground based weather radars) can lead to confusion and communication challenges (Hansman & Davison, 2000). Additionally, if there are no synchronous standards for warning and alert generation, pilots and controllers may be under different impressions as to the urgency of the situation.

This motivates identification of an area of further research – identifying the thresholds of acceptable time-delays for information presented to controllers and pilots. It is important to determine how much delay can be tolerated before normal task performance is affected. It can economically minimize the risks and hazards that are brought by the time difference in receiving information.

3.2.2 Displayed Information Level of Detail

A second key area identified is in specifying how data on the non-cooperative objects should be displayed to pilots and controllers. Decision-making is greatly dependent on the process and evaluation of the given information, and information visualization is an important, and challenging, aspect of the process (Griethe & Schumann, 2005). For pilots or controllers to make a decision with respect to the non-cooperative objects, some basic information can be identified as being necessary: size/threat level, current location, velocity, and potentially acceleration and/or intent information if available.

Enhanced surveillance capabilities may allow very precise resolution of non-cooperative objects, with the possibility of identifying individual small birds, or individual UASs within a swarm. However, it is not clear that this resolution is operationally needed, nor what the consequences of providing too high a resolution of the objects might be. Providing too much detail, for example individual objects for each bird within a flock, or each micro UAS within a larger swarm, could overwhelm the pilot or controller with information; on the other hand, individual objects may be more meaningful, particularly for correlating with other data sources such as an out-the-window view for the pilot.

Secondly, there will be a remaining degree of uncertainty associated with any surveillance system. This can be due to inherent limits of the technology, or time delays in processing, distributing and displaying the information. In the context of rapidly maneuvering objects, it will be important to consider how to show the limits on the precision of any identified objects, and what uncertainty remains about the relative position.

Finally, other display issues that were identified included depiction of relative altitude of non-cooperative objects, showing intent information (if available) and the level of confidence in it, and communicating the degree of cooperation that might be expected of the object.

3.2.3 Dissonance and Warning Integration

The third key area identified was the challenge of integrating warnings and alerts generated based on non-cooperative target information with existing on-board warning systems. The challenge is the potential for dissonance, or "a situation in which information from two or more alerting systems have content or representations that suggest different timing or actions to resolve a hazard" (Song & Kuchar, 2003).

Warning dissonance increases the complexity of the system and presents challenges on human operators' alert perception and execution. Alerting systems are considered as a contributing factor to avionics systems complexity due to different alerting mechanisms and sensors (Kaygusuz & Uyar, 2011). As identified by Dehais et al. (2012), warning dissonance is the primary reason for pilots' lack of reaction to alarms. The conflict and inaccuracy of the information reduces operators' trust in the warnings. Thus, non-cooperative object warning systems should be cautiously designed in accordance with existing warning systems, and the sensor accuracy should be at the same level as the rest of on-board warning systems.

Modality is one of the approaches used to reduce operators' workload and improve situation awareness. For instance, Ground Proximity Warning Systems (GPWS) and Traffic Collision Avoidance System (TCAS) display the alarm in both audio and visual contexts. Theoretically, such a design should assist pilots in quick and accurate decision-making. Yet, in reality, pilots are required to confirm the alarm by visual identification of the hazard outside the window (Cleveland, Fleming,

& Lee, 2011). Earlier research (Pritchett & Hansman, 1997) shows that even when the confirmation is not specified by the system, pilots were still more willing to confirm the alert or take the alert as a cue to perceive more information, rather than taking orders from the alarm system directly. Essentially, operators' are concerned about the accuracy of the information.

3.2.4 Information Intermittency

The final key area identified is the potential for information intermittency, which may happen when an object is operating near the limits of detectability for a surveillance system, and the object may not be continuously detected. It can cause an object to appear and disappear from a surveillance and/or navigation display.

Information intermittency can be considered as disruption and interruption. It presents various challenges on different stages of information perception and decision-making, including information pre-processing, prioritization and attention, information confidence level and information interpretation (Endsley & Jones, 2001). It is likely to increase operators' workload and reduces situation awareness. In certain cases, the operators may not even be aware that they do not have the accurate and entire information of the situation (Beasley et al., 2011).

One of the frequently occurred intermittency effect concerning UAS is loss of link between UAS and ground station control personnel (Kaste, Archer, Neville, Blickensderfer, & Luxion, 2012; Walters, Huber, French, & Barnes, 2002). It is recommended that human-machine interface be improved in detecting and responding to link loss. However, there is not much literature on how often the intermittency occurs, and how it could potentially affect communication and other operators' performance when non-cooperative object information intermittency is involved. Therefore, there is a need to take an initial investigation in understanding the frequency of information intermittency in current ATC system, the average data loss period, and the mitigation strategies of information intermittency that best support operators' needs.

3.3 Chapter Summary

The third chapter presents a current and future ATC surveillance information distribution models. With the deployment of new technologies and concepts, there are also emerging human factors challenges. A thorough examination of the expected future surveillance information distribution model revealed four major challenges in the process of distributing non-cooperative object information, including the potential for asynchronous information, displayed information level of detail, dissonance and warning integration, and information intermittency. Each of the challenges is elaborated in depth. For the purpose of the thesis, the challenges of potential for asynchronous information and displayed information level of detail are selected as the main investigation focus. The following chapters present how these two challenges are approached and examined in details with experiment and survey.

Chapter 4
Initial Study of Information Asynchrony

As identified in Chapter 3, asynchronous information in the radar surveillance systems could potentially trigger miscommunication and confusion. This is already seen in current operations with respect to the presentation of weather information to pilots and controllers. Don Brown, a retired former air traffic controller, pointed out in his blog *Say Again?* #71 (Brown, 2007) that a controllers' weather display is not as accurate as people would think. It not only leaves out important information about the weather (i.e. altitude), but is also turned off to guarantee successful aircraft separation most of the time. There can also be substantial multiple minute delays in the NEXRAD weather image presented to a controller (Brown, 2007). Contrast this with the out-the-window view of weather that pilots can obtain and the potential for miscommunication and confusion is clear.

The introduction of new electronic means of distributing weather to the cockpit is also creating further potential for confusion. According to a report released by the National Transport Safety Board (National Transportation Safety Board, 2012), the weather information displayed to pilots in the cockpit can be delayed as long as 15 to 20 minutes. This is a great example of the existence of information asynchrony in current surveillance systems and how it can reduce overall system performance. In order to understand how the information delay affects operators' performance, Chapter 4 presents an initial experiment in a simplified environment systematically varying the time delay between pilots and controllers in order to investigate the effect of asynchronous information on controller-pilot communication.

The remainder of the chapter presents the experiment methodology, scenario design, experimental tasks, analysis results, and concludes with discussion and implications.

4.1 Goal

While there has been significant previous work on controller-pilot collaboration, there does not appear to be much data available on how differential time delays in a common information source affect the communication and collaboration between pilots and controllers. The goal of the experiment is to take a first step in examining asynchronous information's effect on operators' communication. It aims to extract meaningful results that can verify the hypotheses and be used as a stepping-stone towards a more sophisticated study that would form part of future work.

4.2 Experimental Design

4.2.1 Methodology

The experiment investigated three hypotheses: 1) increasing time delay would cause an increase in the amount of clarifying communications between controllers and pilots; 2) increasing time delay would increase the amount of time taken to coordinate a resolution to an impending conflict in the traffic situation; and 3) increasing time delay would decrease self-assessed performance, and would be positively correlated with self-assessed measures of frustration and task difficulty.

In the experiment, participants were shown static pictures of a radar surveillance display (controller participant) and a primary navigation display (pilot participant). Their tasks were to observe the displays, identify potential conflicts and communicate with each other to resolve the conflict. The experiment manipulated the amount of time delay present between the information presented to the controller participant and the pilot participant. It was also possible that there was no time difference between the two parties' information.

The goal of the experiment is to quickly verify the influence of delayed information on communication. Therefore, participants do not have to have professional experience in air traffic control or as a pilot. Observation, post-trial questionnaires and audio recording were used to facilitate the analysis of the data. Dependent and independent variables are discussed in Chapter 4.2.5.

4.2.2 Experimental Setup

The task was setup to resemble current controller-pilot voice communications. A divider was placed between the two participants (Figure 4-1) allowing them to communicate verbally but without being able to see the other person or any gestures. The researcher sat in the same room with the participants, controlling the static pictures displayed for both participants through a desktop computer connected to two external monitors.

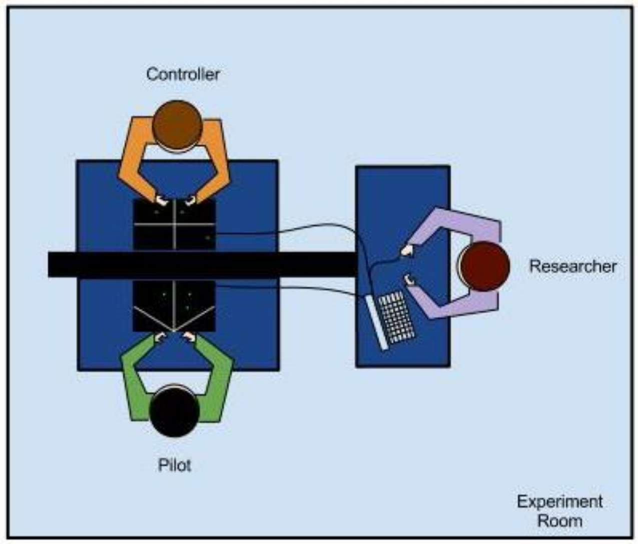

Figure 4-1. Experiment room setting

4.2.3 Participants & Training

Access to trained professionals was not possible; instead, students from a local university were recruited as participants. Consequently, the participants were expected to be not as familiar with air traffic control and piloting operations. However, for the purpose of the intended task, it was felt that the core goal of communicating to negotiate a coordinated resolution to a conflict did not require specialized knowledge. Since the participants were naïve, multiple training trials were provided to make sure that the participants were capable of reading the display, analyzing potential conflicts and communicating with each other.

As part of the training protocol, participants were taught to recognize the legends (aircraft icon, non-cooperative objects icon, etc.) and understand the information presented on the displays. Training on how to communicate was provided; 4 sets of static displays were used to illustrate to participants on how to communicate regarding potential conflicts. By the end of the training session, participants were given some time to get familiar with the setting and their newly acquired knowledge, and to ask the researcher questions. When the participants indicated that they were confident and comfortable with the tasks, the study would proceed onto the experimental tasks stage.

Participants were comprised of 12 pairs (12 female and 12 male participants) with an average age of 29.5 years old. In order to control for possible effects of gender, there were three “male – male” groups, three “female – female” groups and six “female – male” groups. Participants were assigned to the pilot and controller roles randomly at the start of the experiment and remained in the same role throughout the entire experiment. Participants did not previously know each other.

4.2.4 Scenario Design

Ten different scenarios were designed; five were distinct takeoff scenarios and five were distinct landing scenarios. Each scenario constituted a distinct arrangement of traffic, weather, and airspace details. The scenarios were designed so that while they were distinct and would appear novel to participants. They would also be of equivalent difficulty and be expected to produce similar communication patterns between pilots and controllers.

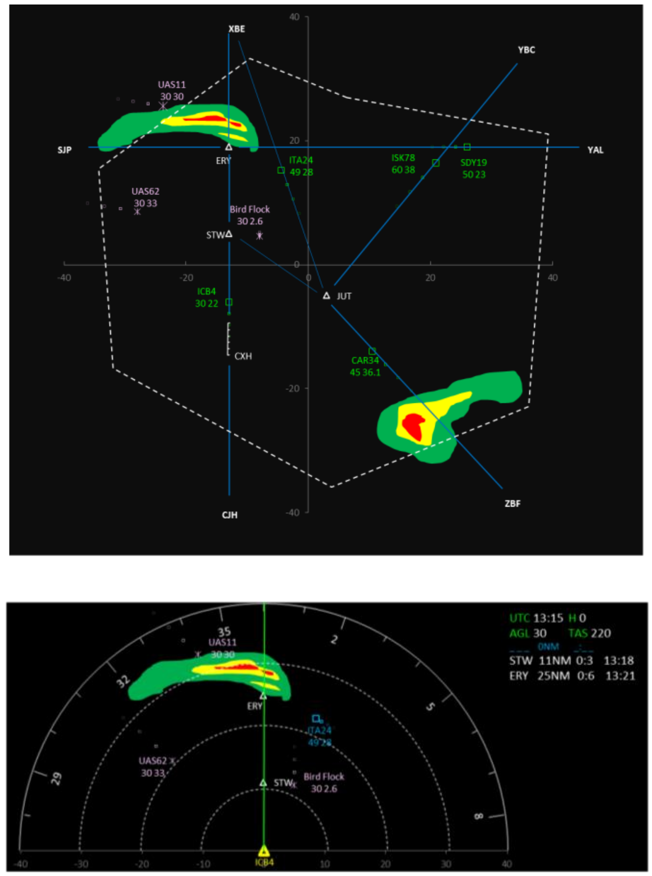

Figure 4-2. Controller View (Top), Pilot View (Bottom)

Each scenario had either 1 or 2 impending conflicts between the pilot’s aircraft and birds and/or UAS and/or weather condition. Scenarios differed in the location of potential conflicts (i.e. in one scenario, participants would see the weather condition directly in the front, whereas in another scenario, the bad weather is approaching from the right side).

For each scenario, pictures for the pilot participant and controller participant were generated using a Microsoft Excel spreadsheet. Figure 4-2 presents an example of the static images used in one scenario for the controller and pilot. The common elements shown on both images included traditional aircraft, as well as depictions of birds, weather and UAS. On the controller’s radar surveillance display, airway, airport and sector were shown. Controllers were also notified of the general traffic situation in their controlled sector by a short briefing message displayed on the screen. On the pilot's navigation display, the same elements were shown from the pilot's point of view.

4.2.5 Time Delays

Five delay intervals were used in the study: 0 (i.e. no delay), 0.5 minute, 1 minute, 5 minute and 10 minutes. While 10 minutes is an extreme case of the potential time delay, it is helpful to magnify the effect of asynchronous information on communication and test the hypotheses.

Using a random assignment process, each time delay was uniquely associated with one takeoff scenario. A separate random assignment process uniquely associated each time delay with one landing scenario. For each scenario, the Microsoft Excel spreadsheet provided the ability to apply the delay to only the non-cooperative objects for either the controller display or the pilot display. This allowed for the creation of distinct "controller ahead" and "pilot ahead" versions of the scenarios. The complete mapping of time delays, "who is ahead", and scenario is shown in Table 4-1.

The delay interval was applied to the non-cooperative objects (UAS, birds and weather information) for either the controller or pilot display, but cooperative objects (e.g. other aircraft) were presented on both pilot and controller displays with no relative time delay. The purpose for this design was to present participants with novel and engaging situations in each trial while at the same time minimizing the potential for differences in the surrounding environment and details of the traffic situation from affecting the results.

Table 4-1: Mapping of Scenarios to Time Delays and "Who is Ahead"

			Time Delay (Minutes)							
		0	**0.5**		**1**		**5**		**10**	
			Controller Ahead	Pilot Ahead	Controller Ahead	Pilot Ahead	Controller Ahead	Pilot Ahead	Controller Ahead	Pilot Ahead
Scenario – Take Off Scenarios	A (S1_T)	**(6)**								
	B (S2_T)		**(2)**	**(3)**						
	C (S3_T)				**(3)**	**(2)**				
	D (S4_T)						**(3)**	**(1)**		
	E (S5_T)								**(2)**	**(3)**
Scenario – Landing Scenarios	F (S1_L)	**(4)**								
	G (S2_L)		**(3)**	**(2)**						
	H (S3_L)				**(2)**	**(3)**				
	I (S4_L)						**(2)**	**(4)**		
	J (S5_L)								**(3)**	**(2)**

4.2.6 Assigning Participants to Scenarios & Time Delays

The full set of combinations of time delay, "who is ahead" and trial order was impractically large to counterbalance for all possible combinations. Unfortunately, the exact process of assigning pairs to scenarios and time delays was not preserved and is not available at the time of writing. However, some considerations were documented and are explained below.

The within-subject experimental design included one independent variable (time delay) and six dependent variables (communication time, number of clarification statements, performance, communication, frustration and level of difficulty). Each pair of participants performed each of the five possible time delays once. To minimize potential learning effects, the sequence of time delays in the experimental trials was randomized.

There were equal numbers of pilot-ahead and controller-ahead trials for each pair, and all of the trials were randomized between takeoff and landing scenarios. The reason for such a design was to counter balance "who is ahead" across all of the trials while providing novel scenarios for the participants. Therefore, "who is ahead" is not considered as a contributing factor in the analysis.

Ten experimental packages, each representing a unique assignments of trial order, time delay, “who is ahead”, and scenario type (takeoff/landing) were designed and are shown in Table 4-2. Each pair of participants performed one experimental package. For each package, Table 4-2 sets the sequence of the scenarios, “who is ahead” and if it is takeoff or landing environment. For example, in Package 1, the first trial presents a takeoff scenario of a 0.5-minute time delay where the pilot participant has the more updated information.

Table 4-2: Experimental Packages

Package #	Trial														
	1			2			3			4			5		
1	0.5[1]	P[2]	T[3]	0	/	T	1	C	T	5	P	L	10	C	L
2	5	C	T	0.5	C	L	0	/	L	10	P	T	1	P	T
3	0	/	L	10	P	T	5	P	L	0.5	C	T	1	C	L
4	10	C	L	0.5	P	L	1	P	T	0	/	L	5	C	T
5	0.5	P	T	0	/	T	10	C	T	1	C	L	5	P	L
6	5	C	T	1	P	L	0.5	C	L	0	/	T	10	P	T
7	10	P	L	5	P	T	0.5	C	L	1	C	T	0	/	L
8	1	P	L	5	C	L	0	/	T	10	C	L	0.5	P	T
9	0	/	T	1	C	T	10	C	T	5	P	L	0.5	P	L
10	1	P	L	10	P	L	5	C	L	0.5	C	T	0	/	T

4.2.7 Experiment Task

In each experimental trial, the participants were asked to evaluate the radar surveillance display/navigation display and identify potential conflicts. Subsequently, the participants were to communicate with each other in order to resolve the conflict. The indication for the completion of one scenario is that an agreement is reached between the controller and the pilot to resolve a conflict. When a conflict cannot be resolved, the discussion would be ended at point of 5 minutes. After 5 minutes, it would be too late to maneuver around the potential hazard and would cause a potential crash.

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[1] This column presents time delay (minute).

[2] This column presents “who is ahead” – controller (C) or pilot (P).

[3] This column presents if this scenario is a takeoff (T) or landing (L) scenario.

4.2.8 Data Collection

Questionnaire. At the end of each experimental trial, the participants completed a post-trial questionnaire. The questionnaire provided four 10-point Likert scales and asked participants to rate their self-assessed *performance, communication effectiveness, frustration level* and *trial difficulty.* Table 4-3 shows the form that the performance question took. For the complete content of the questionnaires, please refer to Appendix A and B. Other scales, like NASA Task Load Index (TLX), were not selected because their measurements are not the most effective ones for the purpose of this experiment.

Table 4-3: Example of the Likert Scale in the post-trial questionnaire (performance)

#	Title	Descriptions	Rating
1	PERFORMANCE	How successful do you think you were in accomplishing the goals of the task set by the researcher? How satisfied were you with your performance in accomplishing these goals?	PERFORMANCE 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Poor Good

Result sheet. Besides the questionnaire, the participants were also asked to write down their negotiation results on a result sheet by the end of each official trial. Usually, the pilot in the group would finish the sheet. The time taken to complete the sheet was not calculated into the communication time.

Audio recording. The experimental trials were audio recorded for the purpose of analyzing communication time and clarification information. In the analysis stage, these recordings were transcribed. The transcriptions were used to develop objective measures of communication time and counts of the number of clarification communication events.

4.3 Results

Across all participants, 60 trials were performed, among which 24 were “pilot ahead”, 24 were “controller ahead” and 12 were zero delay. The matrix in Table 4-4 presents the specific number of the performed scenarios in relation to “who is ahead.” Experimental packages 1 and 2 were experienced by 2 pairs each, while packages 3 to 10 were experience once each.

Table 4-4: Number of Scenarios Performed in relation to "Who is Ahead"

	Delay Interval (min)					Total Number of Scenarios Performed
	0	0.5	1	5	10	
Pilot ahead	/	6	6	6	6	24
Controller ahead	/	6	6	6	6	24
No delay	12	/	/	/	/	12
Total	12	12	12	12	12	60

4.3.1 Objective Data

Communication time. Communication time refers to the time from the beginning of the trial until the participants reached an agreement on a resolution action. Table 4-5 presents the average communication time and standard error for each delay interval. Figure 4-3 (a) provides a visual presentation of the data. Error bars in the figure represent the standard error. The general trend indicates that the communication time increases when someone has more updated information (either the pilot or the controller).

Table 4-5: Communication Time for Each Delay Interval (minute)

	Delay Interval (minute)				
	0	0.5	1	5	10
Mean (minute)	192.333	147.167	182.917	163.417	216.250
Standard Error	28.498	16.382	30.223	17.779	28.604

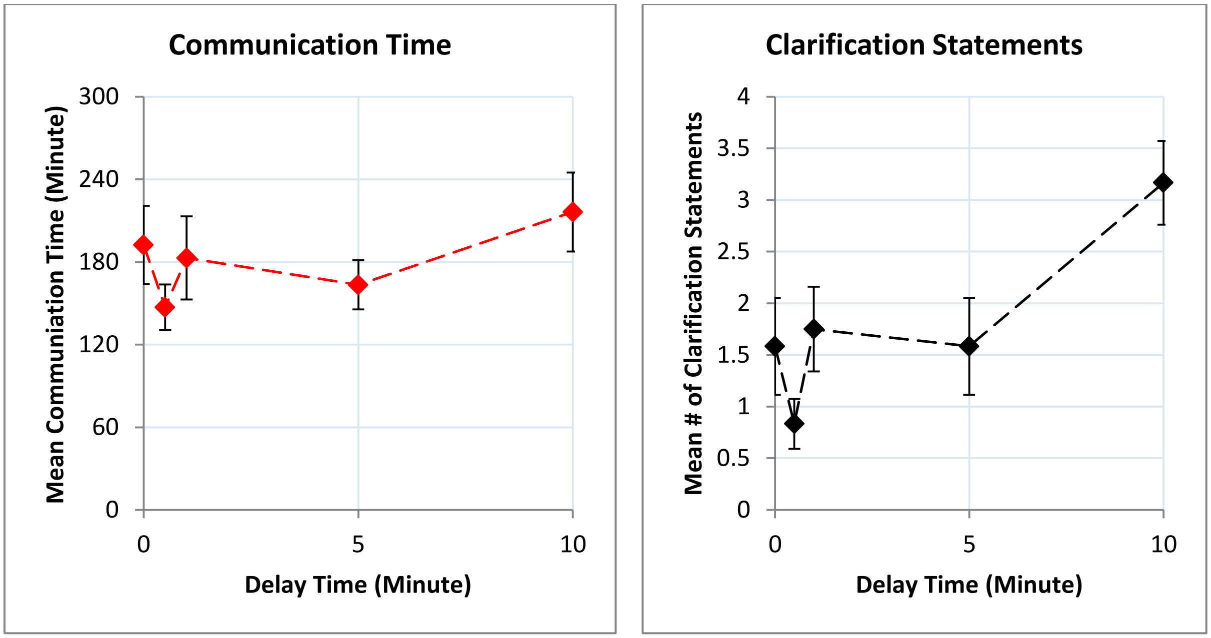
A repeated measures ANOVA was conducted to determine whether there were statistically significant differences in communication time over the five different delay times. There were no outliers and the data was normally distributed for each group, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was not violated, as assessed by Mauchly's test of sphericity, $\chi^2(9) = 7.605$, $p > .05$. The delay time did not elicit statistically significant changes in communication time, $F(4, 44) = 2.344$, $p = .069$.

Number of clarification statements. Based on the review of the transcripts, a clarification was defined as the moment that 1) one party of the pair asks the other party to either confirm and/or describe one or more particular object(s), and/or 2) one party of the pair disagrees with the other on the description/position/information of one/more particular object(s). Therefore, if one party merely does not hear the description clearly and asks for more explanation, it was not counted as a clarification. Table 4-6 presents the average number of clarification statements and standard error for each delay interval. Figure 4-3 (b) plots the relationship between the average number of clarification statements and the delay intervals. The overall trend indicates that an increase of the time delay increases the number of the clarification statements.

Table 4-6: Number of Clarification Statements for Each Delay Interval

	Delay Interval (minute)				
	0	0.5	1	5	10
Mean	1.583	0.833	1.750	1.583	3.167
Standard error	0.468	0.241	0.411	0.468	0.405
Median	1	1	1.5	1	3

Due to the fact that there were extreme outliers in the data and it was not normally distributed, a non-parametric method - Friedman test - was run to determine if the observed differences in the number of clarification statements was statistically significant. The results showed that there was a statistically significant difference in the number of clarification statements depending on the delay intervals, $\chi^2(4) = 19.200$, $p = .001$. A post hoc analysis with Wilcoxon signed-rank test was conducted with a Bonferroni correction applied, resulting in a significant level set at $p < .005$. The only significant difference found was between delay 0.5-minute and 10-minute in number of clarification statements (Z = -2.953, $p = .003$).



(a) (b)

Figure 4-3. Mean Value Plots of Objective Measurements

As shown in Figure 4-3, there is a drop of communication time and number of clarification statements at the time delay of 30 seconds. A review of the scenarios generated for a time delay of 30 seconds indicated that this could be caused by an artificial design flaw in the scenarios. The potential conflicts presented in the 30-second delay scenarios (S2_T and S2_L in Table 4-1) were less pressing compared with other scenarios. Participants tend to find this scenario easier in finding the right resolution for it.

4.3.2 Subjective Data

The main resource of subjective data is the self-rate measurements collected from the post-trial questionnaires. The four measurements were *performance*, *communication effectiveness*, *frustration*, and *trial level of difficulty*. Checks were made for learning effects and the data showed ratings were generally consistent, independent of trial number (Figure 4-4).

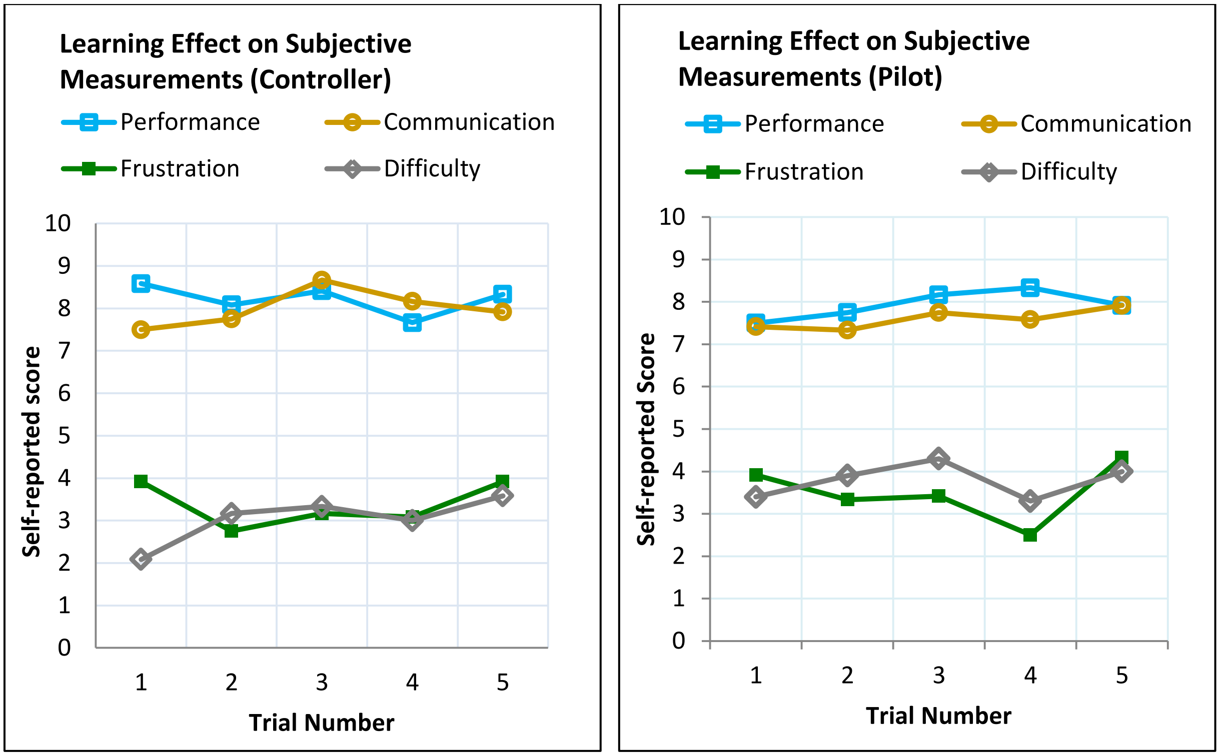
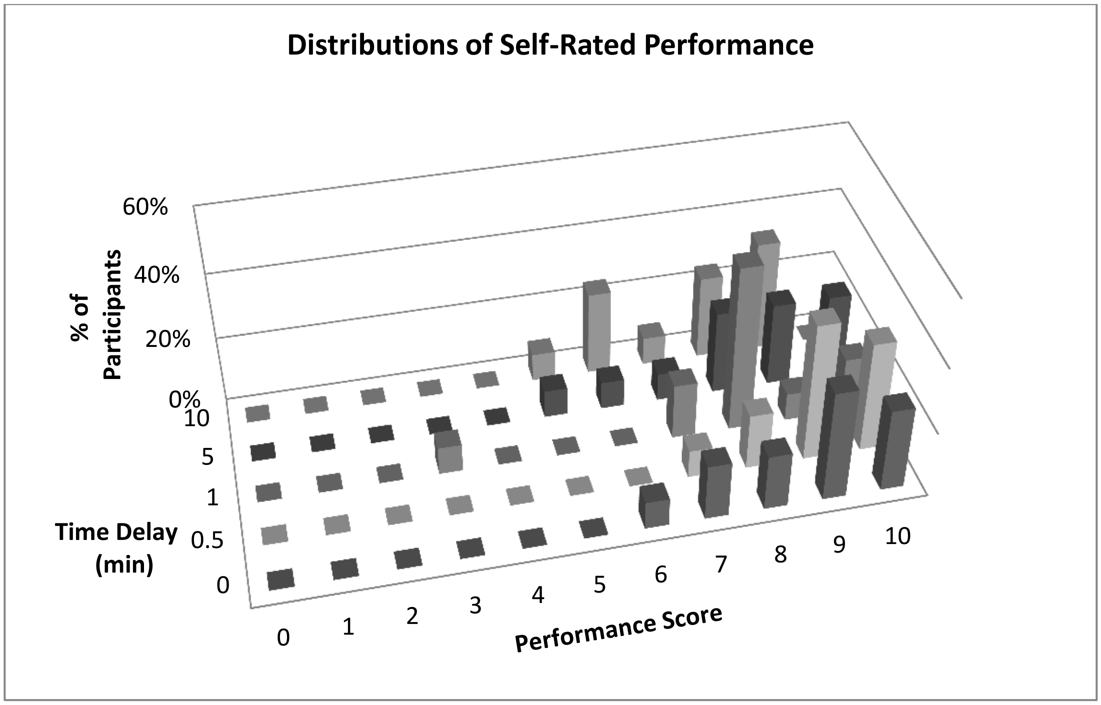
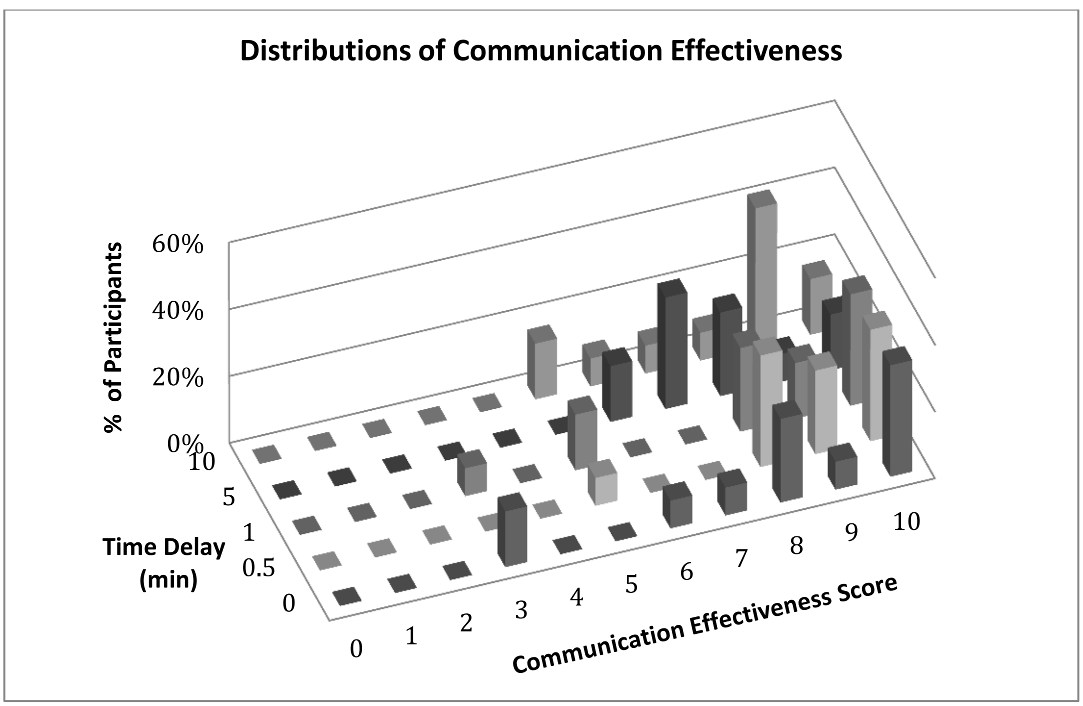


Figure 4-4. Learning Effect

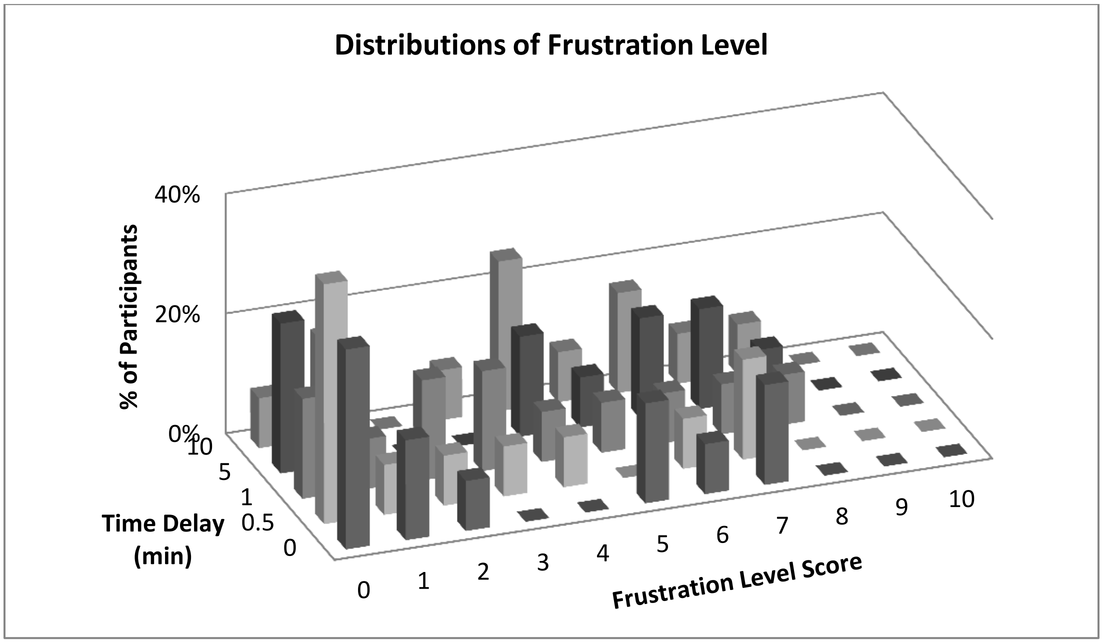
Figure 4-5 and Figure 4-6 show the distributions of observed ratings for the four measurements for controller and pilot participants respectively. The higher the score is, the better the performance and communication effectiveness is. The lower the score is, the less frustration and trial difficulty is experienced. Visual inspections indicate an observable shift of more participants to giving lower scores for performance and communication effectiveness as the time delay increases. The figures also show a shift of more participants to giving higher scores for frustrated and find the trial more difficult as the delay increases.


Distributions of Self-Rated Performance
60%
40%
20%
0%
% of Participants
10
5
1
0.5
0
Time Delay (min)
0 1 2 3 4 5 6 7 8 9 10
Performance Score

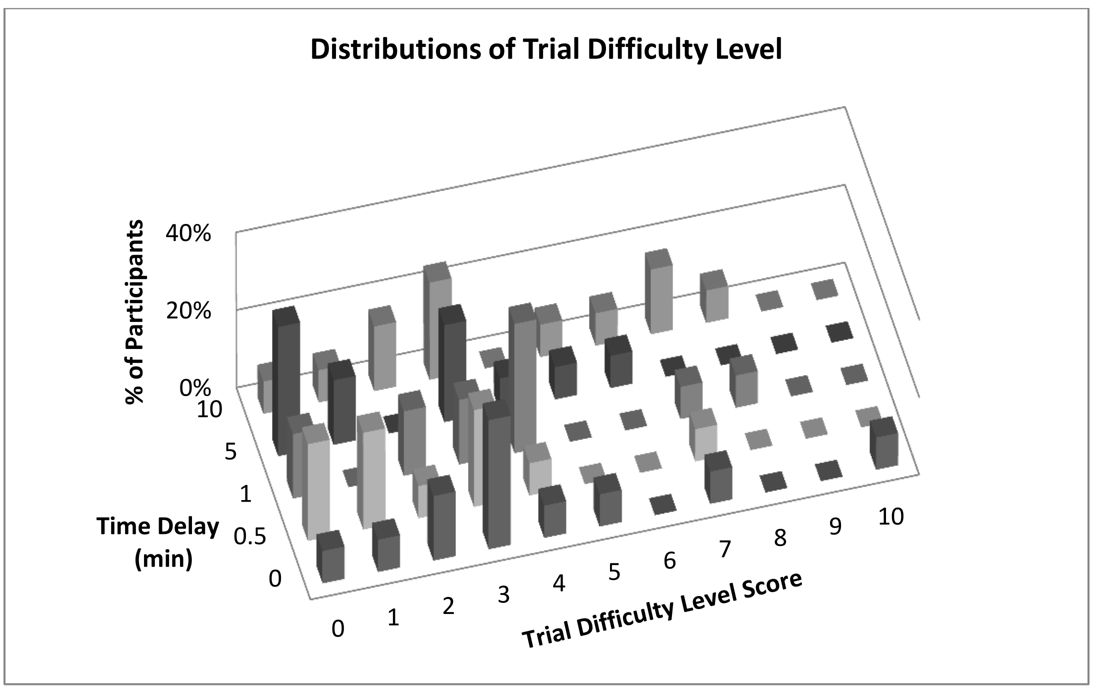
(a)


Distributions of Communication Effectiveness
60%
40%
20%
0%
% of Participants
10
5
1
0.5
0
Time Delay (min)
0 1 2 3 4 5 6 7 8 9 10
Communication Effectiveness Score

(b)

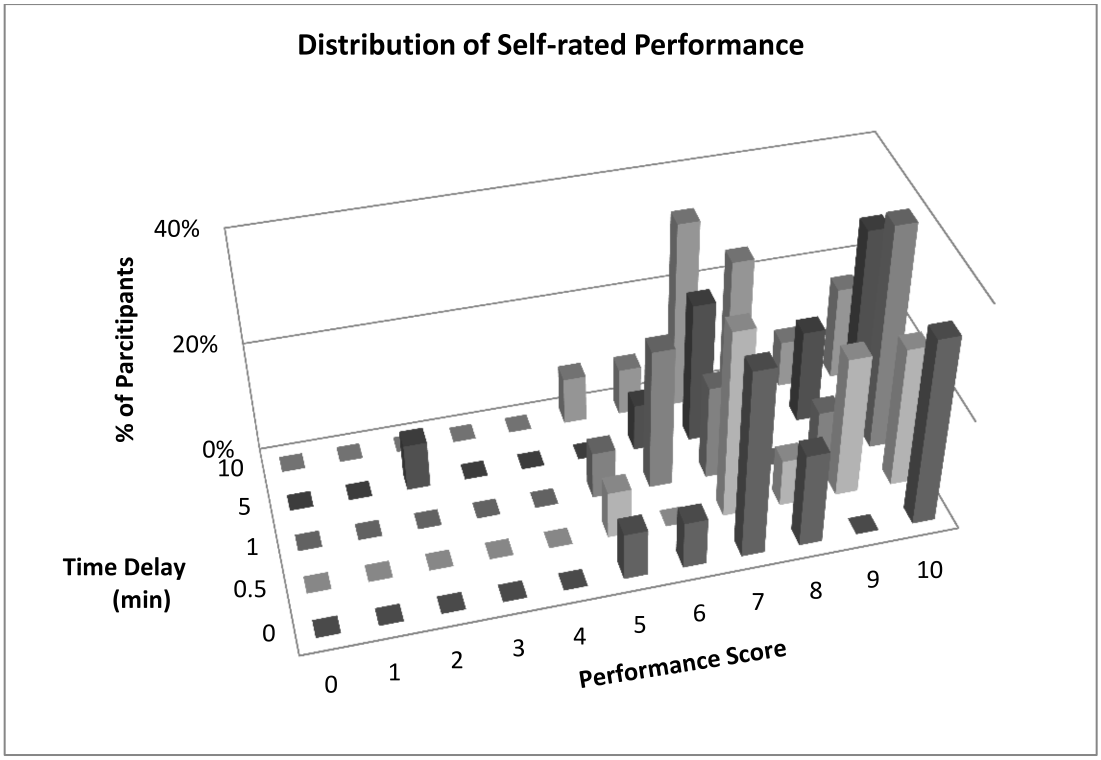


(c)



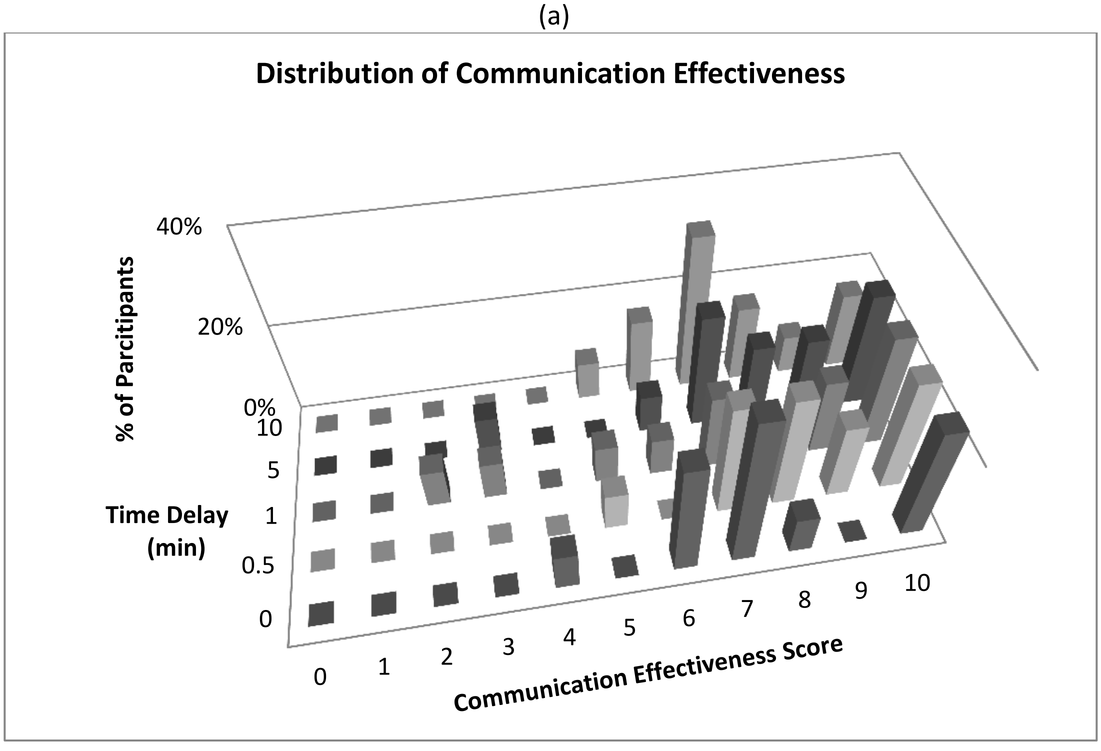
(d)

Figure 4-5. Distributions of the Four Subjective Measurements (Controller Data)



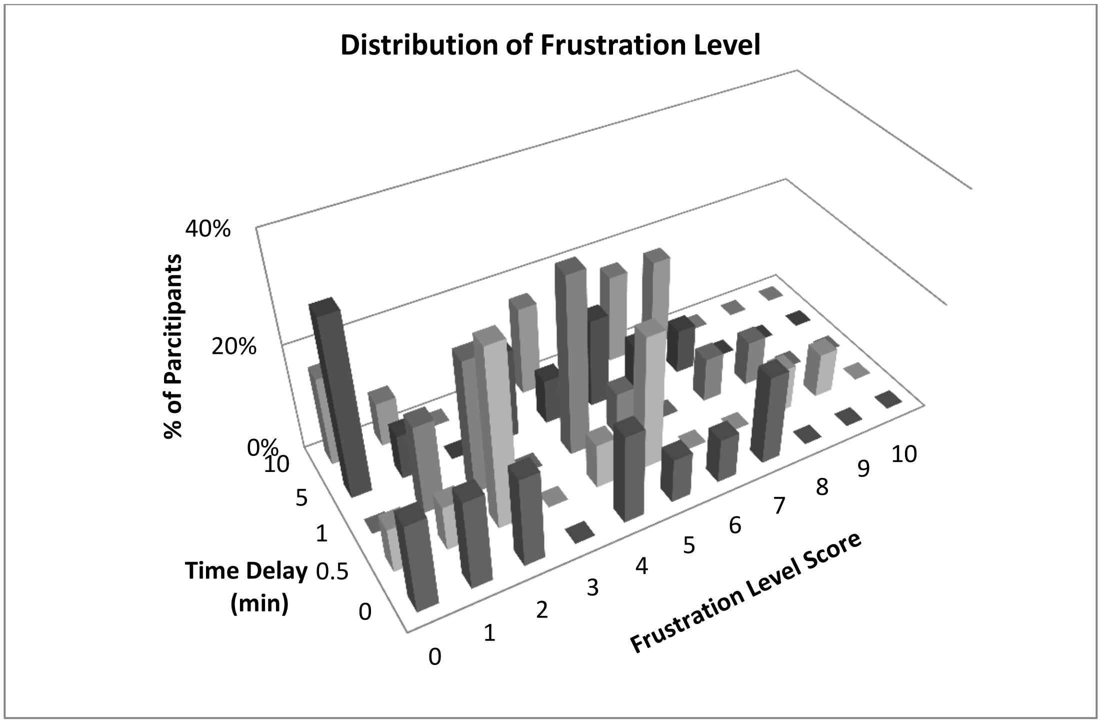
Distribution of Self-rated Performance
40%
20%
0%
% of Parcitipants
10
5
1
0.5
0
Time Delay (min)
0
1
2
3
4
5
6
7
8
9
10
Performance Score

(a)

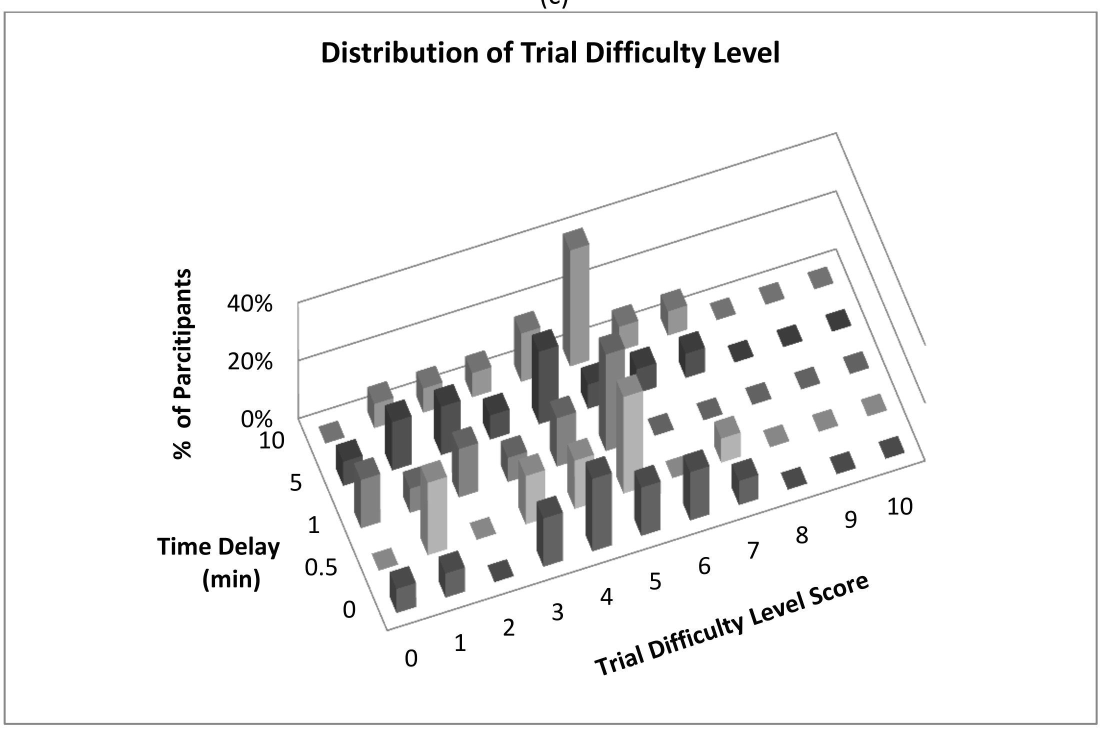


Distribution of Communication Effectiveness
40%
20%
0%
% of Parcitipants
10
5
1
0.5
0
Time Delay (min)
0
1
2
3
4
5
6
7
8
9
10
Communication Effectiveness Score

(b)



(c)



(d)

Figure 4-6. Distributions of the Four Subjective Measurements (Pilot Data)

In order to better understand the relationship between the rating scores and the time delay, Friedman test was used to test if time delay has a statistically significant effect on these four subjective measurements. The reason for choosing the Friedman test is because the self-assessed scores are ordinal rather than interval. The test was conducted on controller and pilot participants' results respectively. The results are shown in Table 4-7.

Table 4-7: Friedman Test Results of Four Measurements

Measurement	Results	
	Controller	Pilot
Performance	$\chi^2(4) = 9.670, p = .046$	$\chi^2(4) = 2.124, p = .713$
Communication Effectiveness	$\chi^2(4) = 3.269, p = .514$	$\chi^2(4) = 2.522, p = .641$
Frustration Level	$\chi^2(4) = 8.834, p = .065$	$\chi^2(4) = 5.200, p = .267$
Level of Difficulty	$\chi^2(4) = 7.116, p = .130$	$\chi^2(4) = 7.073, p = .132$

As demonstrated in the table, the delay only has a statistically significant effect on controller participants' performance. A post hoc analysis with Wilcoxon signed-rank test was conducted with a Bonferroni correction applied. However, none of the follow-up comparisons were significant. This was due to the limitations of the sample size.

4.4 Discussion & Implications

There are several key implications from the results presented above. Delay time had an observable but not statistically significant effect on the participants' communication, performance, frustration level and perceived trial difficulty level. Long delays on the order of 10 minutes produced increased frustration and need for clarifications, and longer conflict resolution times. While 10 minutes is an unrealistic delay time for distributing object locations, it is on the same order of the time delays that are experienced when communicating about weather in current operations.

It was obvious that there is a consistency between the subjective data and objective data. Regardless of who has the most updated information, an increase of time delay would increase the time for communication and number of clarification statements, as well as leading to more frustration and less effective communication. There is also a consistency between controller and pilot participants' results (Figure 4-5 and Figure 4-6).

Although there were observable trends of the time delay effect on subjective measurements, no meaningful statistical significance was found. This result is different from the original hypothesis, which was that there was a causal relationship between time delay and operators' performance, communication effectiveness, frustration level and perceived trial difficulty level. However, the result is insightful in regard of systems design - the delay should be avoided as much as possible to better facilitate every operator's communication and task performance.

During the study, it was observed that the characters of the participants could also affect the final resolution of the conflict. In a pair where one participant takes more initiatives and is more vocal in expressing his/her opinions than the other one, this participant tends to be the dominant leader in the conversation. It would lead to the result that the resolution would be largely based on the dominant participant's recommendations.

There are several limitations to the study that restrict the implications that can be drawn, particularly for shorter delay times; however, these limitations can be addressed in future studies. Effects of differential time delays at the shorter durations were not as pronounced due to the artificial flaw in the scenario design, where the potential conflicts in Delay 0.5 scenarios were not as pressing as other scenarios. It is also thought that the use of static pictures eliminated important time pressure factors and did not present participants with a dynamic vision of the situation. The lack of motion could have affected the participants' ability to make precise predictions and decisions and masked differences in the effects of shorter delay times.

4.5 Future Work

Future work could consider using different update rates for different objects in the airspace. In this study, asynchronous information on UAS, birds, and weather were all updated at the same rate. In operations, however, the dynamics of these objects are not exactly the same and there may be advantages to having different update rates. For slow-moving objects, such as weather and broad areas of bird activity, rapid updates may be perceived as unnecessary as reducing update rate is one method of reducing costs and bandwidth requirements.

Future research will as well narrow the delay window to a smaller range that is more likely to represent the time delays that would be observed for transmitting object position data. The study will be repeated in a part-task dynamic simulation environment and it is hoped that professional controllers and pilots can be recruited.

4.6 Chapter Summary

Chapter 4 presents an initial experiment as a first attempt to understand the possible effect of asynchronous information on communication, where naïve participants were shown static pictures of a radar surveillance display/navigation display. Both subjective and objective measurements were collected and analyzed. Hypotheses 1 and 2 were not fully verified. While, descriptively, an increase in time delay caused more time to be spent on communication, no statistically significant difference was found. However, there was a significant difference in the number of clarification statements depending on the delay intervals, which was found between Delay 0.5 and 10 minutes. The descriptive analysis of subjective measures suggested that as the time delay increases, the participants feel more frustrated and find the trial more difficult. Visual inspection also suggests that an increase in time delay would result in worse performance and communication effectiveness. However, it was found that such an effect was not statistically significant. Therefore, Hypothesis 3 was not fully verified. Limitations of the study have been also identified, and there is future research need to recruit subject matter experts for a more dynamic and advanced study.

Chapter 5
Survey on Information Level of Detail

One of the challenges identified in Chapter 3 – displayed information level of detail – is closely related with operators' decision-making while encountering non-cooperative objects. There are 3 aspects of the challenge that were selected for in depth investigation:

1) what level of detailed information do the operators need? (i.e. do the operators need to know the information about every single bird in a flock?);
2) the limits of current technologies in presenting the information; and
3) the range of operators' desired information (i.e. what are the categories of information that operators need?).

Among the different types of non-cooperative objects, UAS, as discussed in Chapter 2, is a relatively new class of aircraft and is especially in need of more research in order to provide operational guidelines (FAA, 2013). Therefore, the research question was to understand, from pilots and controllers' point of view, what information about UAS they require, and how this information should be displayed to effectively support operators' task performance. In order to explore the research question, an online survey study was designed for pilots and air traffic controllers.

The remainder of the chapter discusses the overall survey structure and objectives, survey implementation and analysis results.

5.1 Goal

The primary goal of the survey was to develop a better understanding of what information pilots and controllers currently have access to about UAS operation in controlled airspace, and what information they will need to have access to should additional UAS (both cooperative and non-cooperative) be introduced into the system. A wide range of types of UAS vehicles were of interest, including the potential of multiple UAS operating within controlled airspace as a group (*swarm/formation of UAS*). In addition, the survey has the secondary goals of testing potential means of displaying swarms/formations to pilots (on navigational displays) and controllers (on radar displays), and understanding better controller and pilot tolerances for time-delays when having access to common surveillance data.

5.2 Survey Design

5.2.1 Survey Design process

The development of the survey occurred in five stages. The first stage was identifying human factors challenges by reviewing a model of the future operational environment (Yuan, Histon, Waslander, Dizaji, & Schneider, 2012). The second stage comprised development of specific areas of interest in consultation with subject matter experts. Discussions were held with air traffic control and flight professionals from the International Civil Aviation Organization (ICAO) in order to generate and validate open research issues and develop an initial set of survey questions.

These issues and potential questions were revised with the help and guidance of industrial partners and other academics (the third stage). Multiple iterations in this stage played a key role in refining the areas of most interest and applicability, and identified additional areas of interest broadening the scope of the survey.

The output of the previous three stages was a complete draft of the survey. In a fourth stage, the draft was shared with a few additional air traffic controllers and pilots who were not engaged in previous stages. They provided feedback on appropriateness of domain-specific wording and graphics, understandability of the instructions, and provided better estimates of the time-to-complete.

The fifth and final stage was distribution and data collection. The survey was developed using SurveyGizmo, an online tool. It was estimated to take 45 minutes to complete. The full sets of surveys are illustrated in Appendix C and D. The survey was distributed to both air traffic controllers (enroute / terminal and tower) and pilots (commercial / general aviation/ student) with wording and images adjusted to be appropriate for the different participant groups (pilot and controller). Section 5.3 discusses the recruitment of the participants and survey distribution in detail.

5.2.2 Final Survey

This section provides the details of the survey design, including the objectives of each survey section and how each question was designed to accomplish the objectives. Notation is used to cross reference specific question numbers in the appendices. For instance, 10^{C} / 9^{P} means it is Question 10 in controller survey and Question 9 in pilot survey; $52^{C/P}$ refers to Question 52 in both controller and pilot survey.

Overall, the survey is organized into six sections:

1. Operators' Previous Experience with UAS;
2. Information Availability and Display Needs for Individual UAS or Formation of UAS with the Same Dynamic;
3. Information Needs for Formation of UAS with Various Dynamics;
4. Presentation of Formation/Swarms of UAS,
5. Communication Ambiguity
6. Information Intermittency.

Section 5.2.2.1 to Section 5.2.2.6 discuss the survey design and objectives in detail.

5.2.2.1 Section 1: Operators' Experience with UAS

The objective of Section 1 was to gather data on controller and pilot experiences with UAS, either operating singly or in a formation, and to identify controller and pilot perceptions of the limits, challenges and needed improvements for existing surveillance sources. In order to meet these objectives, four questions were developed (see Appendix C, Questions $8^{C/P}$-$11^{C/P}$).

Specifically, Questions $8^{C/P}$ and $9^{C/P}$ aimed to understand the current challenges of primary radar (controllers) / surveillance systems (pilots) and identify most desired improvements in the next generation primary radar system / next generation collision avoidance display. Question $10^{C/P}$ was a branch point to separate participants with UAS experience from the ones without. Participants were asked to indicate their experiences with the four possible categories of UAS (combination of cooperative / non-cooperative and operating singly / in formation). For participants who indicated they have had UAS experience in Question $10^{C/P}$, a follow on question - Question $11^{C/P}$ - asked where in their airspace the UAS were operating / where in their flight experience they have seen UAS operating.

5.2.2.2 Section 2: Information Needs and Availability for Individual UAS or Formation of UAS With the Same Dynamic

Having the information from Section 1 of UAS encountering experiences, the objectives of Section 2 were to 1) identify the operators' information needs and availability for handling individually operated UAS or formation of UAS, and 2) identify potential challenges in interpreting the UAS information. Formation flight is defined as “more than one aircraft operating as a single aircraft with regard to navigation and position reporting” (ICAO, 2005). Formations are sometimes also referred to as swarms in the literature. In this section, formation of UAS is considered having similar dynamics as an individual UAS where the individual UAS in the formation would move around in synchrony.

As described in the previous section, the participants were divided into two groups after $10^{C/P}$ – operators with experiences related to UAS and operators without experiences of encountering UAS. These two groups were assigned different paths in Section 2. Figure 5-1 shows the logic design of Section 2.

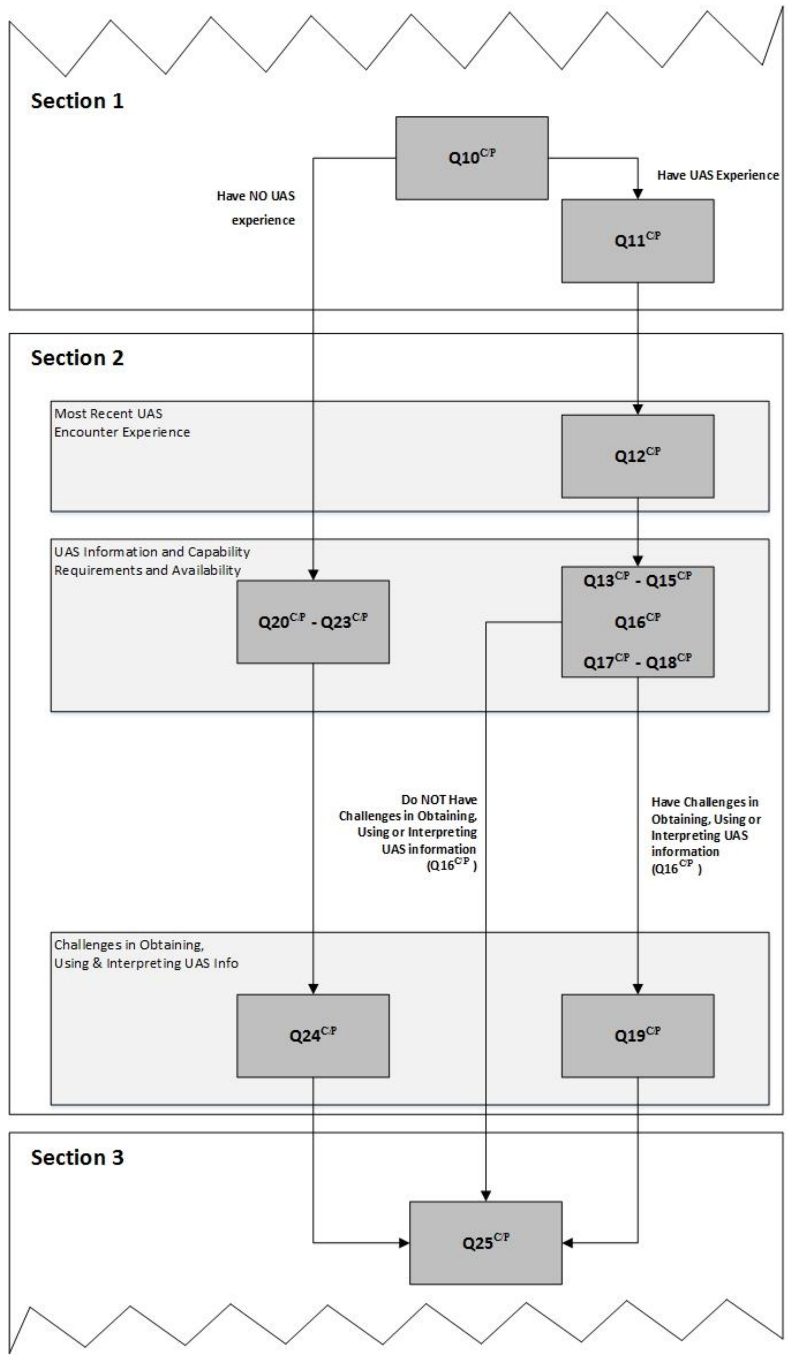


Figure 5-1. Question Logic of Section 2

For operators who have had experience handling UAS, Question $12^{C/P}$ asked the participants what category of UAS was involved in their most recent encounter, which was used to set the context for the following questions. The objective of Questions $13^{C/P}$ – $15^{C/P}$ and Questions $17^{C/P}$ – $18^{C/P}$ was to understand what information about the individual / formation of UAS states and capabilities they had during that encounter and if that information was sufficient for performing the control task. Question $16^{C/P}$ asked the participants if they have any challenges in obtaining, using and interpreting UAS information. If the answer were affirmative, the participants would be shown Question $19^{C/P}$, asking for up to the 3 most important challenges.

For operators who had never encountered situations involving UAS at all, they were presented with similar questions about UAS information requirements (including capabilities) (Questions $20^{C/P}$ – $23^{C/P}$) in an imaginary situation and asked to foresee 3 main challenges in obtaining, using and interpreting the UAS information (Question $24^{C/P}$).

5.2.2.3 Section 3: Information Needs for Formation of UAS with Various Dynamics

In certain situations, the individual aircraft in a formation may be moving quite randomly within the confines of an overall average group motion. Although there is a growing demand of UAS formation application, there is not much research of this operation form, and it is yet unclear what information about the formation is essential for pilots and controllers operating in the same airspace. Therefore, the objective of Section 3 was to assess if and how information needs are different if UAS are operating in a formation or swarm while its individual UAS have different dynamics.

In order to meet the objective, Questions $25^{C/P}$ – $27^{C/P}$ first aimed to understand operators' information needs for each and every individual UAS in a formation as well as for a lead UAS, which is the leader of a formation. For certain information, such as altitude and ground/air speed, it could vary across different individual UAS in a formation. As a result, Question $28^{C/P}$ asked the participants to identify their requirements of information that could be influenced by the dynamics of the formation. Lastly, Questions $29^{C/P}$ – $30^{C/P}$ asked the operators to consider the formation as whole and aimed to identify their requirements of information that is independent of individual UAS dynamics.

5.2.2.4 Section 4: Presentation of Formation/Swarms of UAS

The objectives of Section 4 were to 1) gather feedback on four different methods of presenting swarms of UAS with the goal of further understanding what information is required for decision making, and 2) to examine whether the complexity of a traffic situation or other factors influence preferences amongst the presentation types and information needs.

In order to meet the first objective, participants were first presented with the four presentations in close-up images, low and high traffic density situations respectively. The generation of the presentations was based on consulting certified air traffic controllers and pilots at ICAO.

The four types of presentations are described as below, and for each presentation, there were 4 questions:

1) A present position symbol and data-block is shown for each individual UAS in the swarm, and a single data-block is shown for the swarm as a whole (Questions $31^{C/P}$ – $34^{C/P}$);

2) A present position symbol for the position of a single "lead" UAS, and one data-block shown for the swarm as a whole (Questions $35^{C/P}$ – $38^{C/P}$);

3) A present position symbol is shown for each individual UAS in the swarm, and a single data block is shown for the swarm as a whole (Questions $39^{C/P}$ – $42^{C/P}$);

4) An outline circling all of the individual UAS in the swarm, and a single data-block shown for the swarm as a whole (Questions $43^{C/P}$ – $46^{C/P}$).

Question $31^{C/P}$, $35^{C/P}$, $39^{C/P}$, $43^{C/P}$ evaluated the effectiveness of the presentation in providing helpful information. In order to measure participants' standards for effectiveness, Question $32^{C/P}$, $36^{C/P}$, $40^{C/P}$, $44^{C/P}$ asked the participants to provide up to 3 key words / short phrases to describe their impression of such a display. Question $33^{C/P}$, $37^{C/P}$, $41^{C/P}$, $45^{C/P}$ then aimed to identify any missing information of the swarm on the display. Lastly, Question $34^{C/P}$, $38^{C/P}$, $42^{C/P}$, $46^{C/P}$ tried to understand how effective the presentations are in handling formation breakdown situation.

For the second objective, participants were asked to rank the presentation types in order of preference in both low ($47^{C/P}$) and high (49^{C}) traffic density situations respectively. Pilot participants were not asked to rank high traffic density situation, because pilots normally would zoom in / out on their display to adjust how many planes are shown when the environment gets busy. Both pilot and controller participants were also asked to provide any additional explanation or comments ($48^{C/P}$, 50^{C}). Controllers were asked to comment on any difference in their rankings based on the low and high traffic density situations (51^{C}).

5.2.2.5 Section 5: Communication Ambiguity

The objective of Section 5 was to follow-up on Yuan et al. (2012)'s work to understand better controller and pilot tolerances to asynchronous surveillance information. Asynchronous information was discussed in Chapter 4. It refers to the possibility of two operators both having access to a common data source, but with a time delay meaning the information available at a given moment in time is not the same for both operators. The asynchrony would potentially increase the cognitive complexity and difficulty in pilot-controller communication (Yuan et al., 2012). Section 5 of the survey aimed to identify if there are potential challenges and advantages in sharing non-cooperative object information between controller and pilot, and to identify how information asynchrony affects the communication.

In order to achieve the objectives, participants were first asked to list up to three bullet points respectively for advantages (52^C / 49^P) and concerns (53^C / 50^P) if surveillance information about non-cooperative objects (i.e. birds) was shared directly with pilots/controllers.

The operators were then asked to consider a scenario of a final approach where the pilots' and controllers' displays of non-cooperative objects are not exactly the same. Controllers' display might show more or less up-to-date positions of the non-cooperative objects. Question 54^C / 51^P asked the operators 1) what an maximum acceptable time delay between the two's display can be, 2) if the answer in 1) depends on whose display is more updated, and 3) what the maximum difference in distance (in nautical miles) between the actual position of the non-cooperative objects and the position of the non-cooperative objects shown on their display. The answers help to visualize what an acceptable delay and a maximum difference in distance could be.

5.2.2.6 Section 6: Information Intermittency

Information intermittency is one of the human factors challenges identified in Chapter 3. The objective of Section 6 was to determine the frequency with which intermittency occurs in current operations, understand the limitations and challenges of current techniques in dealing with information intermittency, and identify any difference in how information intermittency for a UAS affect the operators as opposed to traditional piloted aircraft.

In order to meet the objectives, Questions 55^C / 52^P and 56^C / 53^P asked the participants how often they have observed the "intermittency effect" on an aircraft, and if they have ever seen such an effect with surveillance of UAS. If the participants indicated that they did not understand what intermittency means, they would be directly lead to the end of the survey, skipping the rest of the section.

For participants who have observed intermittency effect, Question 57^{C} / 54^{P} quantified the amount of time during which surveillance data is typically not available in intermittency. Question 58^{C} / 55^{P} and 59^{C} / 56^{P} asked the participants how satisfied they are with current technologies in handling the intermittency effect and what the most important challenges are.

Question 60^{C} / 57^{P} and 61^{C} / 58^{P} aimed to identify if there is a difference between handling intermittent UAS information and intermittent traditional manned aircraft information. These two questions are essentially the same but with slightly different wording for participants with and without experience observing intermittent UAS.

5.3 Survey Implementation

5.3.1 Participant Recruitment

The survey was distributed through personal contacts, bulletin boards, and existing academic and industrial relationships. It was also published on several websites and ATC/pilot forums. The forums and websites include LiveATC.net, stuckmic.com, pprune.org, theairlinewebsite.com, AVCanada.ca, ATCmonitor.com, airlinepilotforums.com and LinkedIn professional groups. Participation in the study was voluntary.

5.3.2 Data Collection

Survey data was collected between March 22^{nd}, 2013 and July 7^{th}, 2013, during which 116 and 111 responses were collected from professional air traffic controllers and pilots respectively (Table 5-1). For the purpose of the thesis, only complete responses were used for analyses. Verification of the responses was performed by checking the recorded answers of each completed response for consistency. It was ensured that there were no excessive blanks in the responses and inconsistent answers. Inconsistency appears when participants’ answers 1) in different parts of the survey contradict with each other, and / or 2) do not demonstrate their experience level as indicated at the beginning of the survey.

Table 5-1: Collected Survey Responses

Responses Status	Air Traffic Controllers	Pilots
Complete	51	51
Partial	64	59
Disqualified	1	1
Total	116	111

Due to the length of the complete survey, a branch point was included in the survey after Section 2. All of the participants would go through Section 2, and then they were randomly assigned to either Pathway A or B. Pathway A consists of Section 4 and 5, and Pathway B includes Section 3 and 6. The number of participants who completed the survey in each path is displayed in Table 5-2.

Table 5-2: Number of Participants in Each Path

	Controller		Pilot	
Pathway	A	B	A	B
# of Complete Responses	26	25	28	23

5.3.3 Demographic Information

As shown in Figure 5-2, over 30% of the 51 controller participants are over 50 years old. The majority of the participants were from North America and Europe. Around 50% of the participants have 21 or more years of professional experience as certified air traffic controllers. The top three most recent capacities of the participants' are Enroute specialty (35%), Terminal specialty (39%) and Tower specialty (27%).

Figure 5-3 presents the pilot participants' demographic information. Over 30% of the 51 pilot participants are between 30 to 39 years old. The majority of the participants were from North America and Europe. Over 50% of the participants hold air transport pilot certification. On average, the pilot participants have approximately 7,194 flight hours in total and 104 hours in the past 90 days.

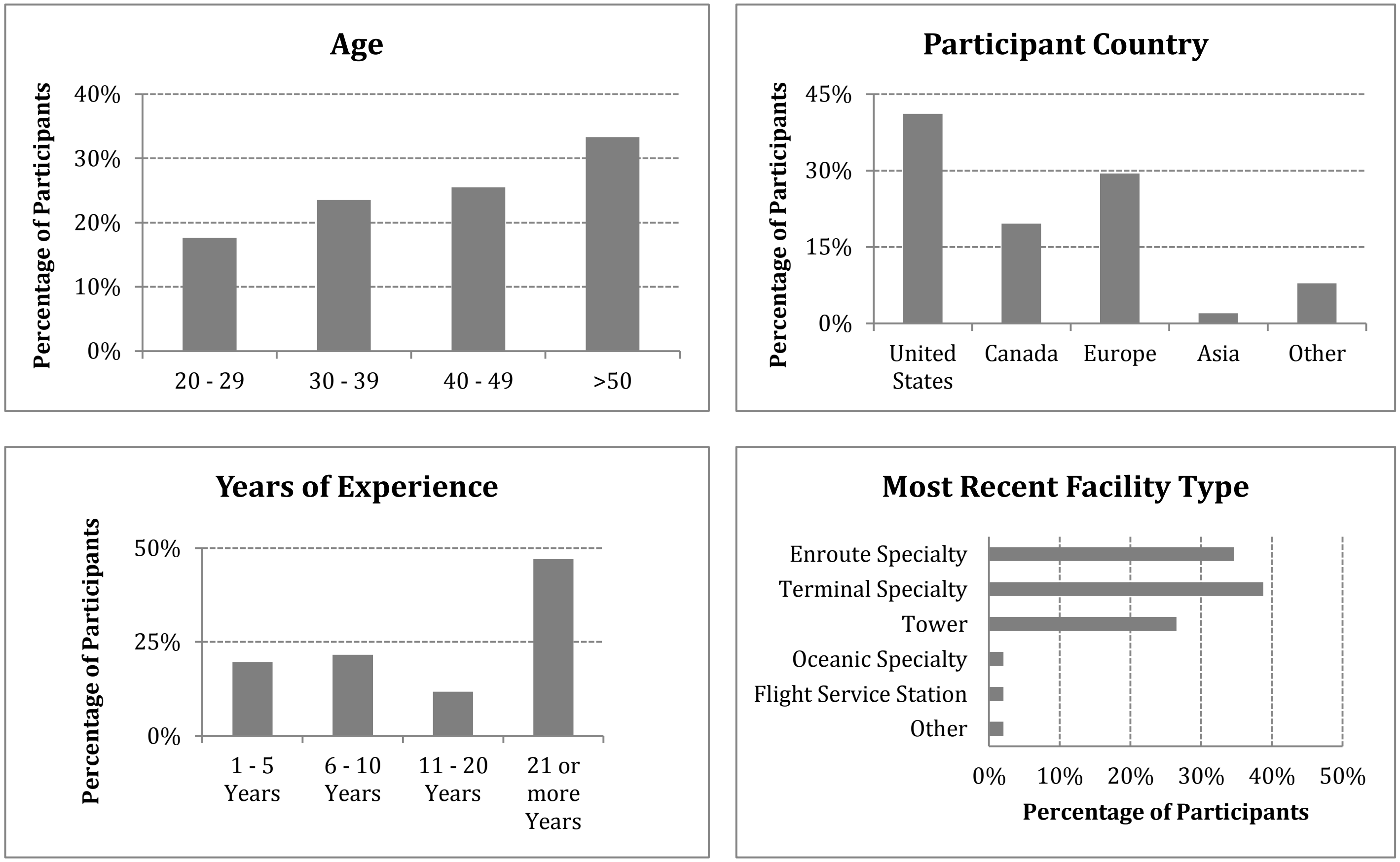


Figure 5-2. Air Traffic Controller Participants' Demographic Information

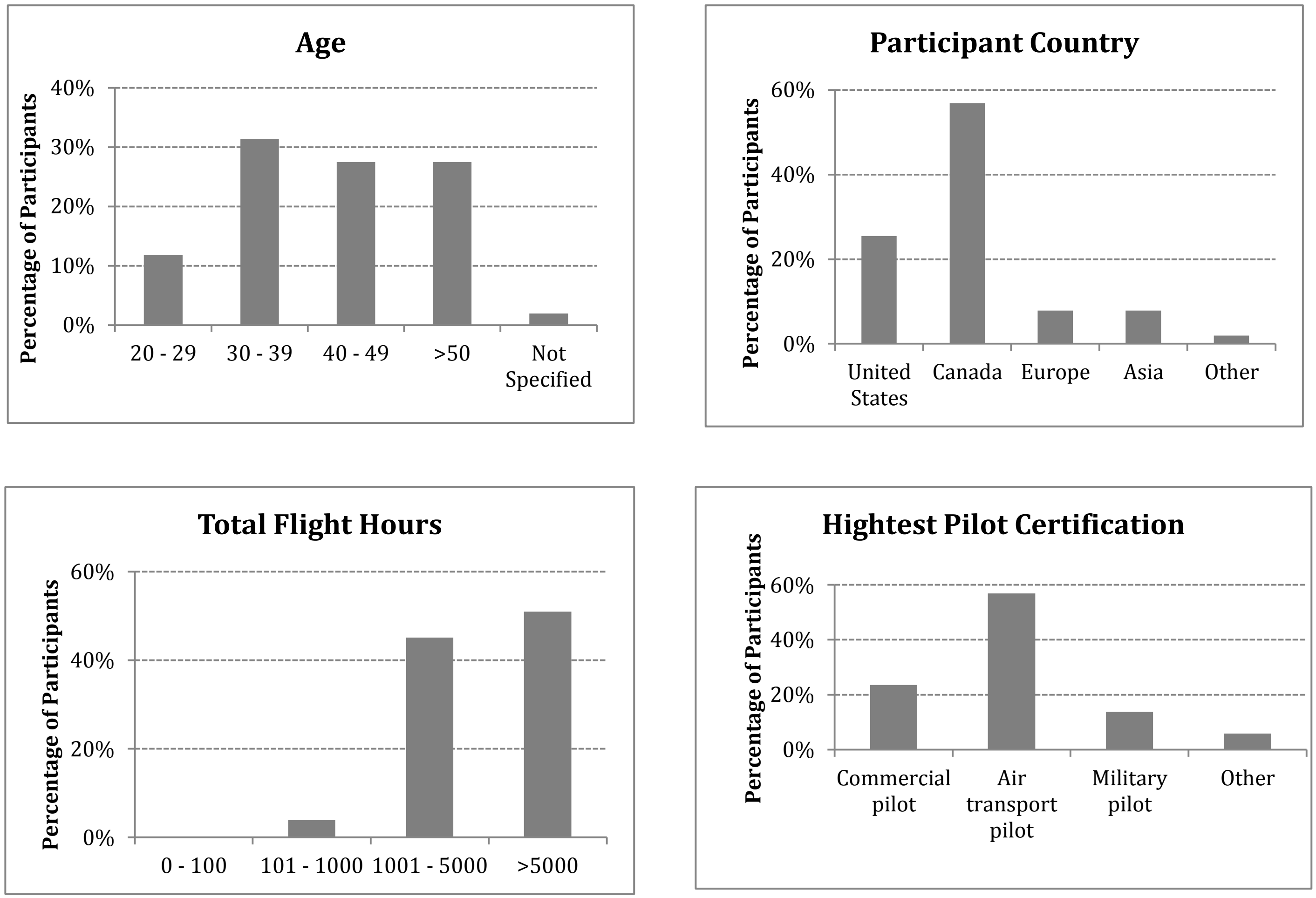


Figure 5-3. Pilot Participants' Demographic Information

5.4 Results

The survey covers a wide range of research questions. However, in the particular interest of the thesis, the following sections present the analyses of results of both pilots and air traffic controllers respectively and their experience with UAS (Survey Section 1), information availability and display needs for individual UAS or formation of UAS with the same dynamic (Survey Section 2), and communication with information asynchrony (Survey Section 5). The purposes of these three sections were previously discussed in Section 5.2.2.1, 5.2.2.2 and 5.2.2.6 of the thesis

5.4.1 Limitations and Improvements of Primary Radar / Surveillance Systems

In the first section of the survey, participants were asked to list up to 3 limitations of the current primary radar and 3 improvements they would like to see in the next generation radar surveillance systems.

5.4.1.1 Air Traffic Controllers

Based on the collected 125 comments of primary radar limitations, some common themes were extracted. For example, “low level coverage” and “altitude, aircraft below coverage” both indicated a limitation of the primary radar coverage. The common theme is then deemed as *radar coverage*. Table 5-3 illustrates the top 5 themes of primary radar limitations that are most frequently mentioned. It also lists examples of representative comments in each theme. The *other* category is comprised of 18 types of limitations that made up the 14% of the total comments.

The difference between *radar coverage* and *lack of information* is that *lack of information* refers to the situation where a target is detected, but no sufficient information is provided, whereas *radar coverage* simply indicates a target is not detected at all.

Similarly, 103 comments were collected for desired potential improvements to primary radar. Table 5-4 shows the top 5 features that needed to be improved along with example comments from the participants. The *other* category consists of 15 different types of improvements and represented 36% of the comments.

Table 5-3: Top 5 Limitations of Primary Radar (Controller)

Themes	Percentage of Comments	Sample Comments from Participants
Information accuracy	29%	• "false radar targets" • "erroneous targets" • "differentiating between ground clutter and low level airborne slow moving targets"
Radar coverage	24%	• "low level coverage" • "radar coverage" • "range"
Display Clutter	14%	• "background clutter" • "If scope is busy with flight data, it's harder to see primary targets"
Lack of information	11%	• "doesn't show heading" • "smaller aircraft not always visible" • "no data associated"
Weather situation	8%	• "weather capabilities" • "weather detection" • "no weather display"
Other (18)	14%	• "data input capabilities" • "replacement part availability" • "increased separation when on maintenance"

Table 5-4: Top 5 Desired Improvements to Primary Radar (Controller)

Themes	Percentage of Comments	Sample Comments from Participants
Improve accuracy	33%	• "make digitized (data) more accurate" • "better filtering" • "better radar returns"
Improve coverage	12%	• "better coverage" • "increased range at all altitudes" • "better low level coverage"
Provide more data	12%	• "altitude reporting" • "ability to see intent of airborne aircraft" • "improved ability to detect birds/other hazards"
Improve data integration and fusion	8%	• "integration of radar and ADS-B" • "satellite integrated with ground based radar" • "multi-radar source"
Declutter	5%	• "reduction of clutter" • "removal of wind farm returns"
Other (15)	36%	• "mode s improvement" • "less radar delay" • "make tracking easier"

5.4.1.2 Pilots

Similarly as controllers' analysis, common themes were extracted based on the 145 comments of limitations collected. Table 5-5 illustrates the top 5 themes of current surveillance systems limitations that are most frequently mentioned. It also demonstrates examples comments in each theme. In *alerting system*, NOTAM stands for a Notice to Airmen, which is a notice filed by aviation authority alerting pilots of potential hazards. *Other* category consists of 15 types of limitations that made up the 21% of the total comments.

Table 5-5: Top 5 Limitations of Surveillance Systems (Pilot)

Themes	Percentage of Comments	Original Comments from Participants
Detection capabilities	25%	• "very limited radar and electronic identification" • "radar contact (low RCS)" • "ground radar usually limited to secondary surveillance radar"
Visual acquisition of targets	19%	• "visual spotting" • "Objects that are between the sun and myself (sun glare)" • "visibility"
Communication	14%	• "subject to the controller having the time to notify you of it" • "communication" • "must be on the same frequency on the radio "
Lack of information	12%	• "lack of ATC awareness" • "traffic calls from ATC are based on track, not heading" • "My aircraft not equipped with TCAS"
Alerting system	9%	• "Info often buried in a slew of Notams and potentially missed" • "Buried deep in NOTAMS" • "NOTAM"
Other (14)	21%	• "Real time information" • "Planning Methods" • "Pilots not following procedures or using radio"

121 comments were collected for the potential improvements to be included in a next generation collision avoidance display. Table 5-6 demonstrates the top 5 features that needed to be improved along with example comments from the participants, with *enhanced technologies and detection capabilities* most needed. The *other* category consists of 13 different types of improvements making up 27% of the comments.

Table 5-6: Top 5 Desired Improvements to Collision Avoidance Display (Pilot)

Themes	Percentage of Comments	Original Comments from Participants
Enhanced technologies and detection capabilities	23%	• “power line detection” • “radar XSection enhancer” • “stationary/slow moving objects identification”
Improve alerting system	22%	• “ability to be warned” • “better notice to pilots when UAS in use”, “provide 'time to impact' based on current dynamics”
Improve information display	9%	• “change in symbols that would define either manned or unmanned” • “a next generation collision avoidance display should be a heads up display (HUD)”
Improve accuracy	9%	• “accuracy of position in display” • “accuracy” • “multi-target (>3) resolution capability”
Provide more information	9%	• “TCAS” • “along with existing TCAS information: target identification data, (type of object, speed, altitude, track, vertical speed)”
Other (13)	27%	• “more radar coverage” • “continue to advance training to keep pace with avionics development” • “reliable”

5.4.2 Operators’ Experience with UAS

In order to accurately map participants’ background in relation to UAS, the second section of the survey asked the participants to indicate if they have previous working / encountering experience with UAS (Question $10^{C/P}$), and, if they do, what type of UAS experience it was (Question $11^{C/P}$).

5.4.2.1 Air Traffic Controllers

If participants indicated they have never encountered any situation involving any of the 4 categories of UAS (cooperative individual UAS, cooperative formation of UAS, non-cooperative individual UAS and non-cooperative formation of UAS),, they were considered as inexperienced with UAS. As discussed in Section 5.2.2.1 (Survey Section 1), participants without UAS experience would be directed into non-experience stream, skip Question 11^{C} and answer Questions 20^{C} – 24^{C}. The definition of “experienced” air traffic controllers are the ones who:

1) have had UAS present in their airspace but it had no effect on operations;

2) have had UAS present in the airspace and it affected the control decisions but no separation services were provided to the UAS; and/or

3) have had UAS present in the airspace and separation services were provided between an aircraft under their control and the UAS.

Based on the literature review, it was expected that the majority of the participants would not have experiences related to UAS. Quite surprisingly, Figure 5-4 shows that close to 60% of the controller participants have previous experiences with UAS. The data is from a random sample of 51 participants, and observations in the sample are independent of each other. The error bars represent an exact confidence interval of 95% for binomial data. The confidence interval is calculated based on Pezzullo's (2009) exact binomial confidence intervals calculator.

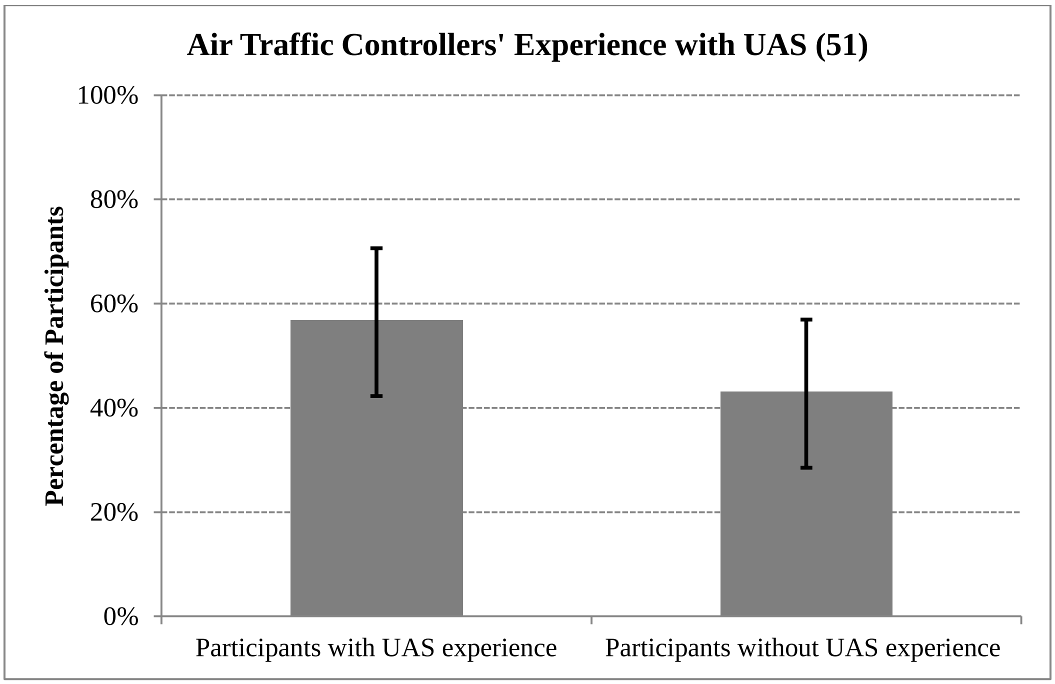


Figure 5-4. Air Traffic Controllers' Experience with UAS[4]

[4] The percentages in the graph represent the percentages of participants who answered this question. As described in Section 5.3.2 of the thesis, because of the different pathways through the survey, not all participants were presented with all questions.

Subsequently, the participants' specific UAS encounter experience was analyzed (Figure 5-5). The percentage is calculated based on the responses from 29 participants with UAS experience. As shown in the figure, participants have notably more experiences with individual UAS rather than formation of UAS. The most frequently occurring situation is air traffic controllers providing separation services for individual UAS (69%).

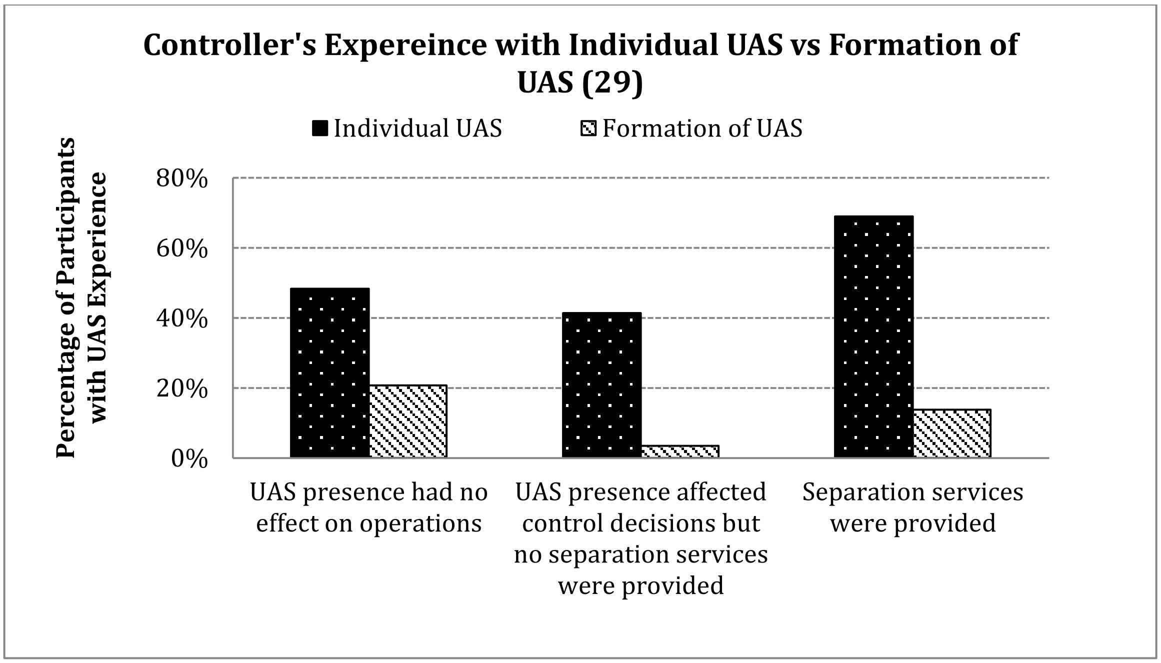


Figure 5-5. Controllers' Encounter Experience with Individual UAS vs. Formation of UAS

Given the specific interest of the thesis in individually operated UAS, an analysis of encounter experience regarding individual cooperative versus non-cooperative UAS was performed. As demonstrated in Figure 5-6, more participants have experienced encountering individual cooperative UAS than non-cooperative ones in general. In particular, around 38% and 14% of the 29 participants with UAS experience indicated that the presence of cooperative and non-cooperative UAS did not affect their routine operations. Most often, however, approximately 62% and 24% of the 29 participants with UAS experience provided separation service to individual cooperative UAS and non-cooperative UAS respectively. The number of participants who provided separation service to non-cooperative UAS seems unusual. However, after reviewing the responses of those participants who indicated they had provided separation services, the value presented does reflect the experiences of the controllers who responded to the survey. Possible explanations for the phenomenon could be that the controllers are considering the provision of separation services to the manned aircraft that are involved in the encounter instead of the non-cooperative UAS.

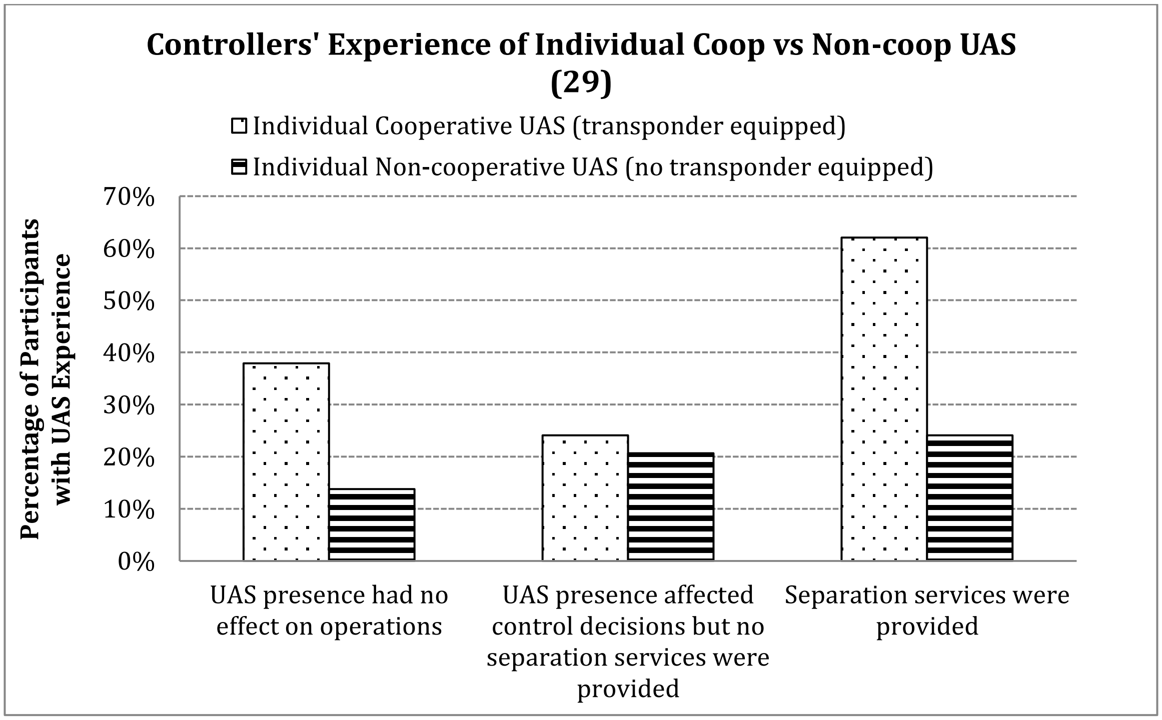


Figure 5-6. Controllers' Encounter Experience of Individual Coop vs. Non-coop UAS[5]

Participants were also asked to indicate the location where they have observed UAS operating in their airspace. Figure 5-7 suggested that, for the 29 participants who have had UAS encounter experience, 62% of them have seen individual cooperative UAS operating in low traffic density regions, and 28% have seen individual non-cooperative UAS operating in designated UAS operation airspace. It should also be noted that around 55% and 22% of the 29 participants with UAS experience have experienced situations where individual cooperative and non-cooperative UAS were in close proximity to the standard flows of aircraft.

[5] The total number of participants who have had experience with one category of UAS in certain situation does not add up to 100%, because one participant can select multiple answers to the question.

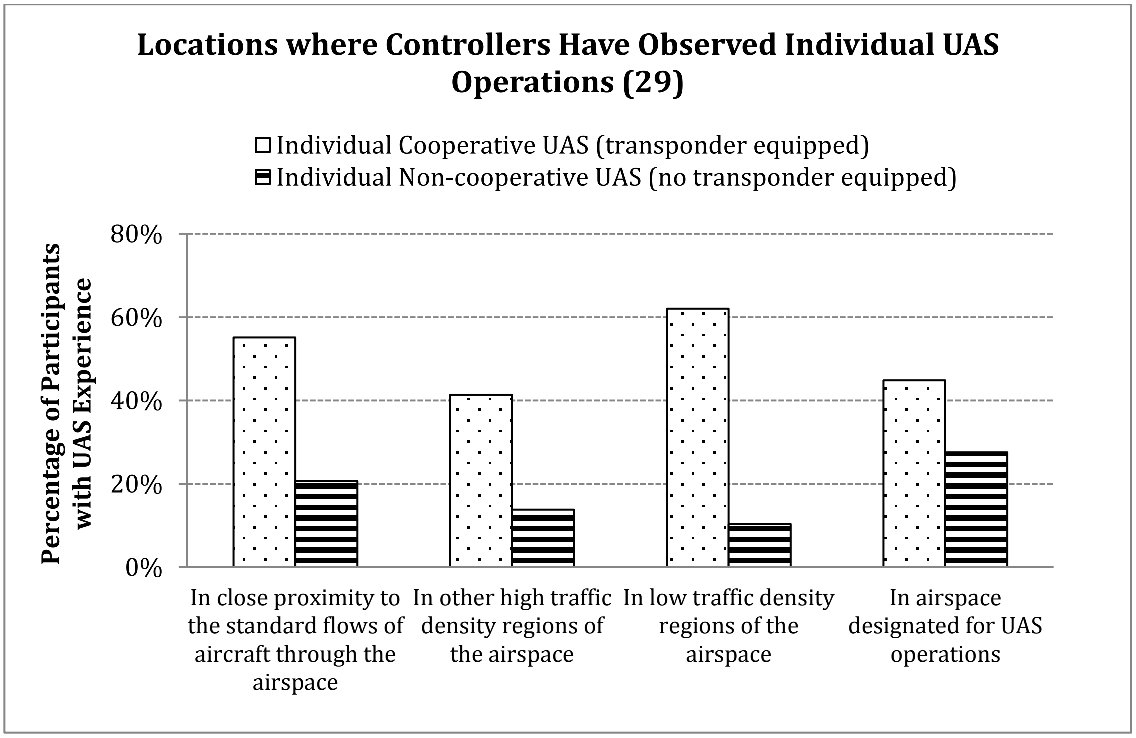


Figure 5-7. Locations where Controllers Have Observed Individual UAS Operations

A comparison of frequency of UAS operation locations is shown in Table 5-7. The most frequently operated location of individual UAS operation is different for cooperative and non-cooperative UAS. Cooperative UAS tend to be operated in low traffic density regions, whereas non-cooperative UAS are mainly operated in designated airspace.

Table 5-7: Frequency of Location of Individual UAS Operations (Controller)

Frequency of Location of Operations	Category of UAS	
	Individual cooperative UAS	Individual non-cooperative UAS
Highest	In low traffic density regions of the airspace	In airspace designated for UAS operations
↓	In close proximity to the standard flows of aircraft through the airspace	In close proximity to the standard flows of aircraft through the airspace
↓	In airspace designated for UAS operations	In other higher traffic density regions of the airspace
Lowest	In other higher traffic density regions of the airspace	In low traffic density regions of the airspace

5.4.2.2 Pilots

In addition to the results of the controller experiences with UAS presented above, pilot experiences with UAS were also collected and analyzed. The definition of "experienced" pilots is the ones who:

1) have discussed with other pilots about their experience maneuvering around UAS;
2) have been aware of the presence of UAS presence at a close range to me;
3) had to alter course of their aircraft while taking into consideration the presence of UAS; and/or
4) have collided with UAS.

If pilot participants indicated they have never encountered any situation involving any of the 4 categories of UAS (cooperative individual UAS, cooperative formation of UAS, non-cooperative individual UAS and non-cooperative formation of UAS), they were considered as inexperienced with UAS. Slightly different from controller participants' result, as illustrated in Figure 5-8, there are fewer pilots who have encountered UAS (42%) than the ones who have not (58%). The data is from a random sample of 48 participants, and observations in the sample are independent of each other. The error bars represent an exact confidence interval of 95% for binomial data.

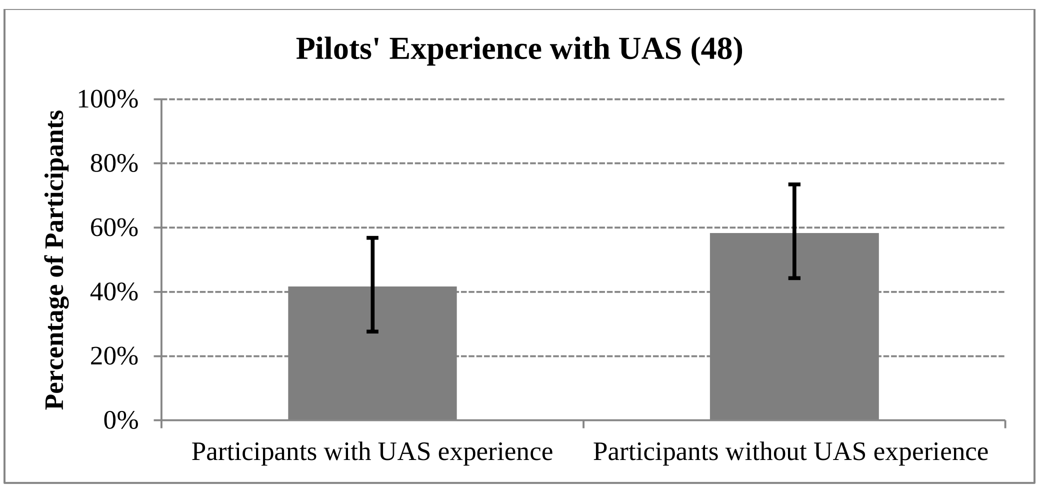


Figure 5-8. Pilots' Experience with UAS[6]

[6] The percentages in the graph represent the percentages of participants who answered this question. As described in Section 5.3.2 of the thesis, because of the different pathways through the survey, not all participants were presented with all questions.

As shown in Figure 5-9, participants have notably more experiences with individual UAS rather than formation of UAS except in the collision situation. While UAS collision incidents / accidents are relatively rare, about 30% of the 20 participants with UAS experience have been directly affected by the presence of individual UAS as well as discussed with other pilots about their maneuver experience around UAS.

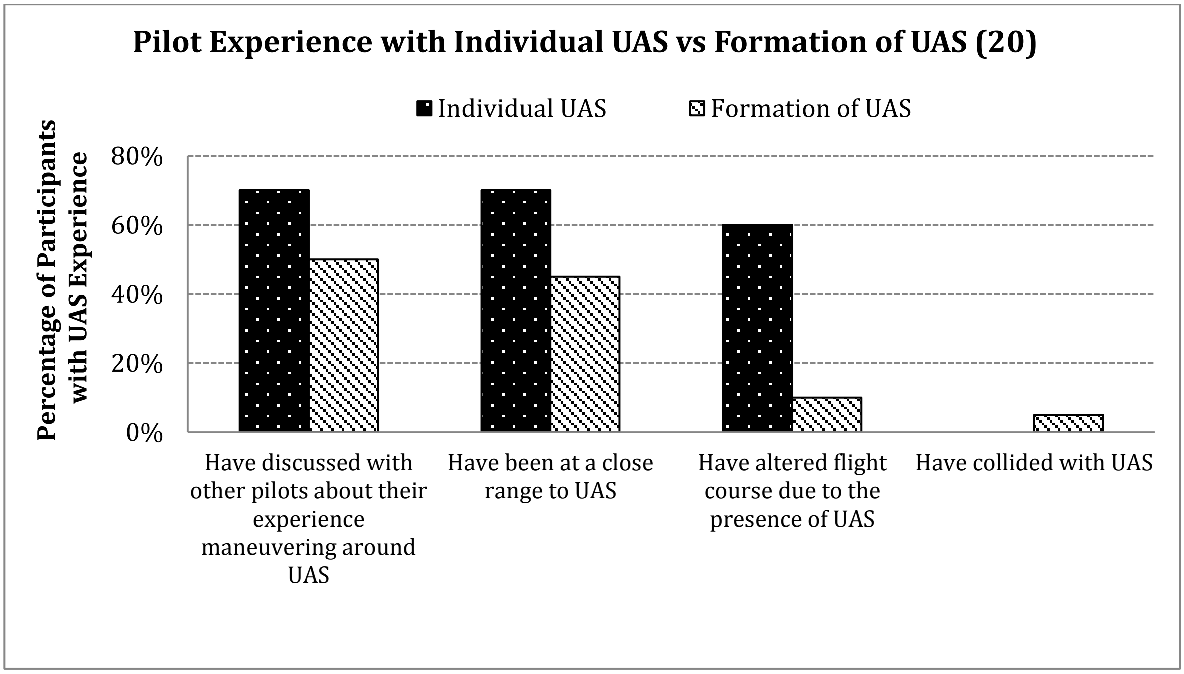


Figure 5-9. Pilot Experience with Individual UAS vs. Formation of UAS

Given the specific interest of the thesis in individually operated UAS, an analysis of encounter experience regarding individual cooperative versus non-cooperative UAS was performed. As demonstrated in Figure 5-10, the rate of encounters with individual UAS is the same for cooperative and non-cooperative UAS.

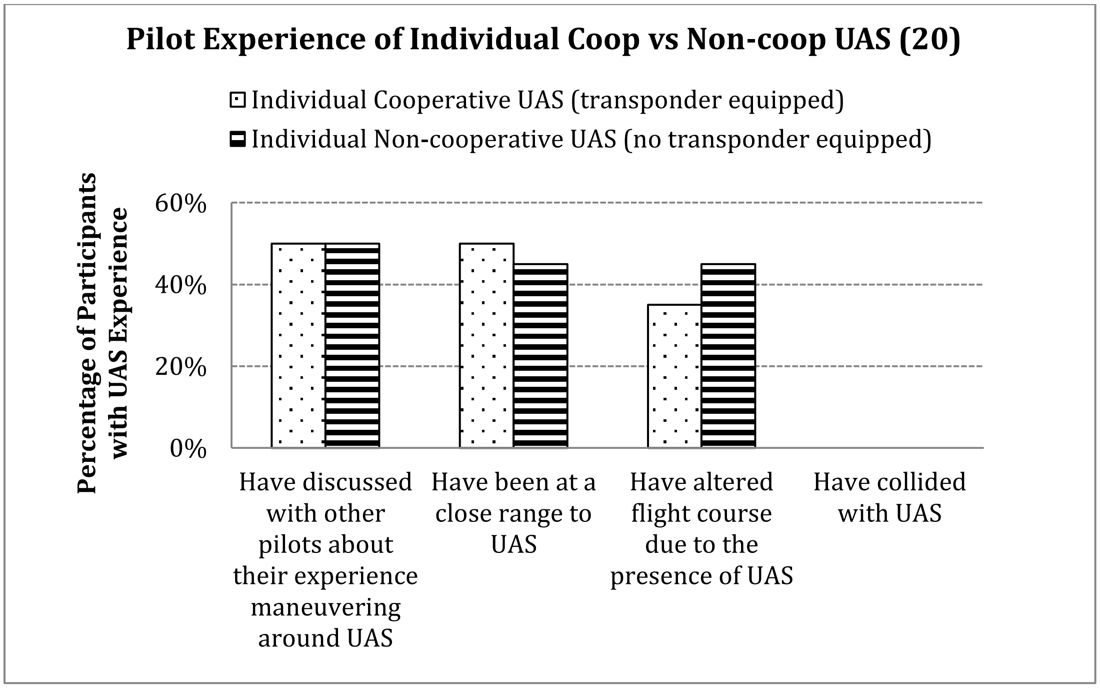


Figure 5-10. Pilot Experience of Individual Coop vs. Non-coop UAS

Participants were also asked to indicate the location where they have observed UAS operating. Figure 5-11 suggested that the main UAS operation area is not their designated airspace. Only about 35% and 25% of the 20 participants with UAS experience, who have had UAS experience, have seen individual cooperative and non-cooperative UAS operating in designated UAS operation area.

Participants also have seen individual cooperative UAS in more places than individual non-cooperative UAS. Fifty-five percent of the 20 participants with UAS experience have seen individual cooperative UAS operating in a close range to manned aircraft, and 45% have seen individual non-cooperative UAS operate in a close range to manned aircraft as well as in designated UAS operation airspace. No individual non-cooperative UAS has been seen operating in the visual flight rules (VFR) airfield traffic pattern or on approach in controlled airspace.

A comparison of the frequency of individual UAS operation location is shown in Table 5-8. Quite surprisingly, the possible location of individual UAS presence is the same for individual cooperative and non-cooperative UAS.

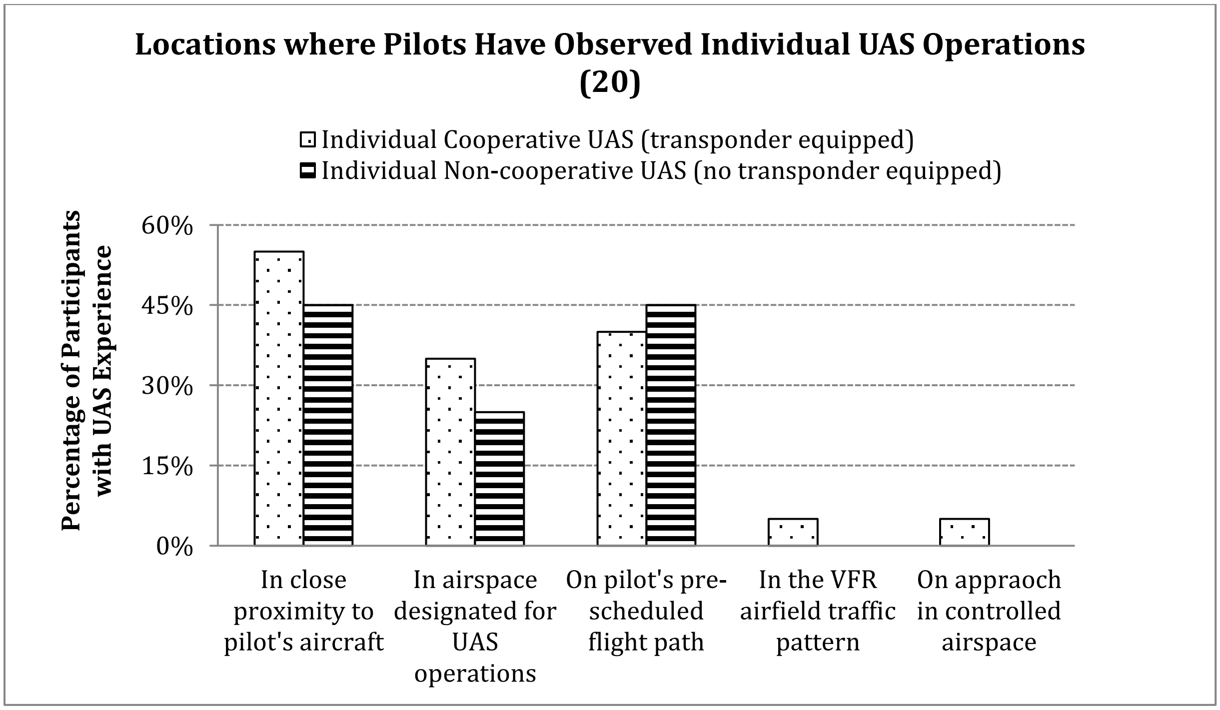


Figure 5-11. Locations where Pilots Have Observed Individual UAS Operations

Table 5-8: Frequency of Location of Individual UAS Operation (Pilot)

<table>
<tr><th rowspan="2">Frequency of Location of Operation</th><th colspan="4">Category of UAS</th></tr>
<tr><th colspan="2">Individual cooperative UAS</th><th colspan="2">Individual non-cooperative UAS</th></tr>
<tr><td rowspan="4">Highest
↓
Lowest</td><td colspan="2">In close proximity to pilot’s aircraft</td><td colspan="2">In close proximity to pilot’s aircraft</td></tr>
<tr><td colspan="2">On pilot’s pre-scheduled flight path</td><td colspan="2">On pilot’s pre-scheduled flight path</td></tr>
<tr><td colspan="2">In airspace designated for UAS operations</td><td colspan="2">In airspace designated for UAS operations</td></tr>
<tr><td>In the VFR airfield traffic patter</td><td>On approach in controlled airspace</td><td>In the VFR airfield traffic patter</td><td>On approach in controlled airspace</td></tr>
</table>

5.4.3 Information Needs & Information Availability for UAS

Certain information is critical for pilots and controllers to successfully perform their tasks of maintaining separation of aircraft and monitoring flight status. For instance, air traffic controllers need to know the altitudes of aircraft in their controlled airspace in order to detect potential collisions and develop resolution strategies. Pilots, similarly, need the information of other aircraft's altitudes in order to prevent collisions. In terms of UAS operations, however, it is still unclear what the proper protocols should be and what information about UAS in particular is crucial to operators' task performance.

In order to understand operators' information requirements and availabilities, the second section of the survey continues the investigation. Specifically, participants with previous UAS experience were asked to indicate what information was needed and available to them during the most recent UAS presence ($13^{C/P}$ – $18^{C/P}$). Participants without UAS experience were asked to think of information that would be helpful in handling a potential UAS presence in their airspace ($20^{C/P}$ – $23^{C/P}$).

5.4.3.1 Air Traffic Controllers

Figure 5-12 presents an overview of controllers' information needs, which are broken down to "information required", "information not required but helpful" and "information not required." The percentages were calculated based on the 51 complete responses, including participants both with and without UAS experience. The questions in this section did not differentiate between cooperative and non-cooperative UAS.

As demonstrated in Figure 5-12, *current altitude* of a UAS is the information identified as being most needed, with not a single participant stating that it should not be required. In addition, *planned maneuvers of UAS*, *type of communication link*, *UAS current track* and *current ground speed* are also listed in the top 5 most important information types.

However, not all of the required information is available in every situation. For instance, the primary radar might be unable to provide the altitude of a UAS due to its small size or other false returns from the background.

For the 28 controller participants who have UAS experience, Questions 13^{C} – 15^{C} asked them which of the pieces of information was available in their last UAS encounter. Figure 5-13 presents these information's availabilities during operation. It can be seen that only 71% of the 28 participants with UAS experience indicated that the information of *current altitude* was immediately available.

Additional analysis was performed to identify the relationship between information availability and the perceived need for that information during operations. The analysis contrasted the percentage of participants who said information was required with the percentage of participants who said the same information was available. This can give an indication of where current system design stands. Therefore, $\Delta^{C\ Available/Required}$ was calculated where:

$$\Delta^{C\ Available/Required} = \% \ of\ participants\ with\ UAS\ experience\ reporting\ information\ was\ required(\%) - \% \ of\ participants\ with\ UAS\ experience\ reporting\ information\ was\ available(\%)$$

This is interpreted as follows:

When $\Delta^{C\ Available/Required} > 0$, the information is required but not available;

When $\Delta^{C\ Available/Required} < 0$, the information is available but not required;

When $\Delta^{C\ Available/Required} = 0$, the information is required and is available.

The delta combines the results shown in Figure 5-12 and 5-13, and Figure 5-14 shows the final results. The limitation of this method is that it aggregates the numbers across different participants on required and available information, when it would be most beneficial to compare at individual participant level. However, this is a first step of understanding the information need and availability.

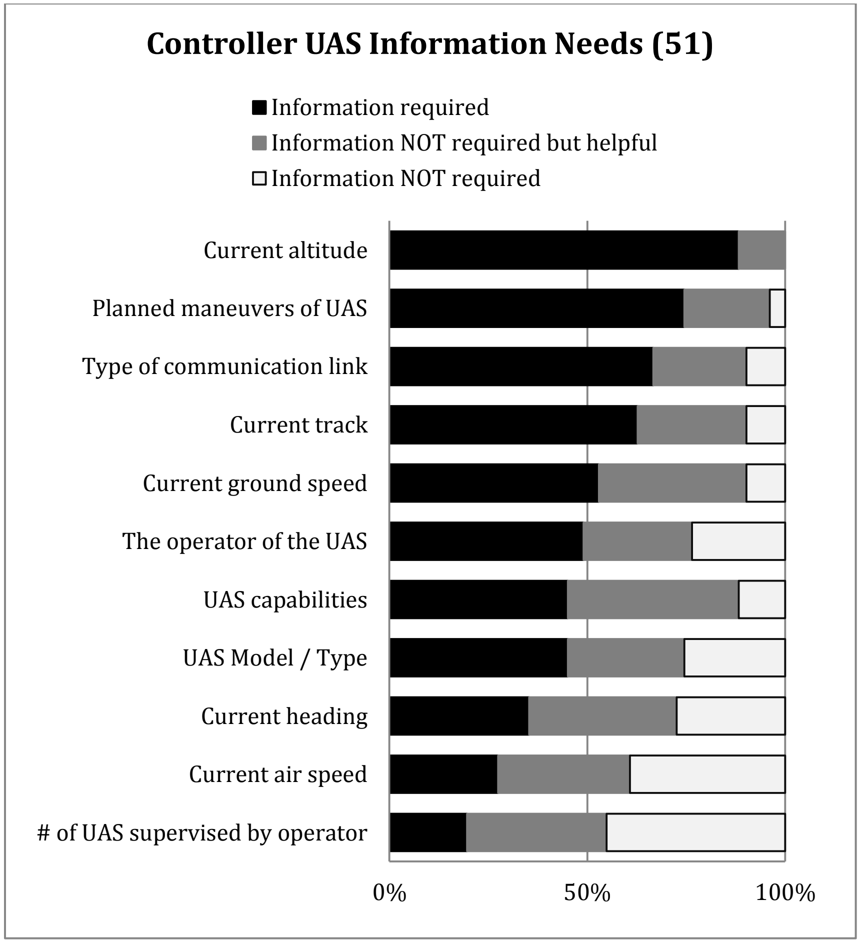


Figure 5-12. Controller UAS Information Needs

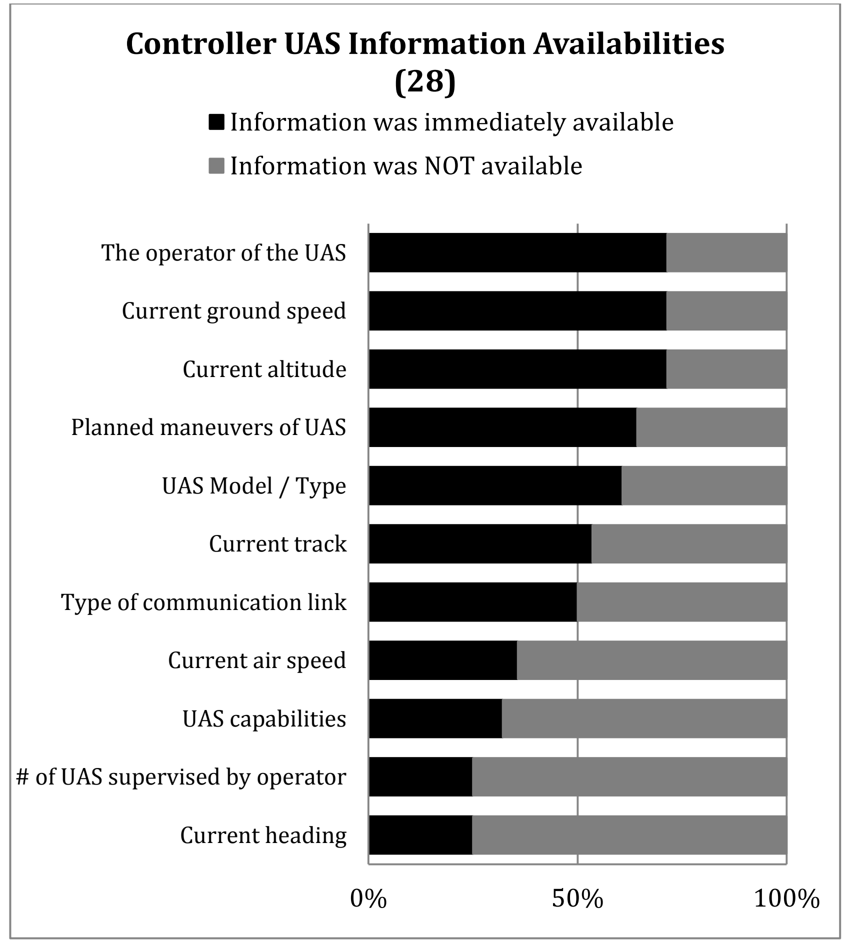


Figure 5-13. Controller UAS Information Availabilities

As shown in Figure 5-14, *Current heading* is the only type of information that equal proportions of controllers say is required and also available. Four types of UAS information stood out for being required but not available, including *UAS capabilities*, *current altitude*, *type of communication link* and *planned maneuvers of UAS*.

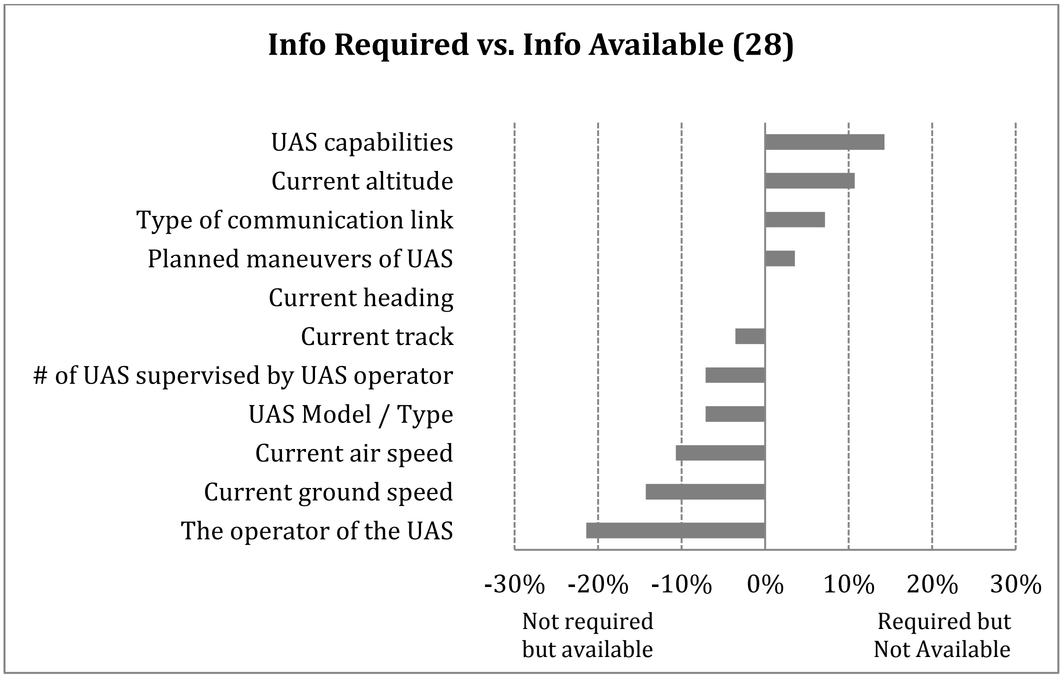


Figure 5-14. Information Requirements & Availabilities (Exp. Controllers)

Follow on Questions 17[C] and 18[C] probed the desired UAS capabilities in more details. Experienced participants were asked to clarify what information about UAS capabilities was needed and available. The participants could either choose from the provided options and/or specify additional ones. The provided capabilities options include: *turn rate, climb rate, min/max speed, weight, size, mission* and *see-and-avoid capabilities*. A couple of participants also indicated that information of UAS endurance and the ability of not being repositioned to expedite overall traffic was not required but would have been helpful. As illustrated in Figure 5-15, only UAS see-and-avoid capabilities information is required but not available to the participants.

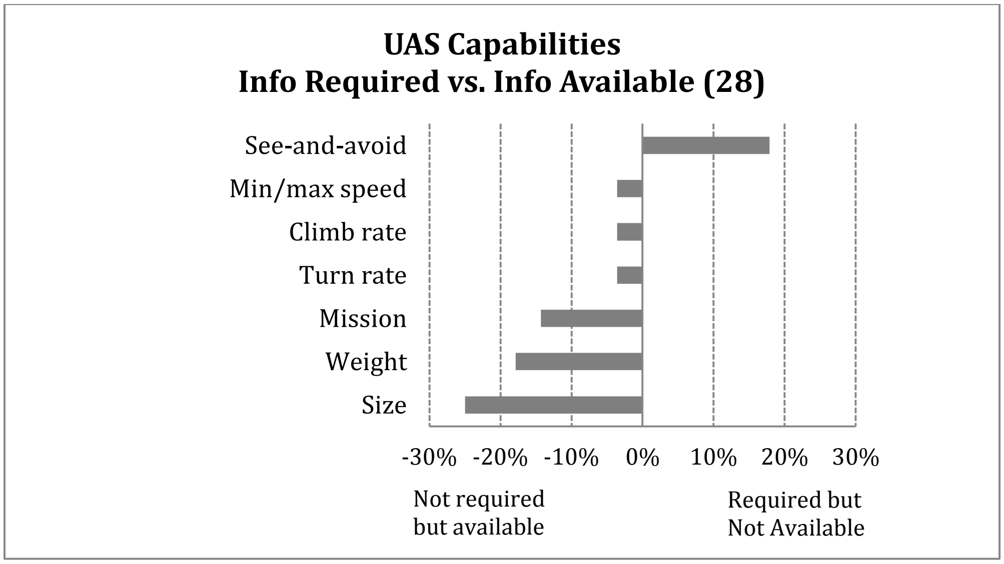


Figure 5-15. UAS Capabilities Info Requirements & Availabilities (Exp. Controllers)

In order to better understand the difference between experienced and inexperienced controllers, the next analysis further compares participants' information needs when they have UAS experience or not. It aims to identify the change in information requirements that is brought by gaining more experience with UAS. To achieve this objective, the difference $\Delta^{C\ With/Without\ Experience}$ was calculated where:

$$\Delta^{C\ With/Without\ Experience} = \\ \%\ of\ participants\ with\ UAS\ experience\ reporting\ information\ required\ (\%) \\ -\ \%\ of\ participants\ without\ UAS\ experience\ reporting\ information\ required\ (\%)$$

This is interpreted as follows:

When $\Delta^{C\ With/Without\ Experience} > 0$, UAS experience increases participants' perception of a need for the information;

When $\Delta^{C\ With/Without\ Experience} < 0$, UAS experience decreases participants' perception of a need for the information;

When $\Delta^{C\ With/Without\ Experience} = 0$, information need is not affected by participants' experience with UAS.

As can be seen in Figure 5-16, there is a greater percentage of participants with UAS experience who felt information about *UAS model/type*, *current ground speed*, *UAS operator*, *UAS capabilities* and *current altitude* was needed. Controllers without UAS experience were more likely than those with UAS experience to state that information about *type of communication link*, *current track* and *heading* was required. Interestingly enough, the number of participants requiring information of *UAS number supervised by UAS operator*, *UAS planned maneuvers* and *current air speed* is not affected by participants' working experience with UAS.

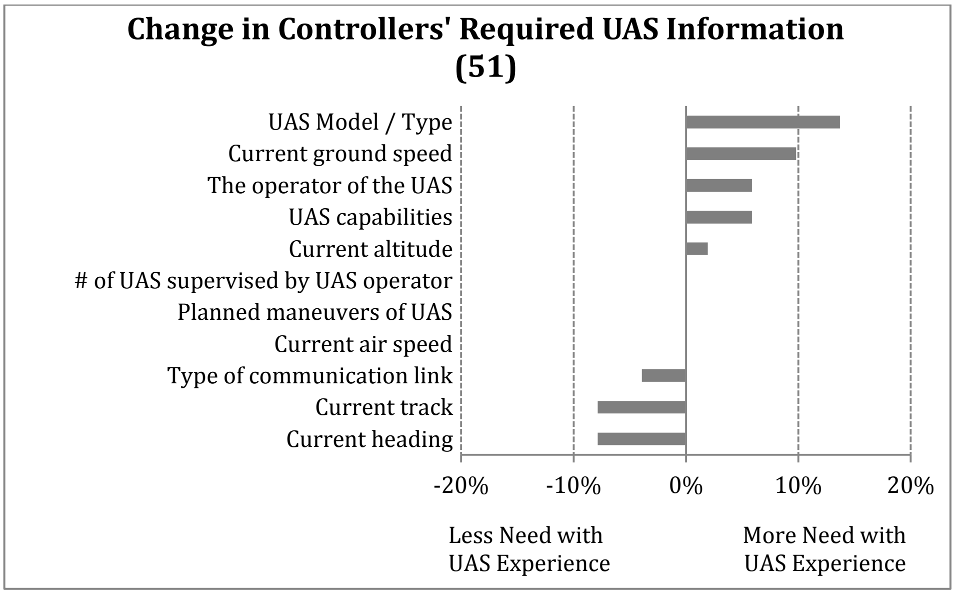


Figure 5-16. Change in Info Requirements Comparing Experienced and Inexperienced Controllers

In terms of UAS capabilities, participants' experience with UAS does not influence how much controller participants need UAS *turn rate* information (Figure 5-17). Yet, UAS experience does affect the perception of the requirements of other types of information. More participants would like to know about the *weight* and *mission* information of a UAS if they have had UAS experience. There is also a decrease in the number of participants who need *size*, *see-and-avoid*, *climb rate* and *min/max speed* information.

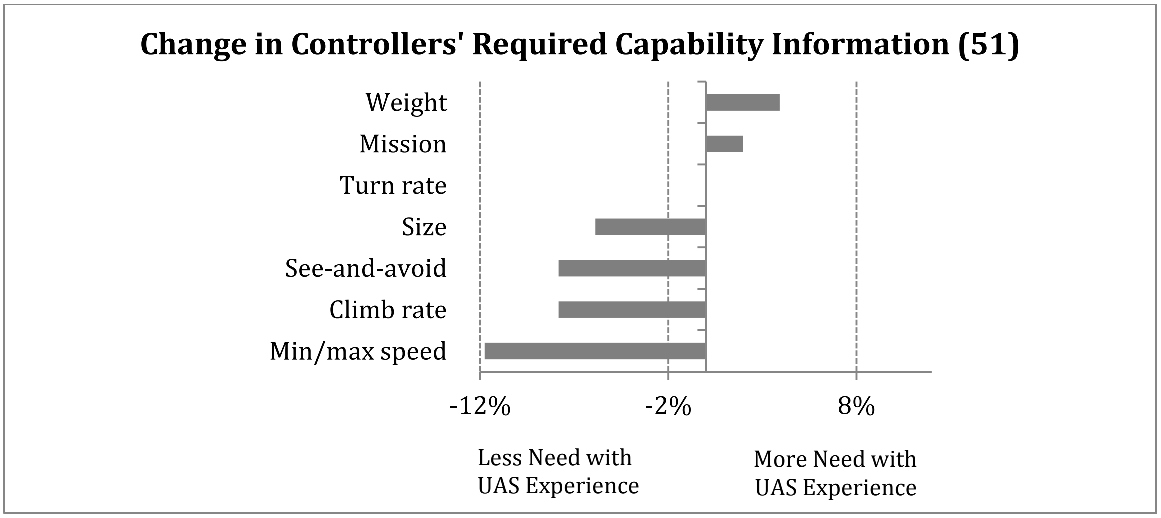


Figure 5-17. Change in Capability Info Requirements Comparing Experienced and Inexperienced Controllers

5.4.3.2 Pilots

Similarly as controllers' analysis, Figure 5-18 presents an overview of pilots' information needs, which were broke down to "information required", "information not required but helpful" and "information not required." The percentages were calculated based on the 46 complete responses. It does not differentiate between cooperative and non-cooperative UAS.

As demonstrated in Figure 5-18, *current altitude* of a UAS is the information identified as being most needed, without a single participant stating that it was not required. In addition, *planned maneuvers of UAS, UAS current track, type of communication link* and *current heading* are also listed in the top 5 most important information types. Interestingly, only the top 3 types of information are required by over 50% of the participants.

However, similar with controllers' situation, not all of the required information is available in every situation. Questions 13^P – 15^P asked the participants with UAS experience which of the pieces of information was available in their last UAS encounter. As shown in Figure 19, most of the time UAS information was not available to the pilots.

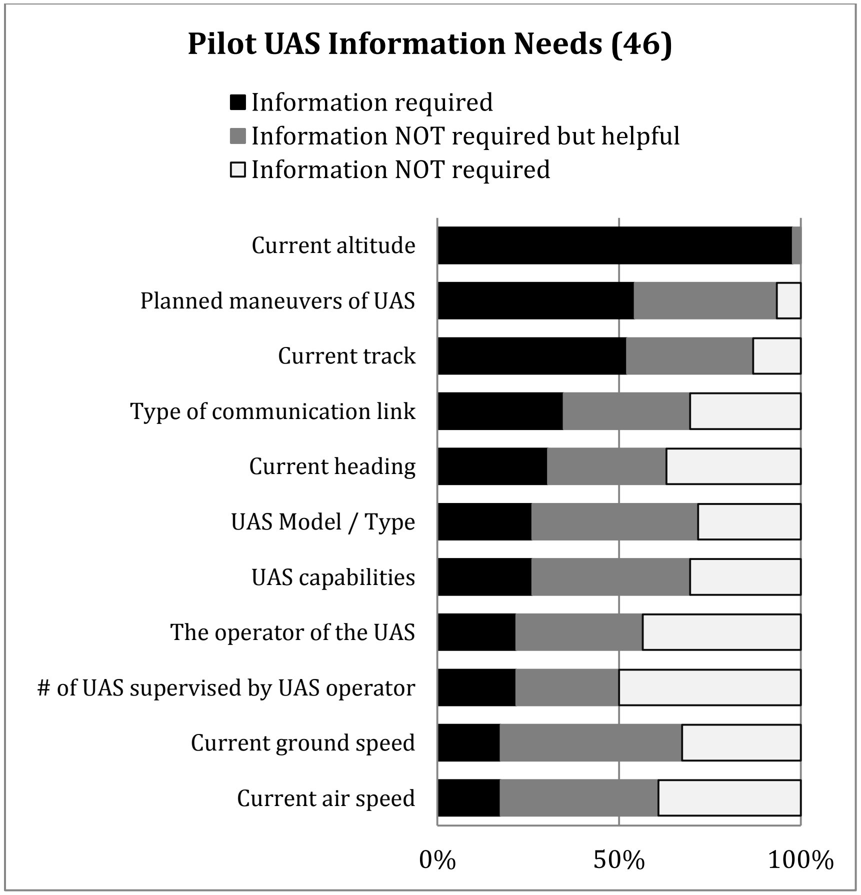


Figure 5-18. Pilot UAS Information Needs

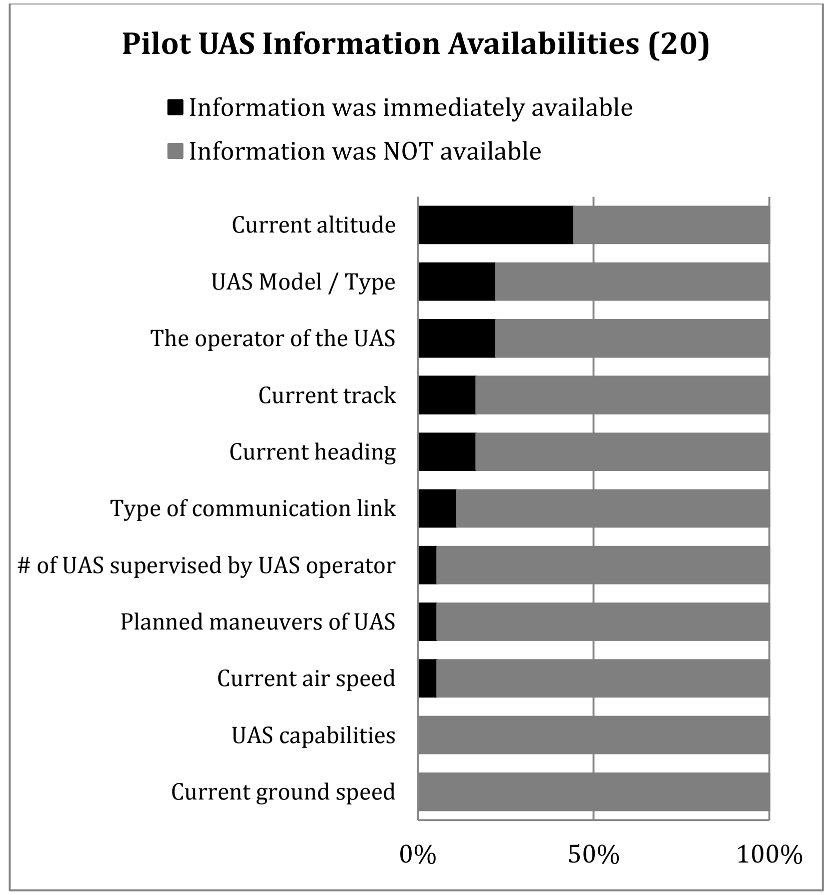


Figure 5-19. Pilot UAS Information Availabilities

Therefore, the same approach used in controller's analysis in Section 5.4.3.1is used again to identify the relationship between information availability and requirements:

$$\Delta^{P\ Available/Required} = \\ \%\ of\ participants\ with\ UAS\ experience\ reporting\ information\ was\ required(\%) \\ - \%\ of\ participants\ with\ UAS\ experience\ reporting\ information\ was\ available(\%)$$

This is interpreted as follows:

When $\Delta^{P\ Available/Required} > 0$, the information is required but not available;

When $\Delta^{P\ Available/Required} < 0$, the information is available but not required;

When $\Delta^{P\ Available/Required} = 0$, the information is required and is available.

The delta combines the results shown in Figure 5-18 and 5-19, and Figure 5-20 shows the final results. As illustrated in Figure 5-20, most information is required but not available. *Current airspeed* is the only type of information that is required and also available to the participants. It is because there was only one participant felt that this information was required, and another participant who happen to have a military background had access to it. Most of the time, the information of *current air speed* is not required and is not available to pilot participants.

Half of the participants indicated that *current altitude* is needed but not available. The top 5 types of UAS information that are required but not available during the presence include *current altitude*, *planned maneuvers of UAS*, *type of communication link*, *current track* and *current heading*.

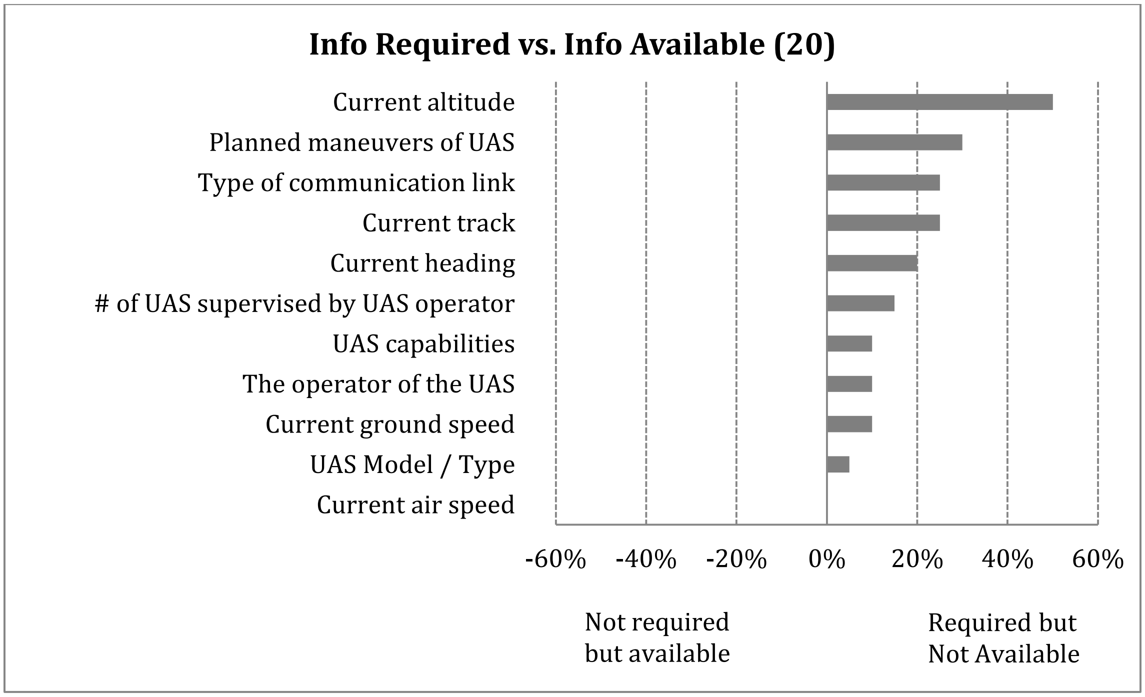


Figure 5-20. Information Requirements & Availabilities (Exp. Pilots)

Similar with the discussion of the controller analysis in Section 5.4.3.1, Questions 17P and 18P probed pilots' UAS capability information need and availability. As illustrated in Figure 5-21, only *UAS size* information is not required but available to the participants. Other important required information, however, is not available. Two pilot participants also indicated that information of general predictability of UAS flight, UAS TCAS capability and video and recording capability was not required but would have been helpful.

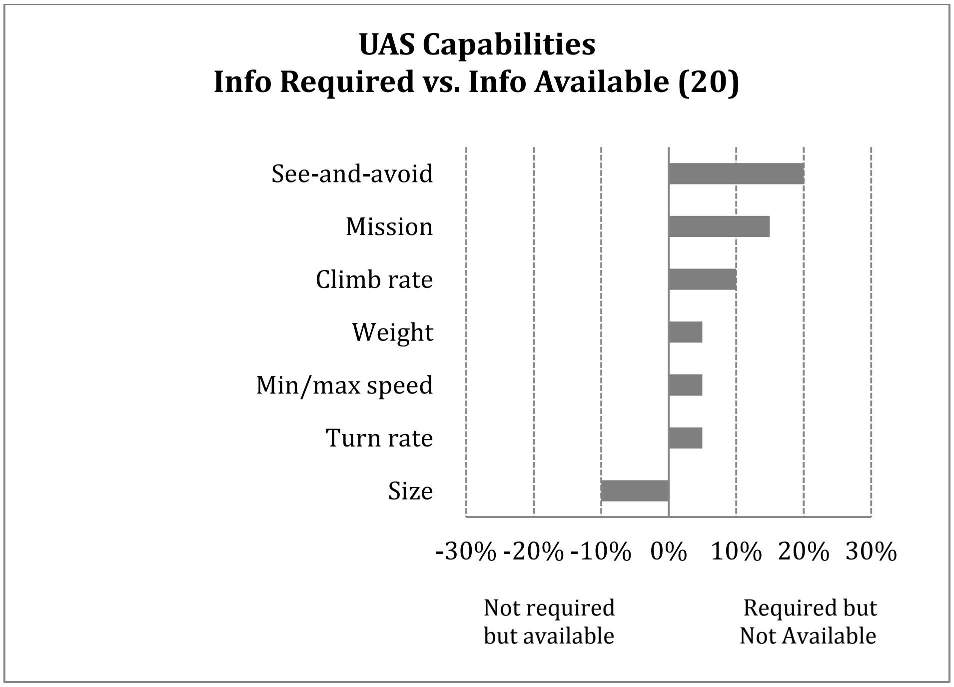


Figure 5-21. UAS Capabilities Info Requirements & Availabilities (Exp. Pilots)

The next analysis compares pilot participants' information need while with and without UAS experience:

$$\Delta^{P\ With/Without\ Experience} =$$

$$\%\ of\ participants\ with\ UAS\ experience\ reporting\ information\ required\ (\%) - \%\ of\ participants\ without\ UAS\ experience\ reporting\ information\ required\ (\%)$$

This is interpreted as follows:

When $\Delta^{P\ With/Without\ Experience} > 0$, UAS experience increases participants' perception of a need for the information;

When $\Delta^{P\ With/Without\ Experience} < 0$, UAS experience decreases participants' perception of a need for the information;

When $\Delta^{P\ With/Without\ Experience} = 0$, information need is not affected by participants' experience with UAS.

As can be seen in Figure 5-22, a greater percentage of pilots with UAS experience felt that information about *UAS operator* was needed. The need of information about *current heading* is not affected by pilots' UAS experience.

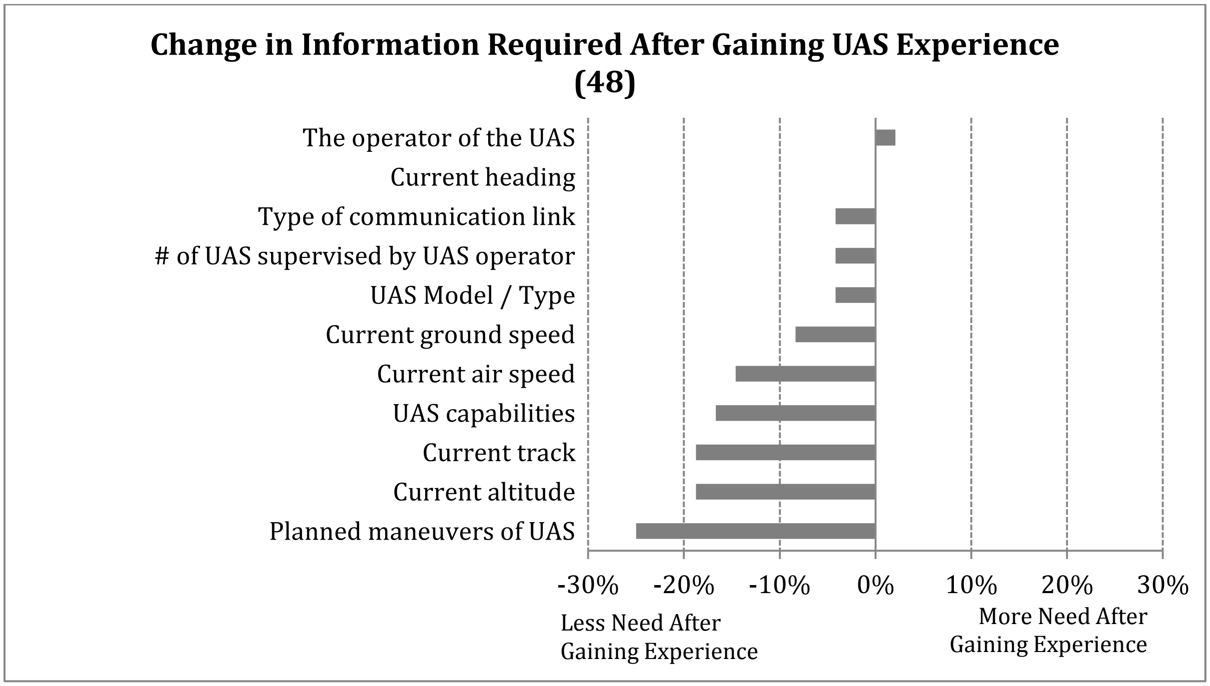


Figure 5-22. Change in Info Requirements Comparing Experienced and Inexperienced Pilots

In terms of UAS capabilities, overall, the information need is influenced by participants' experience with UAS (Figure 5-23). The biggest decreases occur in the number of participants who need *size, climb rate, min/max speed* and *see-and-avoid* information.

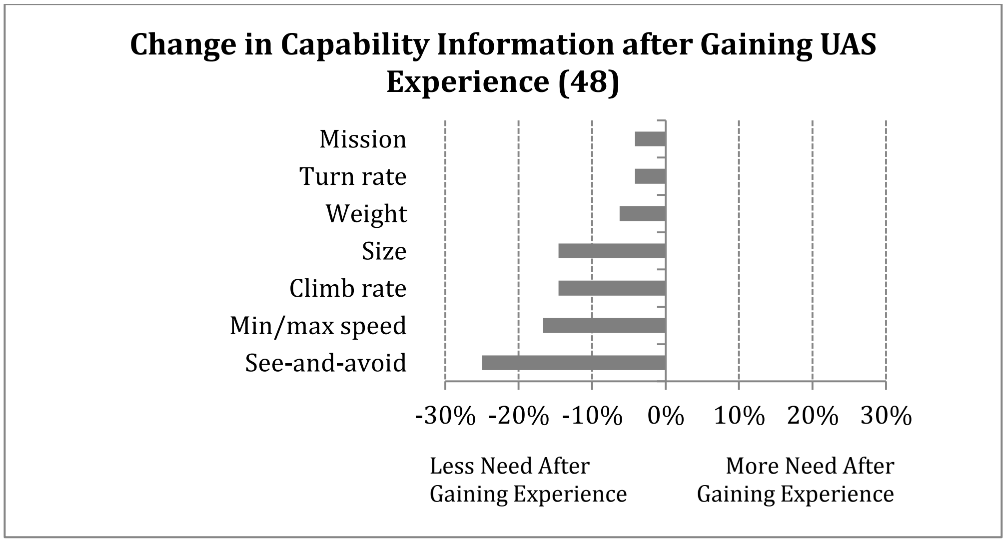


Figure 5-23. Change in Capability Info Requirements Comparing Experienced and Inexperienced Pilots

5.4.4 Challenges in Obtaining, Using and Interpreting UAS Information

Closely associated with information requirements is information perception. It is not unusual that certain factors would inhibit operators' ability in gathering and understanding the information. In order to determine such challenges about UAS information, participants (both experienced and inexperienced) were asked to list up to 3 challenges in obtaining, using and interpreting UAS information.

5.4.4.1 Air Traffic Controllers

In total, 53 comments of challenges were collected, and they share some common themes. For instance, "direct communication with UAS operating uncertainty" and "poor communication with operator" reflects the *communication* challenge. Table 5-9 illustrates the top 5 challenges in obtaining, using and interpreting UAS information. Representative comments from the participants are included. The *other* category consists of 8 types of challenges.

As reflected by the comments, participants were concerned about lack of standard control procedures, UAS intent and UAS capabilities information. The participants also indicated challenges in the capability of current primary and secondary surveillance radar (PSR&SSR) technologies in detecting and identifying small UAS targets. In addition, "controller – UAS operator", "controller –

manned aircraft pilots", and "controller – controller" communication is also one of the major roadblocks for using UAS information.

Table 5-9: Challenges in Obtaining, Using and Interpreting UAS Information (Controller)

Themes	Percentage of Comments	Original Comments from Participants
Lack of information	24%	• "lack of prescribed procedures" • "reason to be in my airspace" • "range of mission unknown"
PSR & SSR capabilities	22%	• "Too small to be seen by primary radar" • "inability to see on radar" • "surveillance SSR info identification"
Communication	15%	• "Determining what to tell a controlled aircraft in close proximity" • "Inability to communicate in a NORDO situation" • "poor communications with operator"
Ability of control	11%	• "having to make other aircraft avoid UAS" • "mission partially in uncontrolled airspace" • "potential conflict with controlled aircraft"
Clutter	7%	• "primary return clutter" • "clutter if no ability to filter by altitude" • "screen clutter"
Other (8)	20%	• "effect of wind on aircraft and wind speed/direction on the target" • "data block dissimilarities" • "monitoring turns on primary radar, update rate was slow and so turns had to be timed as a/c was not capable of flying headings"

5.4.4.2 Pilots

The top 5 challenges were identified based on the 85 comments collected (Table 5-10). Representative comments from the participants were included. The *other* category consists of 11 types of challenges, including information accuracy, warning capabilities, operators' situation awareness, security, radar coverage, etc.

It is interesting to see that participants were concerned about both lack of information and information overload. It could be because the participants want the most critical and relevant UAS information, but do not want to be overwhelmed at the same time.

The participants also indicated challenges in communication with UAS operators and air traffic controllers when additional information is added to the system.

Table 5-10: Challenges in Obtaining, Using and Interpreting UAS Information (Pilot)

Themes	Percentage of Comments	Original Comments from Participants
Lack of information	21%	• "lateral/vertical relationship to my aircraft" • "managing 'Threat and Error' due lack of information" • "no information"
Information overload	15%	• "information overload- I still need my own data to fly my own aircraft, not a bunch of other data about other aircraft" • "too much information can confuse or distract"
Detect and avoid capabilities	14%	• "Aircraft not appearing on radar or in Air Tasking Order" • "The units flight path was aerobatic and was not noticed visually by me" • "Which way to maneuver to avoid UAS"
UAS operation regulations	9%	• "Right of way" • "Regulatory oversight and willingness to address the UAS issue" • "where was the UAS supposed to be operating"
Communication	8%	• "Congested VFR test airspace meant busy radios and required a dedicated radar advisory " • "They are not talking to anybody" • "communication with controller/controlling agency"
Other (11)	32%	• "being automated instead of a real person" • "system accuracy" • "security/encryption"

5.4.5 Communication with Shared Information & Information Asynchrony

Communication with information asynchrony is one of the human factors challenges identified in Chapter 3. Chapter 4 expanded on the concept and presented an initial study of how controller-pilot communication is affect by asynchronous information. However, the participants in the study were naïve and did not have professional air traffic control or pilot experience. As a result, Section 5 of the survey was designated to present an information asynchrony scenario to the operators, and then to gather experienced professionals' opinions on this matter. The first part of the section probed participants' opinion on shared non-cooperative object information. The second part asked the participants how asynchronous shared non-cooperative object information affects their communication.

5.4.5.1 Air Traffic Controllers

The controller participants were asked to think about a situation where non-cooperative object surveillance information (i.e. birds) was shared directly with pilots. The participants identified several advantages as well as concerns with the information sharing. As demonstrated in Table 5-11, based on the 33 collected comments, the participants unanimously agreed on three advantages – *increased safety*, *improved situation awareness* and *reduced controller workload*.

Table 5-11: Advantages Reported by Controllers of Sharing Non-coop Object Information with Pilots

Themes	Percentage of Comments	Original Comments from Participants
Increased safety	52%	• "less chances of mid-air collision" • "increased safety" • "prevention of bird strike"
Improved situation awareness	39%	• "good situation awareness for the crew" • "increased vigilance" • "no possible confusion in transferring information"
Reduced controller workload	9%	• "less workload on Controller" • "reduced communication" • "less information to give on frequency"
Other	0%	N/A

The top 6 concerns for sharing non-cooperative object information are illustrated in Table 5-12. It is interesting to see that the participants consider the information sharing both as an improvement to (as seen in Table 11) and decrease of *situation awareness*. They believe that providing additional information to the pilots would improve the onboard crew's awareness of the traffic and non-cooperative objects, but would also potentially distract the operators (controllers and/or pilots) from their routine work.

Table 5-12: Concerns Reported by Controllers of Sharing Non-coop Object Information with Pilots

Themes	Percentage of Comments	Original Comments from Participants
Inaccuracy	18%	• "too much ghost track" • "inaccuracy" • "false alarms"
Decreased situation awareness	18%	• "may be too late for a pilot to take corrective action" • "might divert attention from other targets" • "pulling the attention of the crew away from their instruments and their windscreen"
Increased controller workload	15%	• "increase controller workload" • "informing ATC of evasive maneuvers" • "pilots may start expecting more information than what we can give"
Information overload	15%	• "information avoidance" • "too much avoidance" • "excess information can lead to mental blockade"
Frequency congestion	12%	• "frequency congestion" • "too much radio chatter" • "frequency congestion with requests to avoid small flocks"
Unexpected maneuvers by pilot	12%	• "unexpected avoiding maneuvers by pilots" • "the crew starting to self-separate without notifying or checking with ATC" • "unexpected deviations"
Other (3)	12%	• "every incident would become a legal nightmare concerning responsibilities" • "liability issues" • "better information than TCAS"

In understanding how information delay affects operations, the participants were first asked what a maximum acceptable time delay between the two's display can be. Fifteen participants gave a specific number (seconds), and the average is 20.5 seconds. Additional comments were provided indicating that the delay should be as short as possible.

Secondly, when asked if their previous answer depends on whose display is more updated, 10 participants stood by their previous answers and said would not change either way. Six participants said their answers would change, but depending on the situation.

Lastly, the participants were asked what the maximum difference in distance (in nautical miles) is between the actual position of the non-cooperative objects and the position of the non-cooperative objects shown on their display. Seventeen participants responded to the question and contributed to an average maximum difference of 3.87 nautical miles.

5.4.5.2 Pilots

Similarly, the pilot participants were asked to think about a situation where the non-cooperative object information (i.e. birds) is directly shared with them by the controllers. The participants identified several advantages as well as concerns of the information sharing. As demonstrated in Table 5-13, based on 42 comments, the participants agreed on three advantages – *increased safety*, *improved situation awareness* and *reduced communication*. Multiple participants also indicated that the same technique could be applied to UAS, and therefore allow for UAS operation in the civil airspace.

Table 5-13: Advantages Reported by Pilots of Sharing Non-coop Object Information with Pilots

Themes	Percentage of Comments	Original Comments from Participants
Increased safety	76%	• "improved safety" • "higher level of safety" • "better avoidance"
Improved situation awareness	22%	• "awareness of position" • "allow for operation of UAS in civil airspace" • "better assessment of flight path"
Reduced communication	5%	• "reduced radio transmission" • "reduced vhf communications"
Other	0%	N/A

On the other hand, the top 6 concerns for sharing non-cooperative object information are shown in Table 5-14). In total, 42 comments were collected. In describing the challenge of *communication*, participants were concerned of radio transmissions increase, language used for communication and the form of communication.

Table 5-14: Concerns Reported by Pilots of Sharing Non-coop Object Information with Pilots

Themes	Percentage of Comments	Original Comments from Participants
Information overload	36%	• "too much information" • "must tell me which contact is a threat" • "cluttering of screen"
Unexpected maneuvers by pilot	17%	• "over reaction to the threat" • "pilots trying to avoid at low altitudes" • "unnecessary maneuvers"
Distraction	14%	• "distractions during takeoff and landing" • "pilot distraction" • "could be distracting at critical phases of flight"
Communication	10%	• "in Canada, language of communication" • "form of communication" • "could cause many transmissions on busy frequencies"
Pilots' dependency on technology	7%	• "pilot would be unable to deal with aircraft without electric systems" • "pilot will rely on technology too much"
Inaccuracy	5%	• "false data" • "false alarms"
Other (6)	12%	• "low moving targets will reduce airspace flow" • "unreliability of the system" • "above a certain altitude, i.e. +150 feet AGL"

In understanding how information delay affects operations, the participants were first asked what a maximum acceptable time delay between the two's display can be. Twenty-one participants gave a specific number (seconds), and the average is 13.64 seconds.

Secondly, when asked if their previous answer depends on whose display is more updated, 14 participants insisted that they would not change their previous answers. Six participants said their answers would change, but depending on who has the more updated information.

Lastly, the participants were asked what the maximum difference in distance (in nautical miles) is between the actual position of the non-cooperative objects and the position of the non-cooperative objects shown on their display. Twenty responses were collected and the average maximum difference is 2.06 nautical miles.

5.5 Discussion

5.5.1 Comparison of Air Traffic Controllers and Pilots

5.5.1.1 Limitations and Improvements of Primary Radar

An overview of controller (Table 5-3) and pilot (Table 5-5) analysis results reveals their different priorities in task performance. Controllers tend to look at the airspace as a big picture and are more concerned about the major aspects of the picture, such as information accuracy and radar coverage. Pilots, on the other hand, are more sensitive to their immediate environment and personal safety. For instance, the limitations pilots have encountered with surveillance systems include detection capabilities, communication and alerting system. One common challenge shared by both parties is the lack of target information. This could be a result of primary radar design, in which certain information is omitted to reduce operators' confusion and prevent information overload. Overall, there is a good correlation between the identified challenges and desired improvements for both parties.

5.5.1.2 Experience with UAS

A notable difference between controllers and pilots in terms of UAS experience is that the majority of controllers have had UAS experience (Figure 5-4) while most pilots do not (Figure 5-8). It was expected that, given the strict regulations of UAS operations in controlled airspace, both controllers and pilots would not have much experience working with / encountering UAS.

The follow-up analysis reveals that controllers and pilots have experienced more situations involving individually operated UAS than formation of UAS (Figure 5-5, Figure 5-9). While controllers' experience indicates that there are more individual cooperative UAS involved than individual non-cooperative UAS, pilots' experience does not show an obvious difference.

In the analysis of pilot participants' UAS encounter experiences, participants who have had "second-hand" experience (i.e. discussed with other pilots about their experience) were counted as experienced. There could potentially be a discrepancy between having experience and being able to answer the information availability question.

As shown in Table 5-7 (controller), individual cooperative UAS are most frequently seen in low-density traffic area, and individual non-cooperative UAS are most frequently seen in designated UAS airspace. Both of the areas do not press immediate threat and danger to manned aircraft. However, the second most possible UAS operation areas for both individual cooperative and non-cooperative UAS are the same – at a close proximity to standard flows of aircraft. It is also verified by pilots' UAS experience, which indicates the most highly possible location for individual cooperative and non-cooperative UAS is at a close range to the pilots' aircraft (Table 5-8).

5.5.1.3 Information Needs & Availability

The top 4 most important UAS information types identified by both air traffic controllers and pilots are the same except for slightly different ranking: *current altitude*, *UAS planned maneuvers*, *type of communication links* and *current track* (Figure 5-12, Figure 5-18). It is an indication that these four types of information are most critical and essential to both controllers and pilots task performance. The fifth most important information is *UAS ground speed* and *UAS heading* for controllers and pilots respectively. The difference could be a result of different perspectives. Based on the radar surveillance display, controllers could tell the track of an aircraft, which gives a general direction of movement. In order to accurately assess the situation and maintain successful separation, they need to know their speed relative to the ground. For pilots, they need to know the relative movement of another aircraft to themselves in order to avoid collisions.

In terms of information availability, there is quite a difference between controllers and pilots. While there are only 4 types of information that are required but not available to controllers (Figure 14), 10 types are required but not available to pilots (Figure 20). It could be due to the fact that current on-board technologies are not sophisticated enough to identify or provide adequate information of UAS to pilots. The most needed but not available UAS capability information for both controllers and pilots is UAS see-and-avoid capability.

It has also been found that participants' real-life UAS experience can influence their information requirements (Figure 5-16, 5-17, 5-22, 5-23). Therefore, UAS encounter trainings and UAS overviews are necessary in helping operators get familiar with relevant procedures and preparing them for potential encounter situations.

5.5.1.4 Challenges in Obtaining, Using and Interpreting UAS Information

The top 5 challenges in obtaining, using and interpreting UAS information identified by controllers and pilots are essentially the same. They fall into 5 categories: *lack of information*, *detect and avoid capabilities*, *communication*, *ability of control/operational requirements* and *information overload*.

First of all, participants universally indicate a lack of UAS information in operation, including altitude, speed, heading, etc. It is possible that the operators are able to see the targets on the display without associate information. Secondly, participants are concerned about the capability of current technologies (primary and secondary surveillance radar) in detecting UAS. The comments urged an exploration and deployment of new technologies like ADS-B. Thirdly, both parties stress on the challenge of communication. It includes controller-controller, controller-manned aircraft pilot, controller-UAS pilot and manned aircraft pilot-UAS pilot communication. As illustrated by the participants, these types of communication could be affected by each party's cooperativeness, situation awareness and workload. Fourth, operators need standardized procedures in handling UAS. It could be obtained from training, documentations and regulations, which requires a wider public awareness of UAS adoption and operation. Last but not least, adding more information in the system imposes the potential of information overload and workload increase. It has to be carefully measured and displayed in order to achieve the most effectiveness.

5.5.1.5 Communication with Shared Information & Information Asynchrony

Both controllers and pilots agreed that by sharing non-cooperative information with each other would increase safety. Situation awareness and workload / communication are listed both as advantages and disadvantages of information sharing. Communication, in this sense, is considered as one indicator of workload, because more frequent communication would result in a rise of workload.

Shown in Table 5-15 is a breakdown of situation awareness and workload/communication as advantages and disadvantages. For example, 39% of the 33 comments gathered from controller participants thought that shared information would improve situation awareness, while 18% of the 34 comments gathered from controller participants disagreed[7]. Overall, the information sharing would still improve controllers' situation awareness.

Similarly, it can be concluded that non-cooperative information sharing could improve controllers and pilots' situation awareness, but it could also increase operators' workload.

Other common disadvantages that are shared by controllers and pilots are information overload, unexpected maneuvers of pilots and information inaccuracy. Display clutter, which is considered as a challenge by the controllers, is considered as part of information overload. It would increase operators' mental workload in disseminating and comprehending the data. Pilots' unexpected maneuvers, as explained by the participants, are what will likely to happen when pilots have access to the non-cooperative information. They may not consult with the controllers first and execute avoidance maneuvers independently. It would greatly increase the chances of confusion and collision.

Table 5-15: Interpretation of Situation Awareness and Workload / Communication as both Advantages and Disadvantages

	Controllers		Pilots	
	Advantages (33)	Disadvantages (34)	Advantages (42)	Disadvantages (42)
Situation Awareness	Improve 39%	Decrease 18%	Improve 22%	Decrease 14%
Workload / Communication	Reduce 9%	Increase 15%	Reduce 5%	Increase 10%

Controllers and pilots' responses to the maximally acceptable delay time are 20.5 seconds and 13.64 seconds respectively with median values of 5 and 5 seconds. The maximum differences in distance between the actual position of the non-cooperative objects and the position of the non-cooperative objects shown on the surveillance display are 3.87 NM and 2.06 NM with median values of both 1NM.

[7] In the original question, participants were asked to write down up to 3 advantages and disadvantages respectively. As not all participants provided 3 advantages or disadvantages, the number of responses is unequal.

The responses are not exactly the same, but both parties' perceptions of time and distance are very close. A Mann-Whitney U test was run to determine if the differences in maximum time delay between controller and pilots' was statistically significant. Distribution of the time data for controller participants and pilot participants were similar, as assessed by visual inspection. The median time for controller participants (5) and pilot participants (5) was not significantly different, $U = 144$, $z = -.438$, $p = .68$, using an exact sampling distribution for U.

Similarly, a Mann-Whitney U test was also run to determine if maximum distance between objects on screen and in reality reported by controller participants and pilot participants were significantly different from each other. Distribution of the reported distance for controller participants and pilot participants were similar, as assessed by visual inspection. Median distance for controller participants (1) and pilot participants (1) was not significantly different, $U = 153.5$, $z = -.505$, $p = .619$, using an exact sampling distribution for U.

The results indicated that the controllers and pilots' perception of possible acceptable time delay and maximum difference of distance are very similar. It is possible to use follow-up information asynchrony study to identify the thresholds of the acceptable time delay and maximum distance difference.

5.5.2 Survey Design: Lessons Learned

The survey design process was extensive and a number of lessons have been learned about the process.

Choose the right software. The software used for the design is SurveyGizmo. It is fairly easy to use for beginners and is quite versatile in creating different types of questions. However, there are potential problems in using tables of checkboxes. Once the question setting is mandatory, there is no way to bypass the question unless the participants check every box in the table.

Use guidelines to support iteration cycles. The survey design is a process of constant iterations, gathering feedback and improving the questions. During the iterations, it is quite common that the focus of the survey is shifted or overlooked at some point. To minimize the possibility, it is always good to have a set of objectives determined prior to the brainstorming session and kept at hand for lookup. This set of objectives should act as a guideline throughout the survey design.

Cut off the unnecessary questions. During the initial generation of the survey, brainstorm technique is used to create a fairly large number of questions. However, not all these questions can be in the final version. A careful scrutiny and elimination has to be performed in accordance with the objectives. Moreover, the proper format of the questions has to be chosen in the interest of collecting quality responses and minimizing response time.

Handle negative feedback. In the consultation process, professionals from the industry have actively participated and shared with us their opinions. During the interaction, some of the feedback was very harsh and difficult to take. Yet, it is important for the researchers to be prepared and being able to extract useful comments from a large amount of feedback.

Make necessary tradeoffs. Continuous iterations can undoubtedly improve the overall survey quality. However, an executive decision has to be made at the right time to release the survey to avoid excessive spending of personnel and resources.

5.5.3 Future Work

The analysis presented in the chapter is only a small portion of the entire survey. More work is needed in completing a thorough examination of the survey, extracting more insights and forming proper design guidelines for the next generation radar surveillance systems.

5.6 Chapter Summary

Chapter 5 presents a survey study researching surveillance information level of details, particularly on UAS and other non-cooperative objects, which should be presented to the operators. In the interest of the thesis, the analysis concentrates on participants’ overall experience with UAS, information requirements and information availability and communication ambiguity with the presence of delayed information. The results indicated that current UAS operation is a lot more frequent in a wider range of area than what was originally expected. It is also confirmed that the integration of UAS into civil airspace presents an urgent need of technology improvement in both object detection and information transmission. Some of the most needed information includes *current UAS altitude*, *UAS planned maneuvers*, *type of communication links* and *current UAS track*. Yet, not all the required information is available to the users in current systems.

Chapter 6
Conclusion & Implications

Non-cooperative objects, including birds, weather and UAS, are presenting increasing challenges and potential dangers to current airspace operators. With the development of new technologies, it is possible to distribute relevant information to air traffic controllers and pilots, which would improve the shared situation awareness and provide for safer operations. However, it is unclear as to how the display of additional non-cooperative information would affect operators' communication and performance. Motivated by this opportunity, the thesis examined the potential human factors challenges in enhanced information distribution, aiming to provide feasible recommendations for future radar surveillance systems design.

6.1 Research Objectives and Key Findings

The general research goal of the thesis stated at the beginning of Chapter 1 is "to identify the potential human factors challenges in the future non-cooperative information distribution process, understand how the challenges affect human operators' performance in the system, and provide guidance for future radar surveillance systems design."

Five objectives for achieving the research goal were presented in Chapter 1. They are restated below with key results achieved in developing this thesis.

Objective 1: *Create surveillance information distribution model of current ATC environment capturing current challenges in handling non-cooperative object surveillance data.*

The first objective was addressed by conducting literature review on current technologies and systems handling non-cooperative objects. As identified in Chapter 2, the constraints of current air traffic control are that there lacks a reliable and real-time warning / forecasting system to alert operators of potential non-cooperative object hazards. The increasingly complex operational environment (i.e. the integration of UAS into the airspace) also presses challenges on the system's non-cooperative objects detection and information sharing capabilities.

The main contribution of the review is that it provided a better understanding of current ATC environment, based on which a current information distribution model was created (Figure 3-1) in Section 3.1.1 in Chapter 3.

Objective 2: *Create surveillance information distribution model of future ATC environments incorporating emerging technologies relevant to handling non-cooperative object surveillance data.*

The second objective was addressed by conducting a literature review on recent advanced radar capabilities and new infrastructure service for information centralization. Section 2.1 and 2.3 in Chapter 2 specifically discussed the new capabilities and technologies, including ADS-B, NextGen and SWIM. Based on the review, a future surveillance information distribution model was created in Section 3.1.2 in Chapter 3 (Figure 3-2). The new model incorporated the core ideas of enabling non-cooperative object detection and information sharing. The model narrowed the research question and provide more detailed context in which human factors challenges was identified in Chapter 3.

Objective 3: *Identify potential human factor challenges in distributing non-cooperative information of the expected future surveillance information distribution model.*

The fourth objective was addressed by critically reviewing the non-cooperative information distribution process in the future surveillance information distribution model and synthesizing literature on related human factors challenges. The four identified human factors challenges are:

1) Potential for asynchronous information for air traffic controller and pilots;
2) Displayed information level of detail;
3) Dissonance and warning integration; and
4) Information intermittency.

These challenges were discussed in details in Section 3.2, Chapter 3 on what they are, what the potential causes are, what past accomplishments are and how they are related with the future surveillance information distribution model.

Objective 4: *Determine how non-equal time delays (HF challenge 1) in the distribution of non-cooperative object radar surveillance information affects the communication between controller and pilot.*

The fourth objective was achieved by designing and conducting an initial experiment of information asynchrony with 12 pairs of participants (Chapter 4), and part of an online survey study (Chapter 5). In the experiment, the effect of asynchronous information on pilot-controller communication was studied by manipulating the delay amount of the shared information between the pilot and controller participants. The results did not fully confirm the hypotheses: an increase of time delay would observably, but not statistically significantly increase operators' communication time; the number of clarification statements vary significantly depending on the time delay which was found between Delay 0.5 and 10 minutes; and as the amount of delay increases, there was an observable but not statistically significant decrease in participants' performance and communication effectiveness and increase in frustration level and perceived trial difficulty level.

The fifth section of the survey probed pilot-controller communication regarding non-cooperative objects. Results showed that sharing non-cooperative object information between controllers and pilots was thought to improve operators' situation awareness while it would also potentially increase controllers' workload. In addition, expected maneuvers from pilots and information overload are also considered as disadvantages to information sharing.

The survey also identified possible acceptable delay time for shared non-cooperative object information based on participants' experience and current operational environment. The time delay reported by controller and pilot participants was not significantly different from each other. But, experimental studies are needed to validate the accurate thresholds.

Objective 5: *Gather information requirements from air traffic controllers and pilots on individual UAS operations (HF challenge 2).*

Finally, the fifth objective was addressed by conducting an online survey study on controllers and pilots' information needs and requirements of UAS (Chapter 5). Fifty-one certified controllers and fifty-one certified pilots provided complete responses to the survey. The results revealed that current UAS operation is already widely existed. Some critical information of individual / formation of UAS with the same dynamics to controllers and pilots' successful performance includes *current altitude, UAS planned maneuvers, type of communication links* and *current tracks*. It was also confirmed that not all required information is available to the operators. For pilots specifically, the majority of needed information is not available in operations. These results should be taken into consideration while designing the next generation radar surveillance systems.

Valuable implications were also drawn from studying challenges in obtaining and interpreting UAS information and communication with shared information and information asynchrony. These implications include:

1) Operators need more information about UAS, including altitude, speed, heading, etc.;
2) Operators are concerned about current technologies in accurately detecting UAS;
3) There are potential challenges in effective communication regarding UAS across different operators in the system, including controllers, manned aircraft pilots and UAS pilots.
4) Operators need standardized procedures in handling UAS. It should be accessible from training and / or documentation;
5) Adding more information in the system should not greatly increase operators' information overload and decrease situation awareness.

6.2 Contributions

There are several major contributions of the thesis. First, information asynchrony of non-cooperative objects has an overall negative effect on operators' communication and performance. Although no statistical significance was found in operators' communication on time delay, a consistency between the subjective and objective measurements was demonstrated. Although there were observable trends of the time delay effect on subjective measurements, no meaningful statistical significance was found. However, in order to improve the overall collaboration performance and shared situation awareness, the system design should still economically minimize the delay as much as possible.

Secondly, the survey results challenge current perception of the limited frequency of UAS operations. There are more controllers and pilots who have had encountered UAS one way or another in their daily tasks than what was originally expected. It is therefore urgent for the authorities and researchers to speed up the development of comprehensive UAS operation regulations and more advanced detecting technologies.

Thirdly, the survey also helped identify operational information requirements and availabilities for individual / formation of UAS with the same dynamics, and challenges in sharing non-cooperative object information. Some of the most needed UAS information includes *current UAS altitude*, *UAS planned maneuvers*, *type of communication links* and *current UAS track*. However, not all of the needed information is available to the operators. Moreover, it should be taken into consideration that by providing more information, it introduces the potential of information overload. Thus, the choice of what information to be displayed to the operators should be based on a more comprehensive investigation, preferably in an experiment form.

6.3 Recommendations and Future Work

The asynchrony experiment presented in the thesis is an initial approach to understanding the effect of information asynchrony on pilot-controller communication. It is recommended that future work continue investigating the topic in a more dynamic environment with subject matter experts as participants. It is believed that an elimination of artificial flaws and a shorten time delay would lead to a more satisfying and significant result. However, the findings so far should also inspire surveillance system design. That is, the amount of delay on shared information should be as small as possible to ensure overall effective collaboration. Understanding that zero delay can be unrealistically difficult and expensive to achieve, future work should find a middle ground and identify an acceptable threshold of the delay that would not affect operators' normal performance.

UAS integration into controlled airspace appears to be inevitable. The survey study provided in-depth knowledge of current UAS operations. The fact that UAS operations are more prevalent than expected highlights an urgent need to address the related operational regulation issues. Although the results of the survey provided first-hand data on what information of UAS is needed, adding these information to the surveillance systems should be validated by experimental studies. The challenges of current surveillance systems in detecting non-cooperative objects and enabling information sharing between pilots and controllers should be addressed in the next-generation radar surveillance systems to better facilitate users' needs.

There are still many more insights to be extracted from the survey study. The analysis presented in the thesis is only a small part of it that is most relevant to the focus of the thesis. It is recommended that future research continue analyzing the data collected from Section 3, 4 and 6 of the survey. It would provide invaluable information about the formation of UAS operation and related information presentation methods in surveillance systems.

In Chapter 3, 4 human factors challenges were identified, and the thesis only addressed two of them. It is highly recommended that future research continue investigating the other two challenges – *dissonance and warning integration* and *information intermittency*. It would provide additional guidance in understanding how these challenges affect operators' performance. The results would also provide rich implications as to how the next-generation radar surveillance system should be designed to best facilitate human operators' performance and requirements.

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Appendix A.

Post-Trial Questionnaire (Controller)

Trial No.:________________ Participant No.: ________________ Date:________________ Scenario No.:________________

Post-Trial Questionnaire (Controller version)

Instruction: In this section, you will be asked to rate several indicators based on you performance and understanding of **the trial you just finished**. Now please take a moment to think about the trial. When you are ready, please read the rating scale definitions and circle your answers in the **Rating** section. When finished the rating, please answer the four questions below the table.

Number	Title	Descriptions	Rating
1	PERFORMANCE	How successful do you think you were in accomplishing the goals of the task set by the researcher? How satisfied were you with your performance in accomplishing these goals?	PERFORMANCE 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Poor … Good
2	COMMUNICATION EFFECTIVENESS	How effective do you think the communication with the pilot is? How easy/difficult is it to communicate your intentions clearly?	COMMUNIATION EFFECTIVENESS 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Poor … Good
3	FRUSTRATION LEVEL	How discouraged and stressed versus gratified and relaxed did you feel during the task?	FRUSTRATION 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Not much … Very
4	TRIAL DIFFICULTY LEVEL	How difficult/easy do you think one trial is?	TRIAL DIFFICULTY LEVEL 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Easy … Hard

1. Please explain **why** you choose your answer in **Question 1** (i.e. what are the factors that make you perform well/poorly):

____

2. Please explain **why** you choose your answer in **Question 2** (i.e. what are the factors that make the communication effective or not):

____

3. Please explain **why** you choose your answer in **Question 3** (i.e. what are the factors that make you feel frustrated/relaxed):

____

4. Please explain **why** you choose your answer in **Question 4** (i.e. what are the factors that make the trial hard/easy):

____

Appendix B.

Post-Trial Questionnaire (Pilot)

Trial No.:________________ Participant No.: ________________ Date:________________ Scenario No.:________________

Post-Trial Questionnaire (Pilot version)

Instruction: In this section, you will be asked to rate several indicators based on you performance and understanding of **the trial you just finished**. Now please take a moment to think about the trial. When you are ready, please read the rating scale definitions and circle your answers in the **Rating** section. When finished the rating, please answer the four questions below the table.

Number	Title	Descriptions	Rating
1	PERFORMANCE	How successful do you think you were in accomplishing the goals of the task set by the researcher? How satisfied were you with your performance in accomplishing these goals?	PERFORMANCE 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Poor ... Good
2	COMMUNICATION EFFECTIVENESS	How effective do you think the communication with the controller is? How easy/difficult is it to communicate your intentions clearly?	COMMUNIATION EFFECTIVENESS 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Poor ... Good
3	FRUSTRATION LEVEL	How discouraged and stressed versus gratified and relaxed did you feel during the task?	FRUSTRATION 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Not much ... Very
4	TRIAL DIFFICULTY LEVEL	How difficult/easy do you think one trial is?	TRIAL DIFFICULTY LEVEL 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 Easy ... Hard

1. Please explain **why** you choose your answer in **Question 1** (i.e. what are the factors that make you perform well/poorly):

   ____

2. Please explain **why** you choose your answer in **Question 2** (i.e. what are the factors that make the communication effective or not):

   ____

3. Please explain **why** you choose your answer in **Question 3** (i.e. what are the factors that make you feel frustrated/relaxed):

   ____

4. Please explain **why** you choose your answer in **Question 4** (i.e. what are the factors that make the trial hard/easy):

   ____

Appendix C.

Survey of Controller Information Needs for Integrating UAS

Welcome to the Survey of Controller Information Needs for Integrating Unmanned Aircraft Systems (UAS) into Controlled Airspace!

In this survey, you will be asked questions about 1) your experience with unmanned aircraft systems, 2) your opinion on how new information about objects should be displayed, and 3) how access to more detailed surveillance information would affect your communications with pilots.

All the information collected in the survey will be anonymous and confidential. You may quit the survey at any time, without penalty, by closing the window.

Please be noted that the survey has to be completed at **one sitting**, because we do not collect your personal information (i.e. IP address).

When you are ready, please click "Next" to proceed to the next page. If at any time, you would like to go back to the previous page, please click the "Back" button in the survey instead of on your browser.

To allow us to compare the perceptions of different groups, the following questions ask you to provide demographic information and details of your professional background.

1. What is your age?

- ○ <20
- ○ 20 - 29
- ○ 30 - 39
- ○ 40 - 49
- ○ >50

2. Gender

- ○ Male
- ○ Female

3. Are you currently licensed to work as an air traffic controller?

- ○ Yes
- ○ No, I am retired
- ○ No, I have never been licensed

4. How many years of experience do you have as a fully licensed air traffic controller?

- Less than 1 year
- 1 - 5 Years
- 6 - 10 Years
- 11 - 20 Years
- 21 or more Years

5. In which country/region have you most recently worked as a controller?

-- Please Select --

6. In what type of ATC facility / area of specialization have you most recently worked?

- Flight Service Station
- Tower
- Terminal Specialty
- Enroute Specialty
- Oceanic Specialty
- Other

7. Are there any other types of facilities in which you have worked? Please select all ATC facilities/areas of specialization in which you have worked.

- Enroute Specialty
- Terminal Specialty
- Tower
- Flight Service Station
- Oceanic Specialty
- Other

Section 1

8. In your current (or most recent) facility, what are the 3 most important limitations of the primary radar?

Limitation #1

Limitation #2

Limitation #3

9. What are the 3 most important features or improvements you would like to see in a "next-generation" primary radar system?

Improvement #1 [ ]

Improvement #2 [ ]

Improvement #3 [ ]

The next series of questions will ask about your previous experiences with Unmanned Aircraft Systems (UAS).

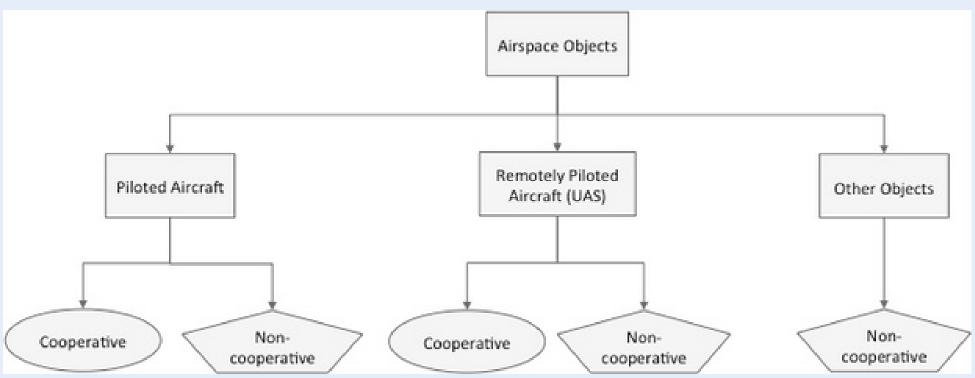
In order to better understand your previous experiences with UAS we ask you to distinguish between 3 categories of objects: piloted aircraft, remotely-piloted aircraft, and other objects.

- **Piloted aircraft** refers to aircraft which are controlled by a pilot(s) on-board the aircraft.
- **Remotely piloted aircraft**, however, do not have the pilot on board but are controlled from a separate control station (typically on the ground). Remotely piloted aircraft are known by several names, we will refer to them as Unmanned Aircraft Systems (UAS). You may also know them as Remote-piloted aircraft (RPAs) and/or Unmanned aerial vehicles (UAVs).

We also ask you to distinguish between two types of objects that can be detected by a surveillance system. One type are objects that are "**cooperative**", and have on-board equipage (e.g. transponders) that work with existing surveillance sources (e.g. secondary radar, ADS-B and variants such as ADS-C). For these objects, the surveillance source can provide information about current altitude, position, and speed for the object.

The second type of object is "**non-cooperative**", and must be detected using surveillance sources that do not rely on the capabilties on-board the object. This may be because the object is incapable (e.g. vintage aircraft), too small, is a bird, balloon, or weather, or because it is actively trying to avoid detection. While these objects may sometimes pose hazards to aircraft, only limited information (e.g. position) is currently available about them.

The following figure illustrates these distinctions:



The following are questions about your previous experiences with cooperative and non-cooperative unmanned aircraft systems (UAS).

10. For each of the types of UAS shown in the columns below, please select any and all applicable experiences listed in the rows.

If there is a type of experience with a UAS that is not covered by the items in the list, please add it in the empty box(es) below.

	A "Cooperative" individual UAS (e.g. equipped with a transponder making traditional surveillance data available)	A "Non-cooperative" individual UAS (e.g. NOT equipped with a transponder making traditional surveillance data NOT available)	A formation of "Cooperative" UAS (e.g. where one or more was equipped with a transponder making traditional surveillance data available)	A formation of "Non-cooperative" UAS (e.g. where NONE were equipped with a transponder making traditional surveillance data NOT available)
I have NEVER encountered any situation involving this type of UAS	☐	☐	☐	☐
I have had this type of UAS present in my airspace but it had no effect on operations	☐	☐	☐	☐
I have had this type of UAS present in my airspace and it affected my control decisions but I was not providing the UAS with separation services.	☐	☐	☐	☐
I have had this type of UAS present in my airspace and have provided separation services between an aircraft under my control and this type of UAS	☐	☐	☐	☐
[ ]	☐	☐	☐	☐
[ ]	☐	☐	☐	☐
[ ]	☐	☐	☐	☐

11. In your airspace, where have you observed UAS operating?

For each type of UAS, please select any and all of the location descriptions that apply.

If there is a location that is not in the list, please add it in one of the blank boxes.

	A "Cooperative" individual UAS (e.g. equipped with a transponder making traditional surveillance data available)	A "Non-cooperative" individual UAS (e.g. NOT equipped with a transponder making traditional surveillance data NOT available)	A formation of "Cooperative" UAS (e.g. where one or more was equipped with a transponder making traditional surveillance data available)	A formation of "Non-cooperative" UAS (e.g. where NONE were equipped with a transponder making traditional surveillance data NOT available)
In close proximity to the standard flows of aircraft through my airspace	☐	☐	☐	☐
In other high traffic density regions of my airspace	☐	☐	☐	☐
In low traffic density regions of my airspace	☐	☐	☐	☐
In airspace designated for UAS operations	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐

Section 2

The following questions ask about your most recent experience dealing with a UAS, or formation of UAS, in your airspace.

12. What type of UAS was involved in your most recent experience with a UAS?

- ○ An individual UAS equipped with a transponder (Traditional surveillance data available).
- ○ An individual UAS NOT equipped with a transponder (Traditional surveillance NOT data available).
- ○ A formation of UAS, one or more equipped with a transponder (Traditional surveillance data available).
- ○ A formation of UAS, with NONE equipped with a transponder (Traditional surveillance data NOT available).

13. In your most recent experience, we would like to know more about what information of the UAS (or formation of UAS) you feel you needed access to and what information you had access to in future operations (if you feel the information is necessary or helpful).

For each of the types of information in the rows below, please select one answer for each of the groups of columns.

	Information Needs *			Information Availability *	
	Information was required	Information was NOT required but would have been helpful	Information was NOT required	Information was immediately available	Information was NOT immediately available
Current altitude	○	○	○	○	○
Current ground speed	○	○	○	○	○
Current air speed	○	○	○	○	○
Current heading	○	○	○	○	○
Current track	○	○	○	○	○
Planned maneuvers of UAS (e.g. flight planned route)	○	○	○	○	○

14. In your most recent experience, we would like to know more about what information about the UAS (or formation of UAS) you feel you needed access to, what information you had access to, and where such information should be accessed from in future operations (if you feel the information is necessary or helpful).

For each of the types of information in the rows below, please select one answer for each of the groups of columns.

	Information Needs *			Information Availability *	
	Information was required	Information was NOT required but would have been helpful	Information was NOT required	Information was immediately available	Information was NOT immediately available
The operator of the UAS (military unit, civilian company)	○	○	○	○	○
UAS Model / Type	○	○	○	○	○
# of UAS currently being supervised by the UAS pilot	○	○	○	○	○
Type of communication link between you and UAS pilot (radio / telephone / data-link)	○	○	○	○	○
UAS capabilities (e.g. turn rate, climb rate, min/max speed, weight, size, etc.)	○	○	○	○	○

15. Is there any additional information that was needed, or would have been useful to have? If so, please specify in the empty box(es) below.

	Information was required	Information was NOT required but would have been helpful
[ ]	○	○
[ ]	○	○
[ ]	○	○

16. Were there any challenges in obtaining, using or interpreting the information about the UAS (or formation of UAS)?

- ◯ Yes
- ◯ No

17. In your most recent experience, what information about the CAPABILITIES of the UAS (or formation of UAS) did you need access to and what information did you have access to in future operations (if you feel the information is necessary or helpful)?

	Information Needs *			Information Availability *	
	Information was required	Information was NOT required but would have been helpful	Information was NOT required	Information was immediately available	Information was NOT immediately available
Turn rate	◯	◯	◯	◯	◯
Climb rate	◯	◯	◯	◯	◯
Min/max speed	◯	◯	◯	◯	◯
Weight	◯	◯	◯	◯	◯
Size	◯	◯	◯	◯	◯
Mission	◯	◯	◯	◯	◯
See-and-avoid capabilities	◯	◯	◯	◯	◯

18. Is there any additional information about the CAPABILITIES of the UAS (or formation of UAS) that was needed, or would have been useful to have? If so, please specify in the empty box(es) below.

	Information was required	Information was NOT required but would have been helpful
[ ]	◯	◯
[ ]	◯	◯
[ ]	◯	◯

19. Please list 3 most important key factors describing the challenges you had in obtaining, using or interpreting the information about the UAS (or formation of UAS).

An example might be "screen clutter"

Factor #1 [ ]

Factor #2 [ ]

Factor #3 [ ]

20. Assume there is a non-transponder equipped UAS operating near an aircraft under your control.

What information about the UAS do you feel you would need access to in future operations (if you feel the information is necessary or helpful)?

For each of the types of information in the rows below, please select one answer for the group of columns.

	Information Needs *		
	Information would be required	Information would NOT be required but would be helpful	Information would NOT be required
Current altitude	○	○	○
Current air speed	○	○	○
Current ground speed	○	○	○
Current heading	○	○	○
Current track	○	○	○
Planned maneuvers of UAS (e.g. flight planned route)	○	○	○

21. For each of the additional types of information in the rows below, please select one answer for the group of columns.

	Information Needs *		
	Information would be required	Information would NOT be required but would be helpful	Information would NOT be required
The operator of the UAS (military unit, civilian company)	○	○	○
UAS Model / Type	○	○	○
# of UAS currently being supervised by the UAS pilot	○	○	○
Type of communication link between you and UAS pilot (radio / telephone / data-link)	○	○	○
UAS capabilities (e.g. turn rate, climb rate, min/max speed, weight, size, etc.)	○	○	○

22. Is there any additional information that would be needed, or would be useful to have? If so, please specify in the empty box(es) below.

	Information would be required	Information would NOT be required but would be helpful
[ ]	○	○
[ ]	○	○
[ ]	○	○

23. For the same situation, what information about the CAPABILITIES of the UAS (or formation of UAS) would you need access to in future operations (if you feel the information is necessary or helpful)?

	Information Needs *		
	Information would be required	Information would NOT be required but would be helpful	Information would NOT be required
Turn rate	○	○	○
Climb rate	○	○	○
Min/max speed	○	○	○
Weight	○	○	○
Size	○	○	○
Mission	○	○	○
See-and-avoid capabilities	○	○	○

24. Please list the 3 most important key factors describing the challenges you can imagine having obtaining, using or interpreting the information about a UAS.

An example might be "screen clutter".

Factor #1 [ ]

Factor #2 [ ]

Factor #3 [ ]

Section 3

A group of UAS may operate as part of a "swarm" or "flock" flying in (often loose) formation. The individual UAS in the formation may be moving quite randomly within confines of an overall average group motion. The following questions ask about the information you would need if a formation of UAS is operating in your airspace.

25. Please assume there is a formation of non-transponder equipped UAS operating near other controlled aircraft in your airspace.

In the table below, there are separate groups of columns for the individual UAS in the formation, and a "lead" or "primary" or "representative" UAS that is the leader of the formation.

For each of these categories, what information do you feel you would need access to in order to control the situation?

	For each and every individual UAS in the formation/swarm			For one (1) "lead" or "primary" UAS in the formation/swarm		
	Not required	Nice to have	Required	Not required	Nice to have	Required
Altitude	○	○	○	○	○	○
Ground Speed	○	○	○	○	○	○
Air Speed	○	○	○	○	○	○
Heading	○	○	○	○	○	○
Planned maneuvers of UAS (e.g. flight planned route)	○	○	○	○	○	○
Capabilities (e.g. turn rate, climb rate, min/max speed, weight, size, etc.)	○	○	○	○	○	○
Model / type	○	○	○	○	○	○
Size	○	○	○	○	○	○

26. Is there any other information about each individual UAS in the formation/swarm that would be nice to have or should be required?

	Nice to have	Required
[ ]	○	○
[ ]	○	○
[ ]	○	○

28. The altitude, direction and speed of a formation can be more complex than for an individual aircraft due to there being a range of possible values. For example, not all UAS in the formation may operate at the same altitude.

With respect to the altitude, direction and speed of a formation as a whole, what information do you feel you would need access to in order to control the situation?

	Not required	Nice to have	Required
Altitude of lowest UAS in formation	◯	◯	◯
Altitude of highest UAS in formation	◯	◯	◯
Average altitude of overall formation	◯	◯	◯
Heading of overall formation	◯	◯	◯
Ground speed of fastest UAS in formation	◯	◯	◯
Ground speed of slowest UAS in formation	◯	◯	◯
Average Ground speed of overall formation	◯	◯	◯
Air speed of fastest UAS in formation	◯	◯	◯
Air speed of slowest UAS in formation	◯	◯	◯
Average Air speed of overall formation	◯	◯	◯

Comments

29. In addition to altitude, direction and speed, there are other pieces of information describing a formation.

For the information pieces listed in the table below, what information do you feel you would need access to in order to control the situation?

	Not required	Nice to have	Required
The operator of the formation (military unit, civilian company)	◯	◯	◯
UAS model(s) / type(s) in the formation	◯	◯	◯
Planned maneuvers of the formation (e.g. flight planned route)	◯	◯	◯
Size of smallest UAS in the formation	◯	◯	◯
Size of largest UAS in the formation	◯	◯	◯
Average size of UAS in the formation	◯	◯	◯
Number of UAS in the formation	◯	◯	◯
Type of communication link between you and UAS pilot (radio / telephone / data-link)	◯	◯	◯

30. Is there any other information about the formation as a whole that is nice to have or should be required?

	Nice to have	Required
[ ]	○	○
[ ]	○	○
[ ]	○	○

Section 4

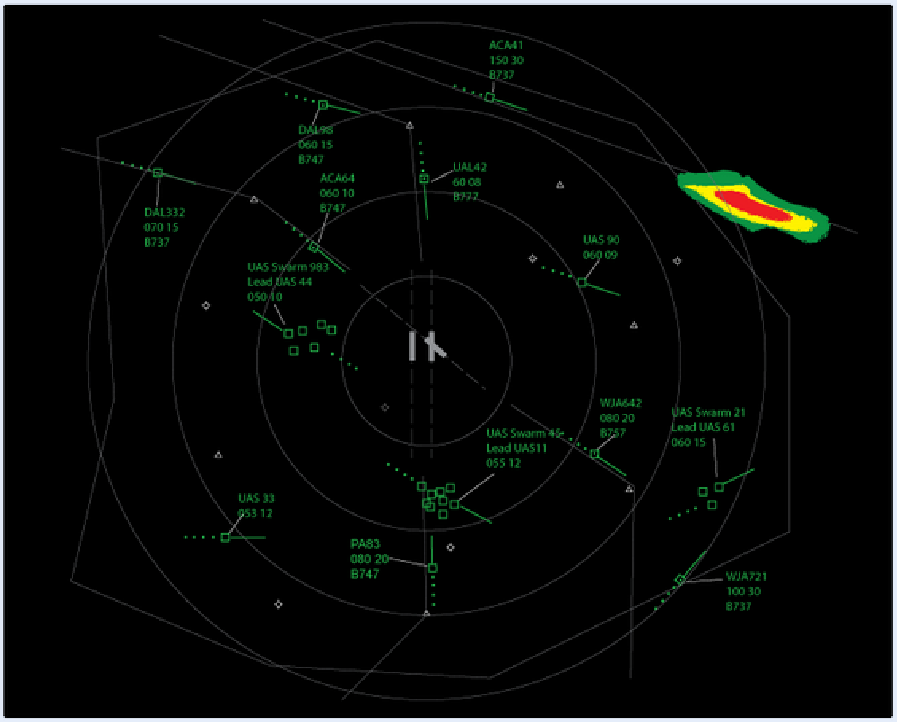
An advanced surveillance environment will likely be able to detect individual UASs operating as part of a formation or swarm.

The following pages show a wide range of potential ways a swarm/formation of non-transponder equipped UAS might be shown on the primary surveillance display. Not all are practical or would be operationally acceptable, but we are interested in your relative assessments of the different features that are present in each.

This page asks about your impressions of a presentation of a swarm where there is (see image below):

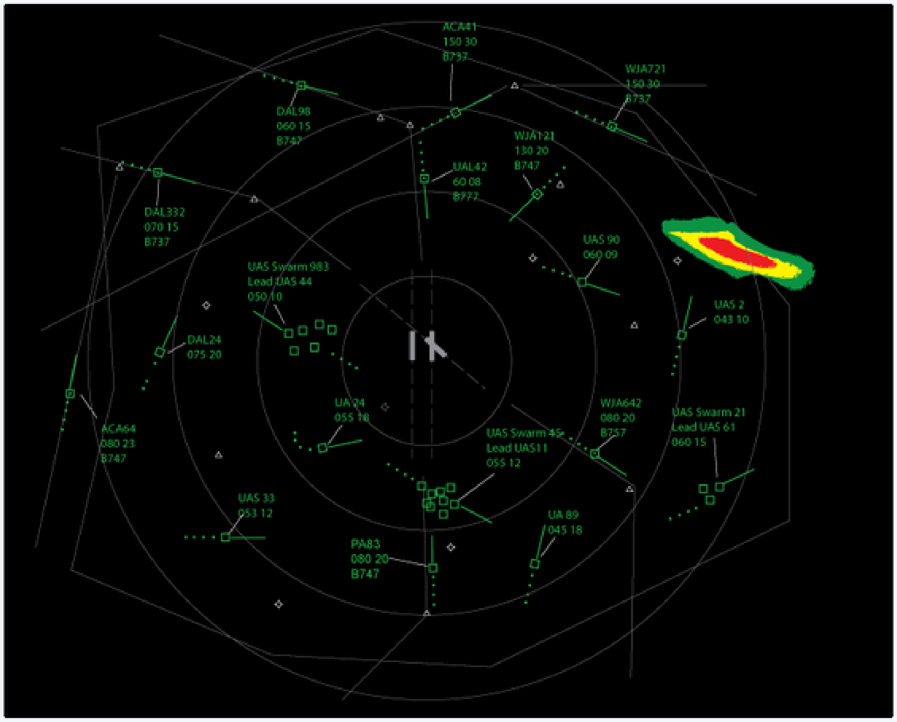
- a present position symbol is shown for each individual UAS in the swarm, and
- a single data-block shown for the swarm as a whole

Shown below are two illustrations of this type of presentation, the first in a relatively simple traffic situation and the second in a more complex traffic situation.



Above: Simple traffic situation (low traffic density)

Above: Simple traffic situation (low traffic density)

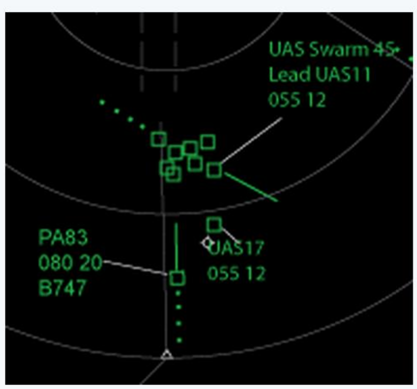


Above: Complex traffic situation (high traffic density)

In answering the questions below, please assume that your task is to separate all aircraft from UAS formations and from any UAS operating on their own.

31. How effective is this type of presentation at providing the information needed about a swarm of UAS to safely control a situation?

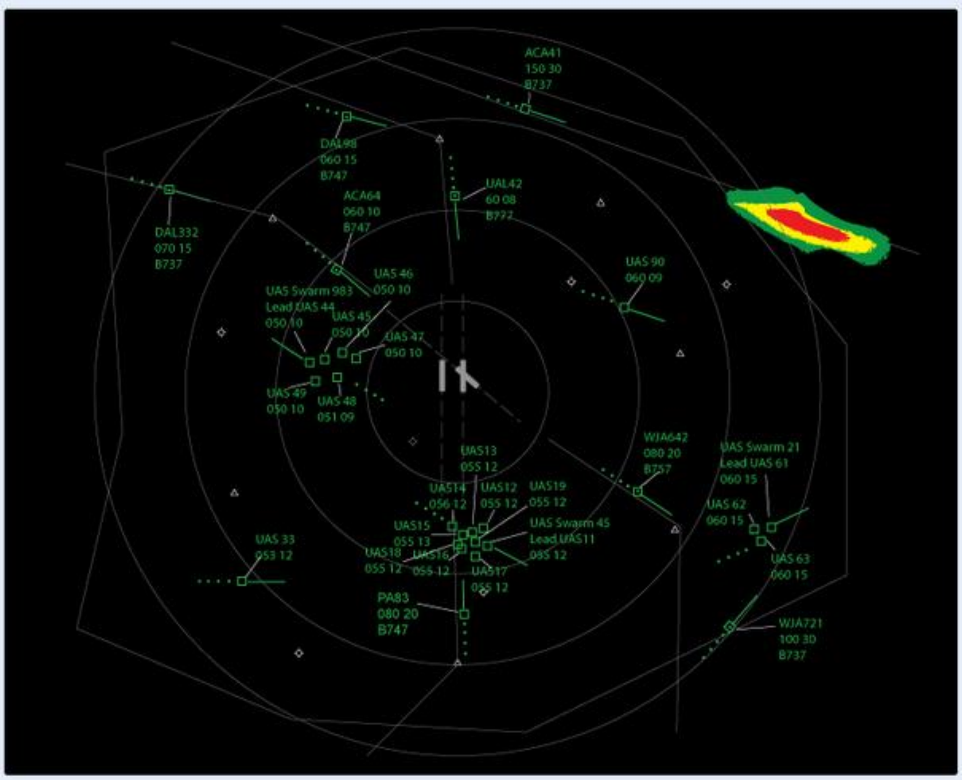
Very ineffective	Ineffective	Neutral	Effective	Very effective
○	○	○	○	○



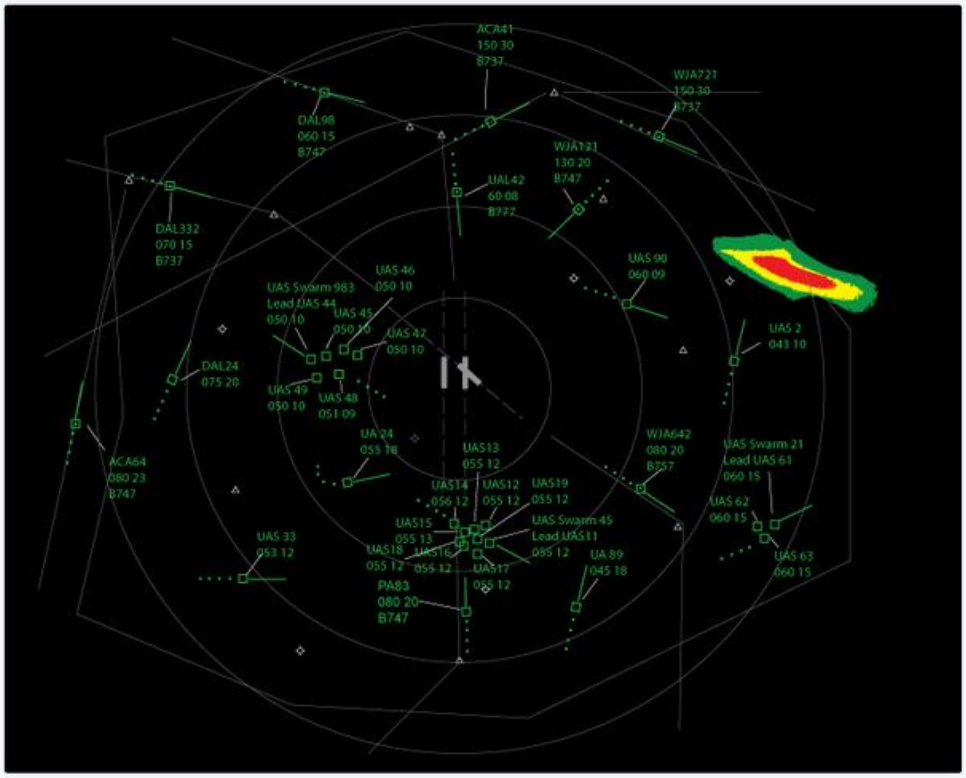
This page asks about your impressions of a presentation of a swarm where there is (see image below):

- a present position symbol AND Data block is shown for each individual UAS in the swarm, and
- a single Data Block is shown for the swarm as a whole

Shown below are two illustrations of this type of presentation, the first in a relatively simple traffic situation and the second in a more complex traffic situation.



Above: Simple traffic situation (low traffic density)



Above: Complex traffic situation (high traffic density)

In answering the questions below, please assume that your task is to separate all aircraft from UAS formations and from any UAS operating on their own.

35. How effective is this type of presentation at providing the information needed about a swarm of UAS to safely control a situation?

Very ineffective	Ineffective	Neutral	Effective	Very effective
○	○	○	○	○

36. Can you provide the 3 most appropriate keywords or short phrases to describe your impression of this type of presentation of a swarm of UAS?

Keyword 1 __________

Keyword 2 __________

Keyword 3 __________

37. Is there any critical information missing from this way of presentation of a formation/swarm of UAS? If yes, please specify in the comments below.

◯ Yes

◯ No

Comments

38. In the display below, assume one of the UAS (UAS 17) in the UAS Swarm 45 fails to maintain the intended formation flight and starts operating as an individual UAS.

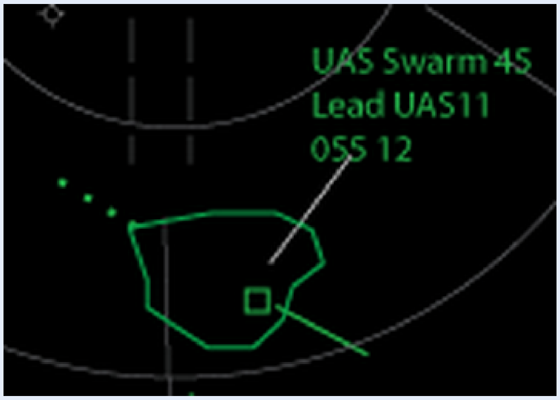
Please rate the effectiveness of this type of presentation for managing this situation.

Very ineffective	Ineffective	Neutral	Effective	Very effective
◯	◯	◯	◯	◯

Comments

This page asks about your impressions of a presentation of a swarm where there is (see image below):

- an outline circling all of the individual UAS in the swarm, and
- a single data-block shown for the swarm as a whole



In answering the questions below, please assume that your task is to separate all aircraft from UAS formations and from any UAS operating on their own.

39. How effective is this type of presentation at providing the information needed about a swarm of UAS to safely control a situation?

Very ineffective	Ineffective	Neutral	Effective	Very effective
○	○	○	○	○

40. Can you provide the 3 most appropriate keywords or short phrases to describe your impression of this type of presentation of a swarm of UAS?

Keyword 1 [ ]

Keyword 2 [ ]

Keyword 3 [ ]

41. Is there any critical information missing from this way of presentation of a formation/swarm of UAS? If yes, please specify in the comments below.

○ Yes

○ No

Comments

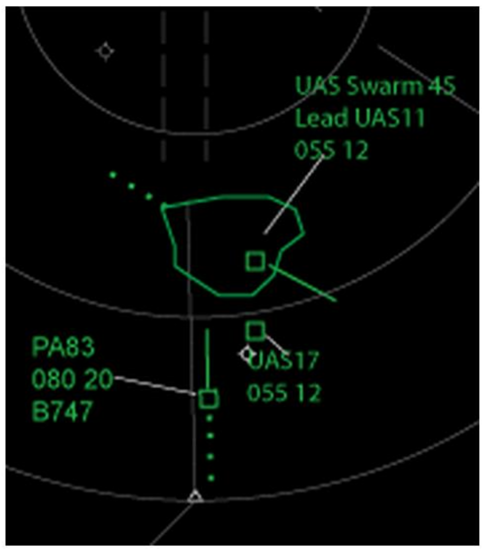
[ ]

42. In the display below, assume one of the UAS (UAS 17) in the UAS Swarm 45 fails to maintain the intended formation flight and starts operating as an individual UAS.

Please rate the effectiveness of this type of presentation for managing this situation.

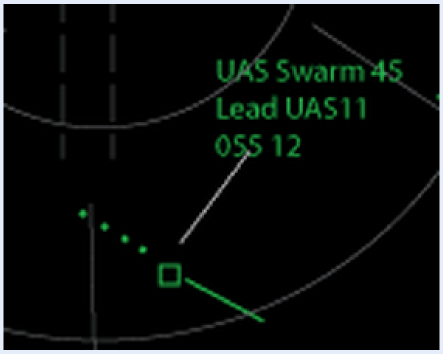
Very ineffective	Ineffective	Neutral	Effective	Very effective
○	○	○	○	○

Comments

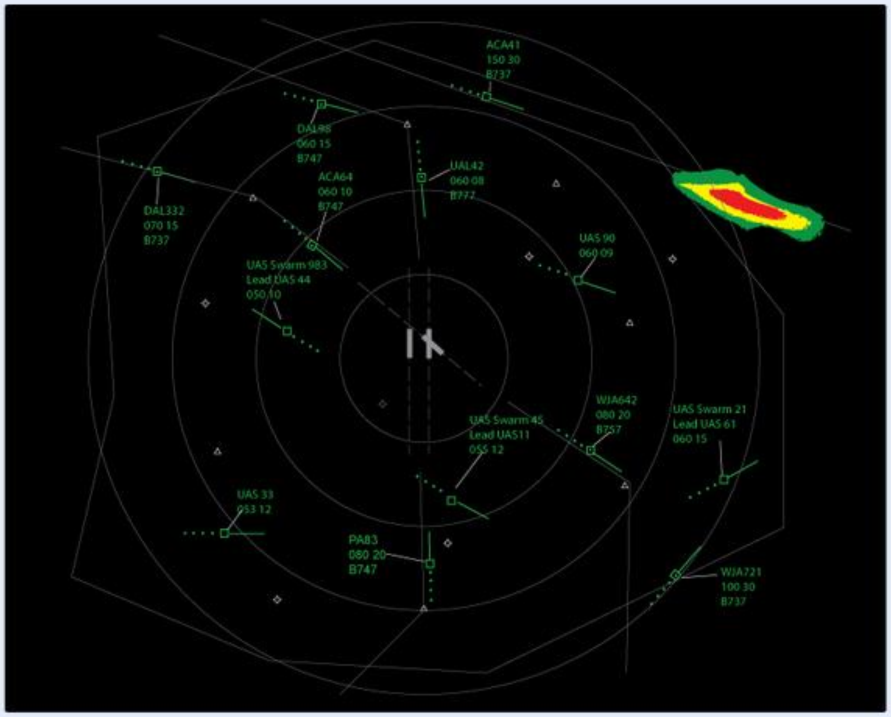


This page asks about your impressions of a presentation of a swarm where there is (see image below):

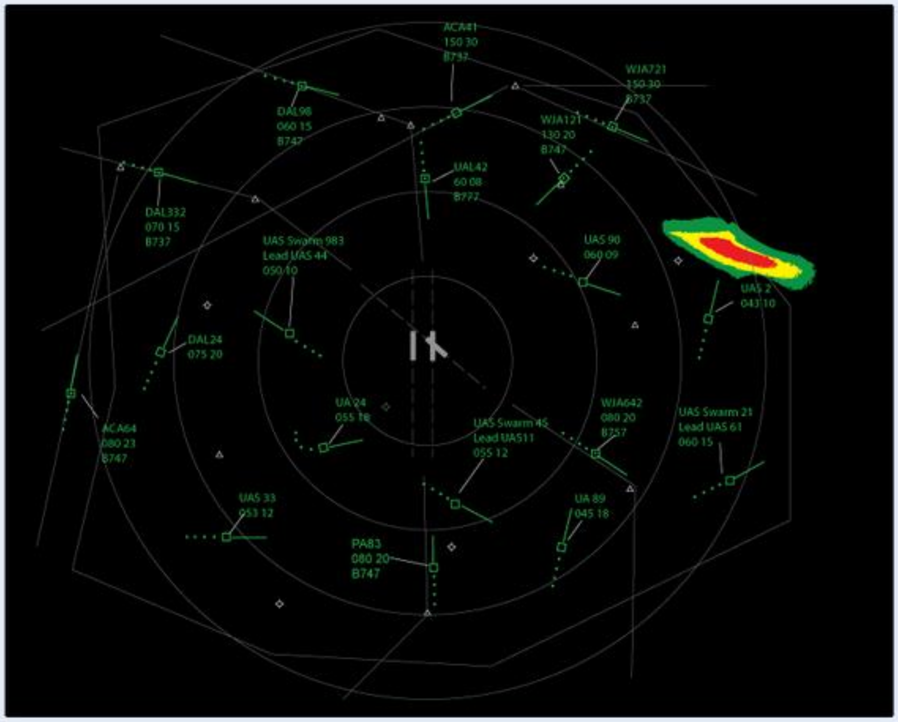
- One present position symbol for the position of a single "lead" UAS, and
- One data-block shown for the swarm as a whole



Shown below are two illustrations of this type of presentation, the first in a relatively simple traffic situation and the second in a more complex traffic situation.



Above: Simple traffic situation (low traffic density)



Above: Complex traffic situation (high traffic density)

In answering the questions below, please assume that your task is to separate all aircraft from UAS formations and from any UAS operating on their own.

43. How effective is this type of presentation at providing the information needed about a swarm of UAS to safely control a situation?

Very ineffective	Ineffective	Neutral	Effective	Very effective
○	○	○	○	○

44. Can you provide the 3 most appropriate keywords or short phrases to describe your impression of this type of presentation of a swarm of UAS?

Keyword 1 ________

Keyword 2 ________

Keyword 3 ________

45. Is there any critical information missing from this way of presentation of a formation/swarm of UAS? If yes, please specify in the comments below.

◯ Yes

◯ No

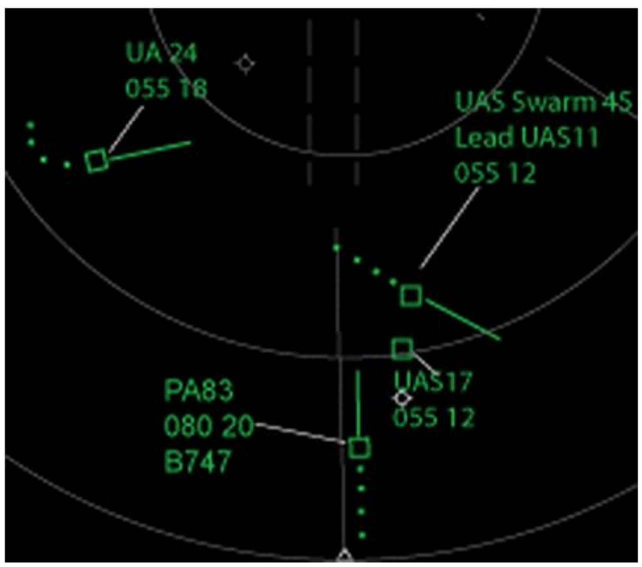
Comments

46. In the display below, assume one of the UAS (UAS 17) in the UAS Swarm 45 fails to maintain the intended formation flight and starts operating as an individual UAS.

Please rate the effectiveness of this type of presentation for managing this situation.

Very ineffective	Ineffective	Neutral	Effective	Very effective
◯	◯	◯	◯	◯

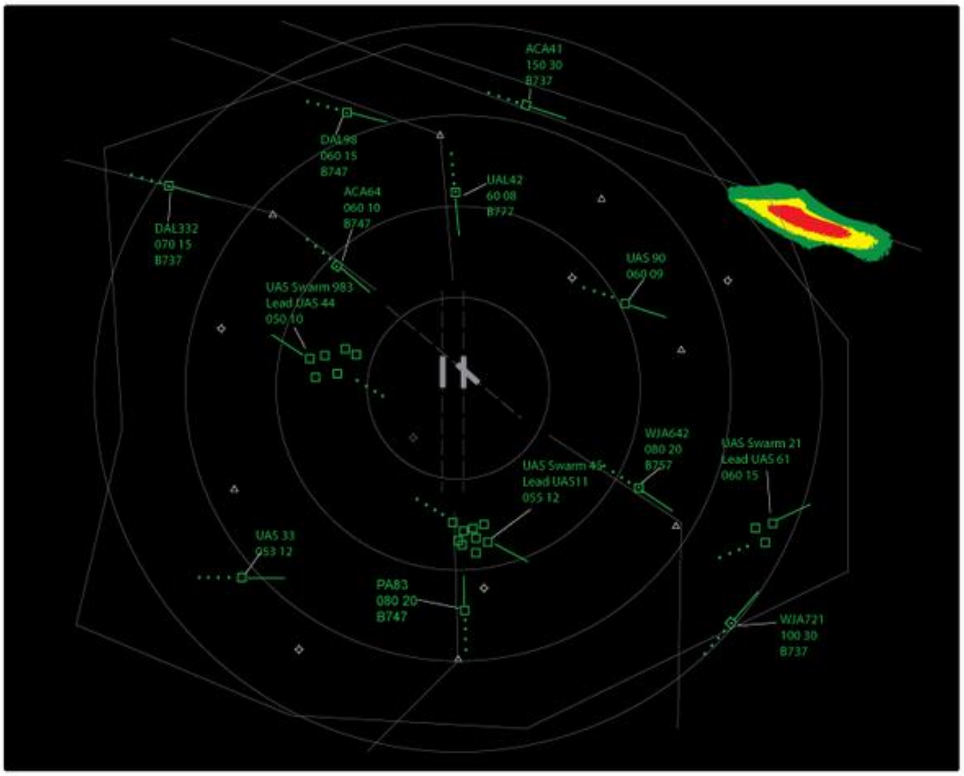
Comments



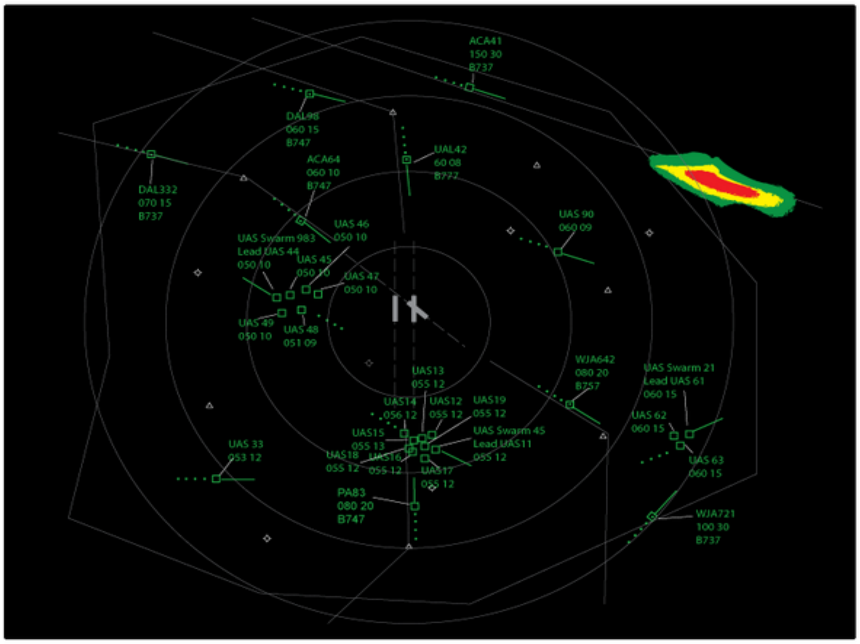
On the previous pages, you were presented with 4 different ways of showing a UAS swarm/formation.

The different types of presentation are shown again below for the case of a simple (low traffic density) situation.

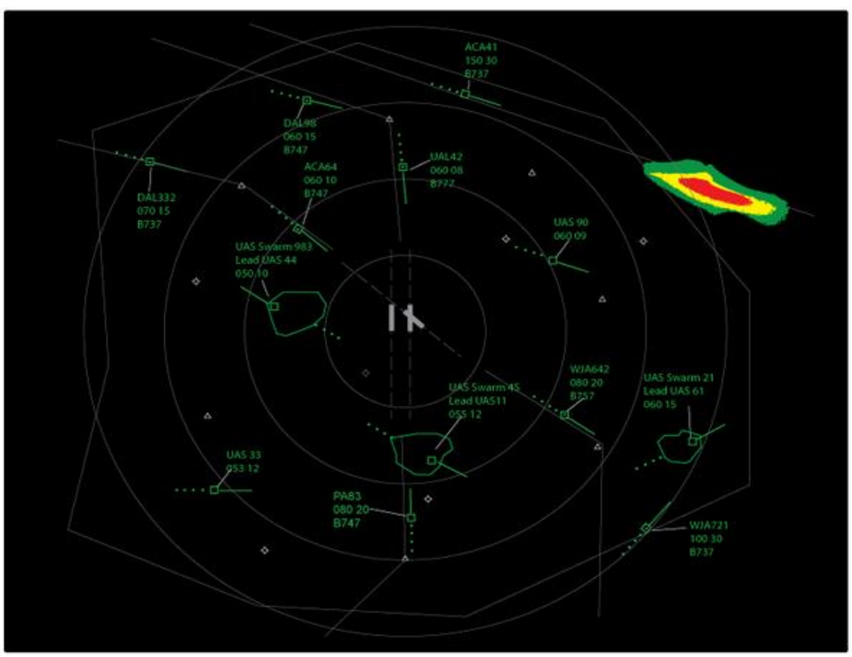
Presentation 1. Present position symbol of each UAS is shown with one datablock for the swarm as a whole.



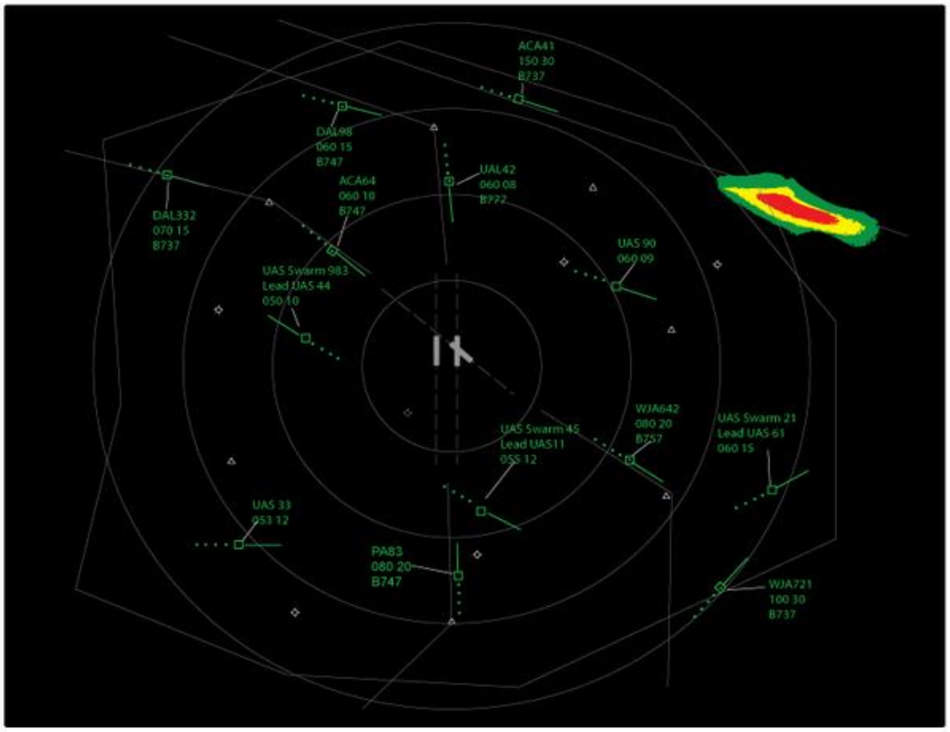
Presentation 2. Present position symbol and datablock of each and every UAS is shown as well as one datablock for the swarm as a whole.



Presentation 3. Outline circling positions of all UAS is shown with one datablock for the swarm as a whole



Presentation 4. Present position symbol of **only** the lead UAS is shown as well as one datablock for the swarm as a whole



47. For the low traffic density situation illustrated above, please rank the 4 types of presentation from most preferred to least preferred.

Please use the mouse to drag the options to the box on the right side.

The option you put in the first place would be the one you prefer the most. The one at the end would be the least desired type of presentation.

We ask you to please carefully examine the pictures above. **The order may not be the same as the order you answered questions about the individual presentation types**

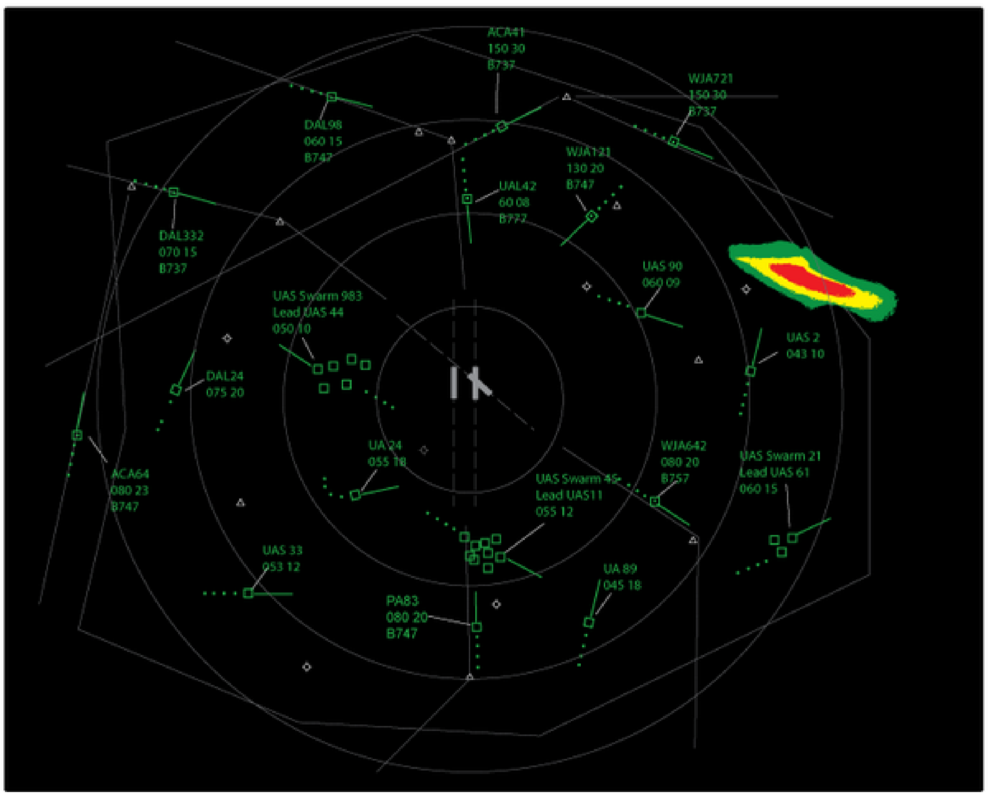
Drag items from the left-hand list into the right-hand list to order them.

- Present position symbol of each UAS is shown with one datablock for the swarm as a whole (Presentation 1)
- Present position symbol and datablock of each and every UAS is shown as well as one datablock for the swarm as a whole (Presentation 2)
- Outline circling positions of all UAS is shown with one datablock for the swarm as a whole (Presentation 3)
- Present position symbol of Only the lead UAS is shown as well as one datablock for the swarm as a whole (Presentation 4)

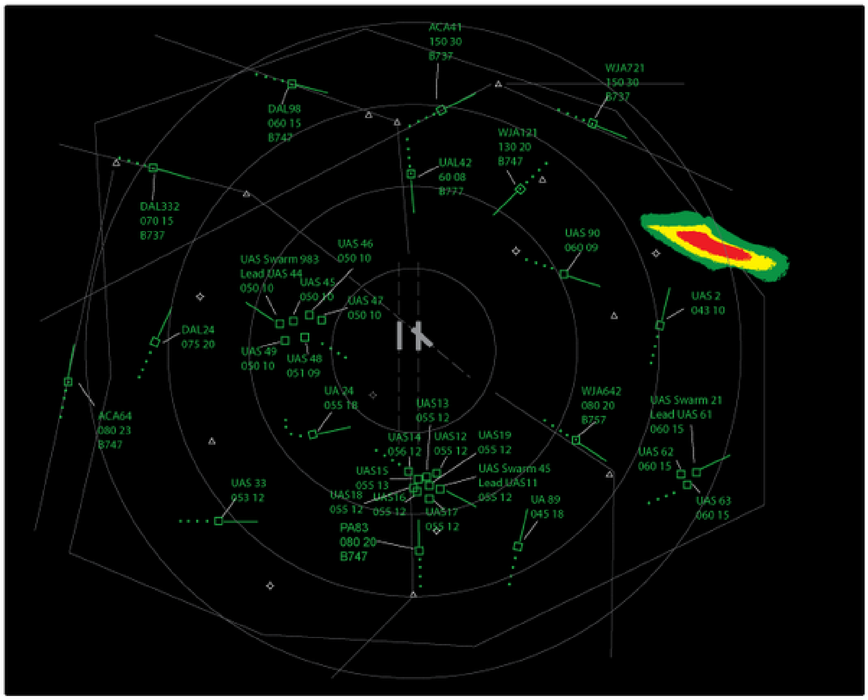
48. Could you briefly explain your choice for the ranking question?

The different types of presentation are shown again below for the case of a more complex (high traffic density) situation.

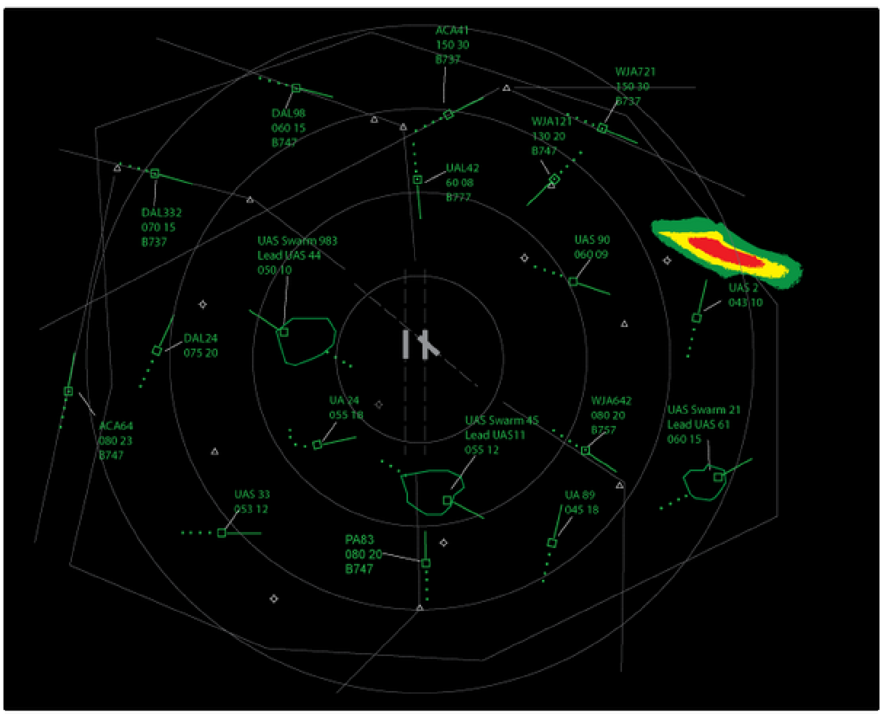
Presentation 1. Present position symbol of each UAS is shown with one datablock for the swarm as a whole.



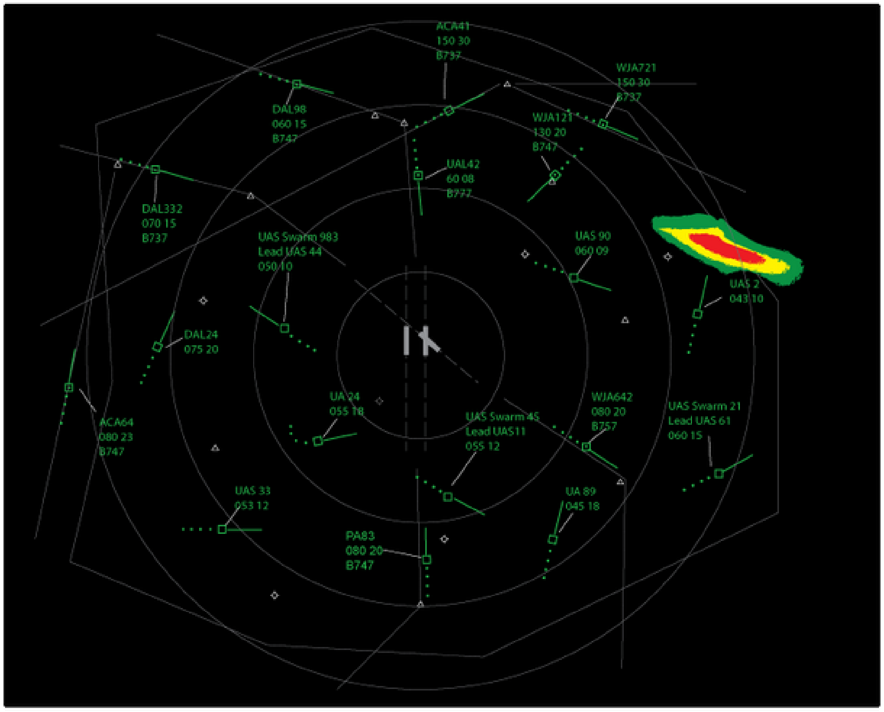
Presentation 2. Present position symbol and datablock of each and every UAS is shown as well as a datablock for swarm as a whole.



Presentation 3. Outline circling positions of all UAS is shown with one datablock for the swarm as a whole.



Presentation 4. Present position symbol and datablock of **only** the lead UAS is shown.



49. For the high traffic density situation illustrated above, please rank the 4 types of presentation from most preferred to least preferred.

Please use the mouse to drag the options to the box on the right side.

The option you put in the first place would be the one you prefer the most. The one at the end would be the least desired type of presentation.

We ask you to please carefully examine the pictures above. **The order may not be the same as the order you answered questions about the individual presentation types.**

Drag items from the left-hand list into the right-hand list to order them.

- Present position symbol of each UAS is shown with one datablock for the swarm as a whole (Presentation 1)
- Present position symbol and datablock of each and every UAS is shown as well as one datablock for the swarm as a whole (Presentation 2)
- Outline circling positions of all UAS is shown with one datablock for the swarm as a whole (Presentation 3)
- Present position symbol of Only the lead UAS is shown as well as one datablock for the swarm as a whole (Presentation 4)

50. Could you briefly explain your choice for the ranking question?

51. Under what circumstances, if any, would the ranking of the presentation you provided in previous question be different?

Section 5

In a next-generation surveillance environment, additional information about "non-cooperative" objects will become available (e.g. "non-cooperative" objects). For example, individual birds could be reliably identified, and species information used to filter which birds are shown or not shown.

More importantly, this enhanced surveillance information could also be made available directly to pilots in their cockpit.

The following questions ask about your perspective on current challenges communicating with pilots about objects that pose potential hazards, and the communication challenges that might be created by sharing additional surveillance information directly with pilots.

52. What are the 3 most important advantages you can see occurring if surveillance information about non-cooperative targets (e.g. birds) was shared directly with pilots?

Advantage #1 [ ]

Advantage #2 [ ]

Advantage #3 [ ]

53. What are the 3 most important concerns you might have if surveillance information about non-cooperative targets (e.g. birds) was shared directly with pilots?

Concern #1 [ ]

Concern #2 [ ]

Concern #3 [ ]

Sometimes there are differences in how long it takes surveillance information about a common "non-cooperative" object to reach a pilot and the controller.

For example, controllers and pilots each have access to weather radar displays, but the data is collected in different ways and at different points in time. Therefore, there might be a difference in the information age.

54. Please assume you are working a final approach position for a busy terminal area.

On your primary surveillance display there are several non-cooperative objects (birds and/or UAS).

One of the non-cooperative objects is crossing a plane's flight path on the final approach, creating the need for a non-emergency evasive maneuver.

The pilots of the plane have a display that also shows the non-cooperative objects. However, the pilot's display may have more up-to-date or less up-to-date positions of the non-cooperative objects than the positions shown on your display.

Please answer the following questions based on your own experiences and with respect to what you feel would be operationally acceptable differences.

For this situation, what is the maximum time delay (in seconds) between your display and the pilot's display? [ ]

Would your answer change if the pilot's display is the one that is more up-to-date or if it is your display that is more-up-to-date? [ ]

For this situation, what is the maximum distance (in nautical miles) between the actual (real world) position of the non-cooperative objects and the position of the non-cooperative objects shown on your primary surveillance display? [ ]

Section 6

If objects are operating near the limits of detectability for a surveillance system, the object may not be continuously detected. This "**intermittency effect**" can cause an object to appear and disappear from the surveillance display or the surveillance display may show the present position with a different symbol to indicate that surveillance data has been temporarily lost (e.g. "coast mode").

We are interested in learning more about the consequences of this characteristic of any surveillance system and how it may impact the integration of UAS into airspace in the future.

55. From your experience as a controller, in your last year of experience, how often have you observed the "intermittency effect" for an aircraft under your control? Please select the best answer. *

- ◯ I don't understand what is meant by the "intermittency effect".
- ◯ Never. I have never observed the "intermittency effect."
- ◯ Very rarely. I have observed the "intermittency effect" but it happens very infrequently.
- ◯ Rarely. I have observed the "intermittency effect" about every month.
- ◯ Sometimes. I have observed the "intermittency effect" about once a week.
- ◯ Often. I have observed the "intermittency effect" at least once a day.
- ◯ Very often. I have observed the "intermittency effect" hourly.

56. Have you observed the "intermittency effect" with any UAS operating in your airspace?

- ◯ Yes
- ◯ No

57. When the "intermittency effect" occurs for an aircraft under your control, on average, how long are the periods of time during which no surveillance data is available? Please select the best response below, or use the blank box to provide your own estimate.

- ◯ 0 to 5 seconds
- ◯ 6 to 10 seconds
- ◯ 11 to 30 seconds
- ◯ 31 to 60 seconds
- ◯ More than 1 minute
- ◯ Other [ ]

58. Please rate your level of satisfaction with how the current technology in the current radar surveillance environment handles the "intermittency effect" for aircraft under your control.

- ◯ Not very satisfied
- ◯ Not satisfied
- ◯ Neutral
- ◯ Satisfied
- ◯ Very satisfied
- ◯ Don't know / Not enough experience to answer

59. Which of the following are examples of challenges with how the "intermittency effect" for an aircraft under your control is currently handled. Please select any and all that apply.

If there are important challenges that you have experienced but they are not listed below, please add them in the boxes provided.

- [ ] The only change on my display is in the type of symbol used to indicate the position of the aircraft. This is difficult to notice.
- [ ] Aircraft disappear completely from the surveillance screen, forcing me to remember where the aircraft were.
- [ ] There is no indication that the present position is estimated or projected rather than an actual position.
- [ ] "Intermittency effect" appears to occur randomly, in locations and at times that cannot be predicted.
- [ ] Alerts and warnings that surveillance tracking has been lost are distracting and draw my attention away from more critical tasks.
- [ ] Other ______
- [ ] Other ______
- [ ] Other ______

60. Are there any differences in how the "intermittency effect" for a UAS affects your decision making as compared to the "intermittency effect" for a traditional, piloted, aircraft? If you have not observed the "intermittency effect" with any UAS, please click "Not Applicable" to proceed to the next page.

- ( ) Yes
- ( ) No
- ( ) Not Applicable

Comments

______

61. Do you think there will be any differences in how the "intermittency effect" for a UAS affects your decision making as compared to an "intermittency effect" for a traditional aircraft? Please comment or explain.

- ( ) Yes
- ( ) No

Comments

______

One final question....

62. Would you like to share with us any more thoughts? Any comments and feedback are welcome!

______

Congratulations! You have just finished the survey.

Thank you for taking our survey. Your response is very important to us.

This survey is part of Xiaochen Yuan's Master's thesis. Would you like to receive the results of the study after it is finished? If so, please contact Xiaochen Yuan at xiaochen.yuan@uwaterloo.ca. Do you know of any other controllers who would be interested in completing the survey? If so, please have them contact Xiaochen Yuan.

Feedback Letter

Systems Design Engineering
University of Waterloo

Dear Participant,

I would like to thank you for your participation and time commitment to this study entitled Investigating the controller and pilot preference of non-cooperative objects information level of detail. As a reminder, the purpose of the study is to identify the controllers' and pilots' requirements of non-cooperative objects information, especially unmanned aircraft systems information. The data collected during the study will contribute to a better understanding of the operators' perception of non-cooperative object information.

Please remember that any data pertaining to you as an individual participant will be kept confidential. Once all the data are collected and analyzed for this project, I plan on sharing this information with the research community through seminars, conferences, presentations, and journal articles. If you are interested in receiving more information regarding the results of this study, or would like a summary of the results, please email the researcher at Xiaochen.yuan@uwaterloo.ca , and when the study is completed, anticipated by June 30th, 2013, I will send you the information. In the meantime, if you have any questions about the study, please do not hesitate to contact me by email or telephone as noted below. As with all University of Waterloo projects involving human participants, this project was reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. Should you have any comments or concerns resulting from your participation in this study, please contact Dr. Maureen Nummelin, the Director, Office of Research Ethics, at 1-519-888-4567, Ext. 36005 or maureen.nummelin@uwaterloo.ca.

If you are interested in learning more about this project and background, please refer to [1] for more detailed information.

Your participation is greatly appreciated.

Xiaochen Yuan
Human in Complex Systems Lab
Systems Design Engineering
University of Waterloo
226-338-8312
xiaochen.yuan@uwaterloo.ca

Reference

[1] X. Yuan, J. Histon, S. Waslander, R. Dizaji and C. Schneider. "Distributing Non-cooperative Surveillance Data: A Preliminary Model and Evaluation of Potential Use Cases," presented at the 12th Integrated Communications Navigation and Surveillance Conference, VA, U.S.A, 2012.

Appendix D.

Survey of Pilot Information Needs for Integrating UAS

Welcome to the Survey of Pilot Information Needs for Integrating Unmanned Aircraft Systems (UAS) into Controlled Airspace!

In this survey, you will be asked questions about

1. your experience with unmanned aircraft systems,
2. your opinion on what information about UAS should be displayed as part of collision avoidance displays,
3. and how access to more detailed surveillance information would affect your communications with controllers.

All the information collected in the survey will be anonymous and confidential. You may quit the survey at any time, without penalty, by closing the window.

Please be noted that the survey has to be completed at **one sitting**, because we do not collect your personal information (i.e. IP address).

When you are ready, please click "Next" to proceed to the next page. If at any time, you would like to go back to the previous page, please click the "Back" button in the survey instead of on your browser.

To allow us to compare the perceptions of different groups, the following questions ask you to provide demographic information and details of your professional background.

1. What is your age?

- ◯ <20
- ◯ 20 - 29
- ◯ 30 - 39
- ◯ 40 - 49
- ◯ >50

2. Gender

- ◯ Male
- ◯ Female

3. Are you currently licensed to work as a pilot?

- ◯ Yes
- ◯ No, I am retired
- ◯ No, I have never been licensed

4. What is the highest pilot certification that you currently hold? If other, please specify.

- ◯ Sport pilot
- ◯ Private pilot
- ◯ Commercial pilot
- ◯ Air transport pilot
- ◯ Other __________

5. Approximately how many flight hours do you have in total?

[ ]

6. Approximately how many flight hours do you have in the past 90 days?

[ ]

7. In what country/region do you fly the most?

-- Please Select --

Section 1

8. In your experience, what are the 3 most important limitations of the current methods by which you become aware of the location of other potentially hazardous objects (birds / UAS / balloons etc..) near your aircraft?

Limitation #1 [ ]

Limitation #2 [ ]

Limitation #3 [ ]

9. What are the 3 most important features or improvements that should be included in a next generation collision avoidance display?

Improvement #1 [ ]

Improvement #2 [ ]

Improvement #3 [ ]

The next series of questions will ask about your previous experiences with Unmanned Aircraft Systems (UAS).

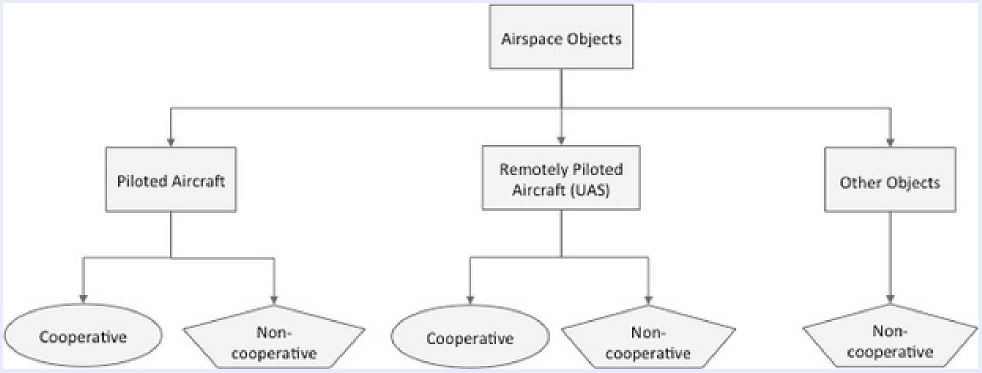
In order to better understand your previous experiences with UAS we ask you to distinguish between 3 categories of objects: piloted aircraft, remotely-piloted aircraft, and other objects.

- **Piloted aircraft** refers to aircraft which are controlled by a pilot(s) on-board the aircraft.
- **Remotely piloted aircraft**, however, do not have the pilot on board but are controlled from a separate control station (typically on the ground). Remotely piloted aircraft are known by several names, we will refer to them as Unmanned Aircraft Systems (UAS). You may also know them as Remote-piloted aircraft (RPAs) and/or Unmanned aerial vehicles (UAVs).

We also ask you to distinguish between two types of objects that can be detected by a surveillance system. One type are objects that are "**cooperative**", and have on-board equipage (e.g. transponders) that work with existing surveillance sources (e.g. secondary radar, ADS-B and variants such as ADS-C). For these objects, the surveillance source can provide information about current altitude, position, and speed of the object.

The second type of object is "**non-cooperative**", and must be detected using surveillance sources that do not rely on the capabilties on-board the object. This may be because the object is incapable (e.g. vintage aircraft), too small, is a bird, balloon, or weather, or because it is actively trying to avoid detection. While these objects may sometimes pose hazards to aircraft, only limited information (e.g. position) is currently available about them.

The following figure illustrates these distinctions:



The following are questions about your previous experiences with cooperative and non-cooperative unmanned aircraft systems (UAS).

10. For each of the types of UAS shown in the columns below, please select any and all applicable experiences listed in the rows.

If there is a type of experience with a UAS that is not covered by the items in the list, please add it in the empty box(es) below.

	A "Cooperative" individual UAS (e.g. equipped with a transponder making traditional surveillance data available)	A "Non-cooperative" individual UAS (e.g. NOT equipped with a transponder making traditional surveillance data NOT available)	A formation of "Cooperative" UAS (e.g. where one or more was equipped with a transponder making traditional surveillance data available)	A formation of "Non-cooperative" UAS (e.g. where NONE were equipped with a transponder making traditional surveillance data NOT available)
I have NEVER encountered any situation involving this type of UAS	☐	☐	☐	☐
I have discussed with other pilots about their experience maneuvering around this type of UAS	☐	☐	☐	☐
I have been aware of the presence of this type of UAS at a close range to me	☐	☐	☐	☐
I had to alter the course of my aircraft while taking into consideration the presence of this type of UAS	☐	☐	☐	☐
I have collided with this type of UAS	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐

11. In your flight experience, where have you observed UAS operating?

For each type of UAS, please select any and all of the location descriptions that apply.

If there is a location that is not in the list, please add it in one of the blank boxes.

	A "Cooperative" individual UAS (e.g. equipped with a transponder making traditional surveillance data available)	A "Non-cooperative" individual UAS (e.g. NOT equipped with a transponder making traditional surveillance data NOT available)	A formation of "Cooperative" UAS (e.g. where one or more was equipped with a transponder making traditional surveillance data available)	A formation of "Non-cooperative" UAS (e.g. where NONE were equipped with a transponder making traditional surveillance data NOT available)
In close proximity to my aircraft	☐	☐	☐	☐
In airspace designated for UAS operations	☐	☐	☐	☐
On my pre-scheduled flight path	☐	☐	☐	☐
[blank text box]	☐	☐	☐	☐
[blank text box]	☐	☐	☐	☐
[blank text box]	☐	☐	☐	☐

Section 2

The following questions ask about your most recent experience dealing with a UAS, or formation of UAS, in your airspace.

12. What type of UAS was involved in your most recent experience with a UAS?

- ○ An individual UAS equipped with a transponder (Traditional surveillance data available).
- ○ An individual UAS NOT equipped with a transponder (Traditional surveillance data NOT available).
- ○ A formation of UAS, one or more equipped with a transponder (Traditional surveillance data available).
- ○ A formation of UAS, with NONE equipped with a transponder (Traditional surveillance data NOT available).

13. In your most recent experience, we would like to know what information about the UAS (or formation of UAS) you feel you needed access to and what information you had access to.

For each of the types of information in the rows below, please select one answer for each of the groups of columns.

	Information Needs *			Information Availability *	
	Information was required	Information was NOT required but would have been helpful	Information was NOT required	Information was immediately available	Information was NOT immediately available
Current altitude	○	○	○	○	○
Current ground speed	○	○	○	○	○
Current air speed	○	○	○	○	○
Current heading	○	○	○	○	○
Current track	○	○	○	○	○
Planned maneuvers of UAS (e.g. flight planned route)	○	○	○	○	○

14. In your most recent experience, we would like to know what information about the UAS (or formation of UAS) you feel you needed access to, and what information you had access to.

For each of the types of information in the rows below, please select one answer for each of the groups of columns.

	Information Needs *			Information Availability *	
	Information was required	Information was NOT required but would have been helpful	Information was NOT required	Information was immediately available	Information was NOT immediately available
The operator of the UAS (military unit, civilian company)	○	○	○	○	○
UAS Model / Type	○	○	○	○	○
# of UAS currently being supervised by the UAS pilot	○	○	○	○	○
Type of communication link between the air traffic control system and the UAS pilot (e.g. radio / telephone / data-link)	○	○	○	○	○
UAS capabilities (e.g. turn rate, climb rate, min/max speed, weight, size, etc.)	○	○	○	○	○

15. Is there any additional information that was needed, or would have been useful to have? If so, please specify in the empty box(es) below.

	Information was required	Information was NOT required but would have been helpful
[ ]	○	○
[ ]	○	○
[ ]	○	○

16. Were there any challenges in obtaining, using or interpreting the information about the UAS (or formation of UAS)?

- ◯ Yes
- ◯ No

Comments

[ ]

17. In your most recent experience, what information about the CAPABILITIES of the UAS (or formation of UAS) did you need access to and what information did you have access to?

	Information Needs *			Information Availability *	
	Information was required	Information was NOT required but would have been helpful	Information was NOT required	Information was immediately available	Information was NOT immediately available
Turn rate	◯	◯	◯	◯	◯
Climb rate	◯	◯	◯	◯	◯
Min/max speed	◯	◯	◯	◯	◯
Weight	◯	◯	◯	◯	◯
Size	◯	◯	◯	◯	◯
Mission	◯	◯	◯	◯	◯
See-and-avoid capabilities	◯	◯	◯	◯	◯

18. Is there any additional information about the CAPABILITIES of the UAS (or formation of UAS) that was needed, or would have been useful to have? If so, please specify in the empty box(es) below.

	Information was required	Information was NOT required but would have been helpful
[ ]	◯	◯
[ ]	◯	◯
[ ]	◯	◯

19. Please list 3 most important key factors describing the challenges you had in obtaining, using or interpreting the information about the UAS (or formation of UAS).

An example might be "screen clutter"

Factor #1 [ ]

Factor #2 [ ]

Factor #3 [ ]

20. Assume there is a non-transponder equipped UAS operating near your aircraft.

What information about the UAS do you feel you would need access to in future operations?

For each of the types of information in the rows below, please select one answer.

	Information Needs *		
	Information would be required	Information would NOT be required but would be helpful	Information would NOT be required
Current altitude	○	○	○
Current air speed	○	○	○
Current ground speed	○	○	○
Current heading	○	○	○
Current track	○	○	○
Planned maneuvers of UAS (e.g. flight planned route)	○	○	○

21. For each of the additional types of information in the rows below, please select one answer.

	Information Needs *		
	Information would be required	Information would NOT be required but would be helpful	Information would NOT be required
The operator of the UAS (military unit, civilian company)	○	○	○
UAS Model / Type	○	○	○
# of UAS currently being supervised by the UAS pilot	○	○	○
Type of communication link between the air traffic control system and the UAS pilot (radio / telephone / data-link)	○	○	○
UAS capabilities (e.g. turn rate, climb rate, min/max speed, weight, size, etc.)	○	○	○

22. Is there any additional information that would be needed, or would be useful to have? If so, please specify in the empty box(es) below.

	Information would be required	Information would NOT be required but would be helpful
[ ]	○	○
[ ]	○	○
[ ]	○	○

24. Please list the 3 most important key factors describing the challenges you can imagine having obtaining, using or interpreting the information about a UAS.

An example might be "screen clutter".

Factor #1 [ ]

Factor #2 [ ]

Factor #3 [ ]

23. For the same situation, what information about the CAPABILITIES of the UAS (or formation of UAS) would you need access to in future operations (if you feel the information is necessary or helpful)?

	Information Needs *		
	Information would be required	Information would NOT be required but would be helpful	Information would NOT be required
Turn rate	◯	◯	◯
Climb rate	◯	◯	◯
Min/max speed	◯	◯	◯
Weight	◯	◯	◯
Size	◯	◯	◯
Mission	◯	◯	◯
See-and-avoid capabilities	◯	◯	◯

Section 3

A group of UAS may operate as part of a "swarm" or "flock" flying in (often loose) formation. The individual UAS in the formation may be moving quite randomly within confines of an overall average group motion. The following questions ask about the information you would need if a formation of UAS is operating near your aircraft.

25. Please assume there is a formation of non-transponder equipped UAS operating near your aircraft.

In the table below, there are separate groups of columns for the individual UAS in the formation, and a "lead" or "primary" or "representative" UAS that is the leader of the formation.

For each of these categories, what information do you feel you would need access to in order to navigate safely?

	For each and every individual UAS in the formation/swarm			For one (1) "lead" or "primary" UAS in the formation/swarm		
	Not required	Nice to have	Required	Not required	Nice to have	Required
Altitude	◯	◯	◯	◯	◯	◯
Ground Speed	◯	◯	◯	◯	◯	◯
Air Speed	◯	◯	◯	◯	◯	◯
Heading	◯	◯	◯	◯	◯	◯
Planned maneuvers of UAS (e.g. flight planned route)	◯	◯	◯	◯	◯	◯
Capabilities (e.g. turn rate, climb rate, min/max speed, weight, size, etc.)	◯	◯	◯	◯	◯	◯
Model / type	◯	◯	◯	◯	◯	◯
Size	◯	◯	◯	◯	◯	◯

26. Is there any other information about each individual UAS in the formation/swarm that would be nice to have or should be required?

	Nice to have	Required
[ ]	○	○
[ ]	○	○
[ ]	○	○

27. Is there other information about the lead UAS in the formation/swarm that would be nice to have or should be required?

	Nice to have	Required
[ ]	○	○
[ ]	○	○
[ ]	○	○

29. In addition to altitude, direction and speed, there are other pieces of information describing a formation.

For the information pieces listed in the table below, what information do you feel you would need access to in order to maintain safe operations around the formation?

	Not required	Nice to have	Required
The operator of the formation (military unit, civilian company)	○	○	○
UAS model(s) / type(s) in the formation	○	○	○
Planned maneuvers of the formation (e.g. flight planned route)	○	○	○
Size of smallest UAS in the formation	○	○	○
Size of largest UAS in the formation	○	○	○
Average size of UAS in the formation	○	○	○
Number of UAS in the formation	○	○	○
Type of communication link between Air Traffic Control and the UAS pilot (radio / telephone / data-link)	○	○	○

Comments

[ ]

28. The altitude, direction and speed of a formation can be more complex than for an individual aircraft due to there being a range of possible values. For example, not all UAS in the formation may operate at the same altitude.

With respect to the altitude, direction and speed of a formation as a whole, what information do you feel you would need access to in order to maintain safe operations while near the formation of UAS?

	Not required	Nice to have	Required
Altitude of lowest UAS in formation	○	○	○
Altitude of highest UAS in formation	○	○	○
Average altitude of overall formation	○	○	○
Heading of overall formation	○	○	○
Ground speed of fastest UAS in formation	○	○	○
Ground speed of slowest UAS in formation	○	○	○
Average Ground speed of overall formation	○	○	○
Air speed of fastest UAS in formation	○	○	○
Air speed of slowest UAS in formation	○	○	○
Average Air speed of overall formation	○	○	○

Comments

30. Is there any other information about the formation as a whole that is nice to have or should be required?

	Nice to have	Required
	○	○
	○	○
	○	○

Section 4

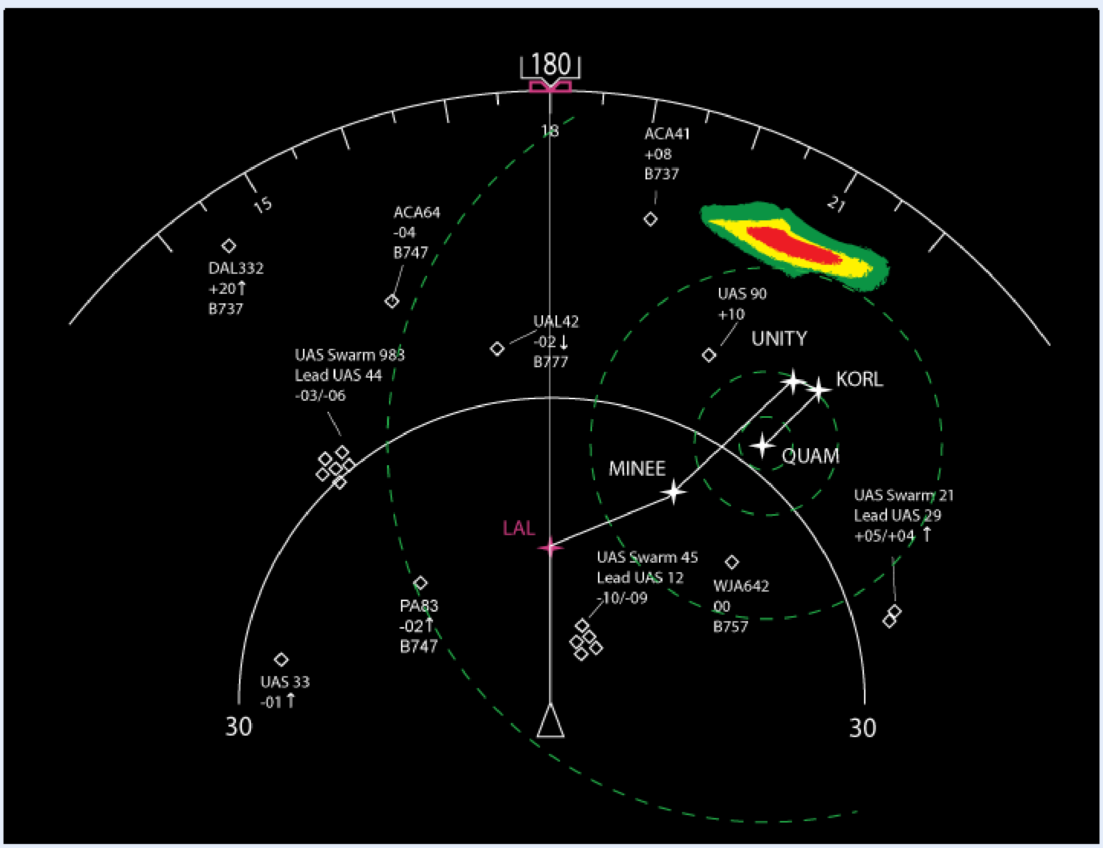
An advanced surveillance environment will likely be able to detect individual UASs operating as part of a formation or swarm.

The following pages show a wide range of potential ways a swarm/formation of non-transponder equipped UAS might be shown on a primary navigation display/collision avoidance system display. Not all are practical or would be operationally acceptable, but we are interested in your relative assessments of the different features that are present in each.

This page asks about your impressions of a presentation of a swarm where there is (see image below):

- a present position symbol is shown for each individual UAS in the swarm, and
- a single data-block shown for the swarm as a whole

Shown below is an illustration of this type of presentation in a navigation display.



In answering the questions below, please assume that your task is to follow the pre-scheduled path and land at QUAM.

31. How effective is this type of presentation at providing the information needed to operate safely near a swarm of UAS?

Very ineffective	Ineffective	Neutral	Effective	Very effective
◯	◯	◯	◯	◯

32. Can you provide the 3 most appropriate keywords or short phrases to describe your impression of this type of presentation of a swarm of UAS?

Keyword 1 __________

Keyword 2 __________

Keyword 3 __________

33. Is there any critical information missing from this way of presentation of a formation/swarm of UAS? If yes, please specify what is missing in the comments below.

◯ Yes

◯ No

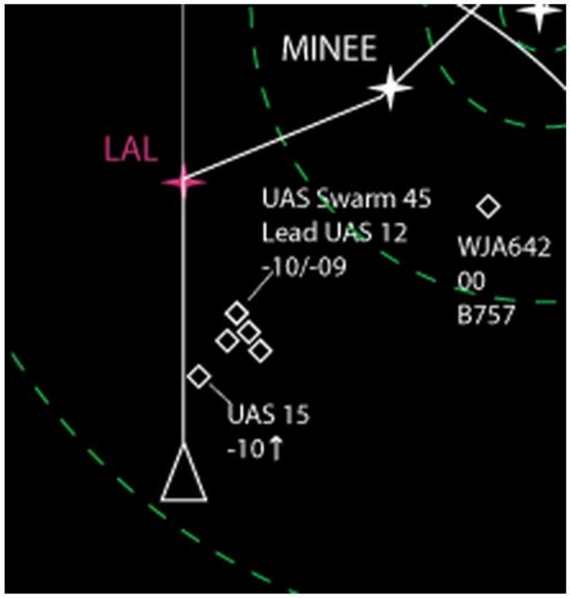
Comments

34. In the display below, assume one of the UAS (UAS 15) in the UAS Swarm 45 fails to maintain the intended formation flight and starts operating as an individual UAS.

Please rate the effectiveness of this type of presentation for managing this situation.

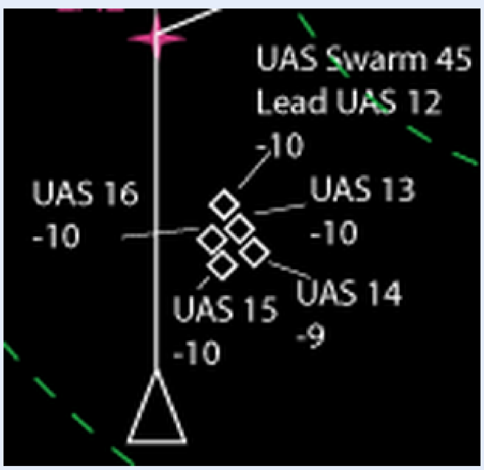
Very ineffective	Ineffective	Neutral	Effective	Very effective
◯	◯	◯	◯	◯

Comments

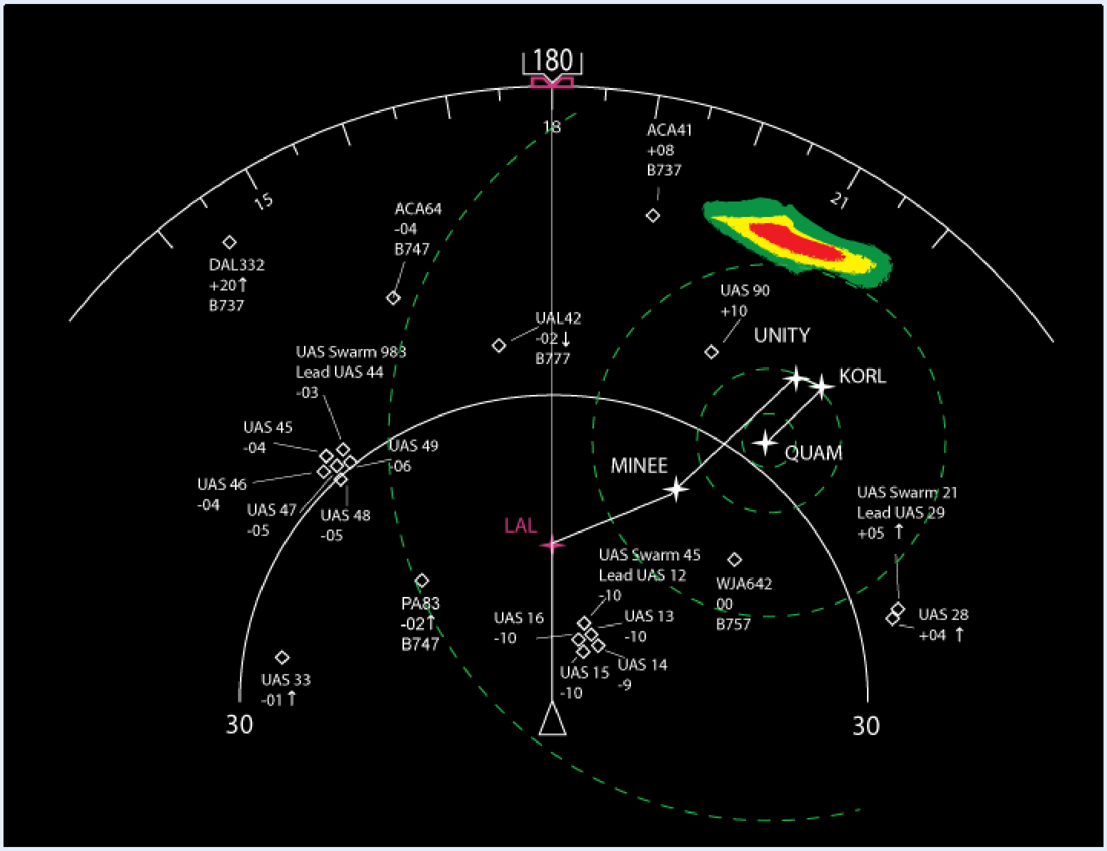


This page asks about your impressions of a presentation of a swarm where there is (see image below):

- a present position symbol AND Data block is shown for each individual UAS in the swarm, and
- a single Data Block is shown for the swarm as a whole



Shown below is an illustration of this type of presentation in your navigation display.



In answering the questions below, please assume that your task is safely navigate your aircraft, follow the prescheduled path and land at QUAM.

35. How effective is this type of presentation at providing the information needed to operate safely near a formation of UAS?

Very ineffective	Ineffective	Neutral	Effective	Very effective
○	○	○	○	○

36. Can you provide the 3 most appropriate keywords or short phrases to describe your impression of this type of presentation of a swarm of UAS?

Keyword 1 __________

Keyword 2 __________

Keyword 3 __________

37. Is there any critical information missing from this way of presentation of a formation/swarm of UAS? If yes, please specify in the comments below.

- Yes
- No

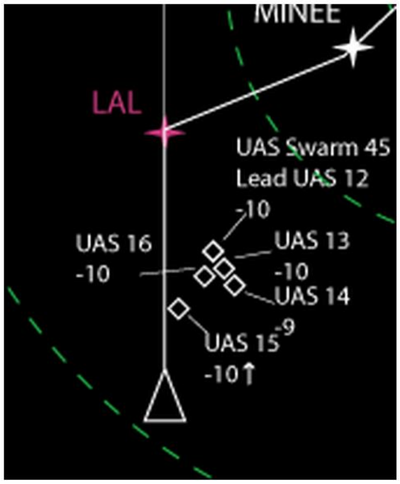
Comments

38. In the display below, assume one of the UAS (UAS 15) in the UAS Swarm 45 fails to maintain the intended formation flight and starts operating as an individual UAS.

Please rate the effectiveness of this type of presentation for managing this situation.

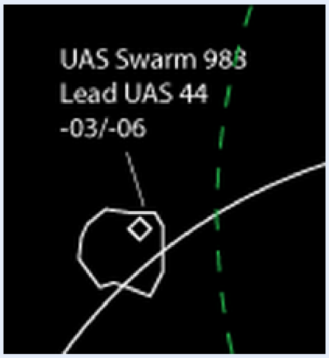
Very ineffective	Ineffective	Neutral	Effective	Very effective
○	○	○	○	○

Comments

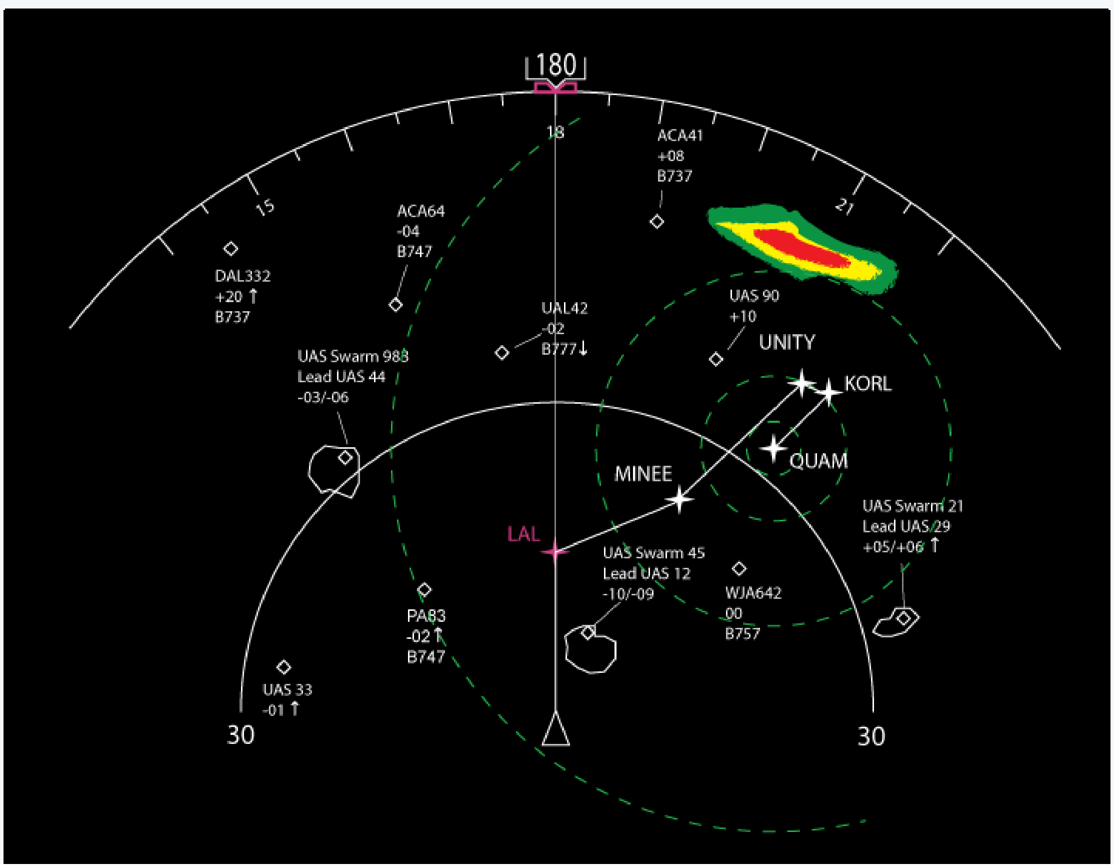


This page asks about your impressions of a presentation of a swarm where there is (see image below):

- an outline circling all of the individual UAS in the swarm, and
- a single data-block shown for the swarm as a whole



Shown below is an illustration of this type of presentation in your navigation display.



In answering the questions below, please assume that your task is to follow the pre-scheduled path and land at QUAM.

39. How effective is this type of presentation at providing the information needed to operate safely near a formation of UAS?

Very ineffective	Ineffective	Neutral	Effective	Very effective
◯	◯	◯	◯	◯

40. Can you provide the 3 most appropriate keywords or short phrases to describe your impression of this type of presentation of a swarm of UAS?

Keyword 1 __________

Keyword 2 __________

Keyword 3 __________

41. Is there any critical information missing from this way of presentation of a formation/swarm of UAS? If yes, please specify in the comments below.

◯ Yes

◯ No

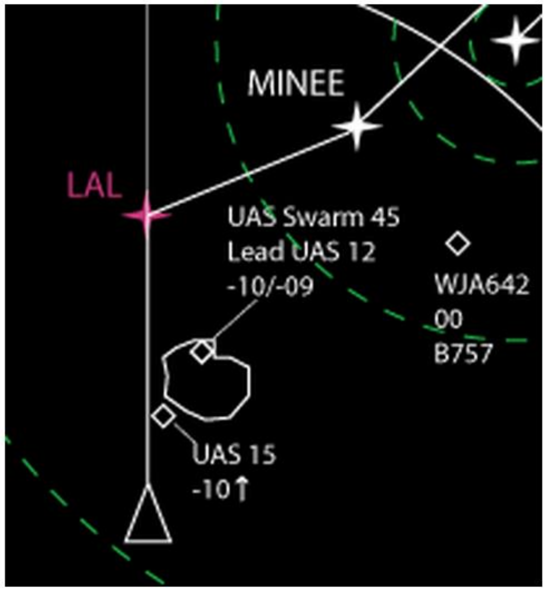
Comments

42. In the display below, assume one of the UAS (UAS 15) in the UAS Swarm 45 fails to maintain the intended formation flight and starts operating as an individual UAS.

Please rate the effectiveness of this type of presentation for managing this situation.

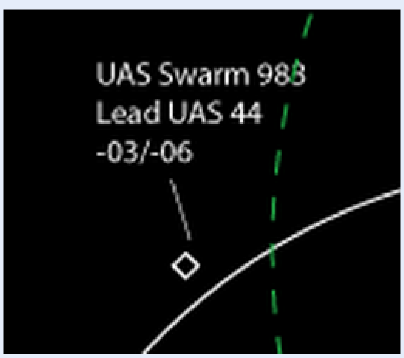
Very ineffective	Ineffective	Neutral	Effective	Very effective
◯	◯	◯	◯	◯

Comments

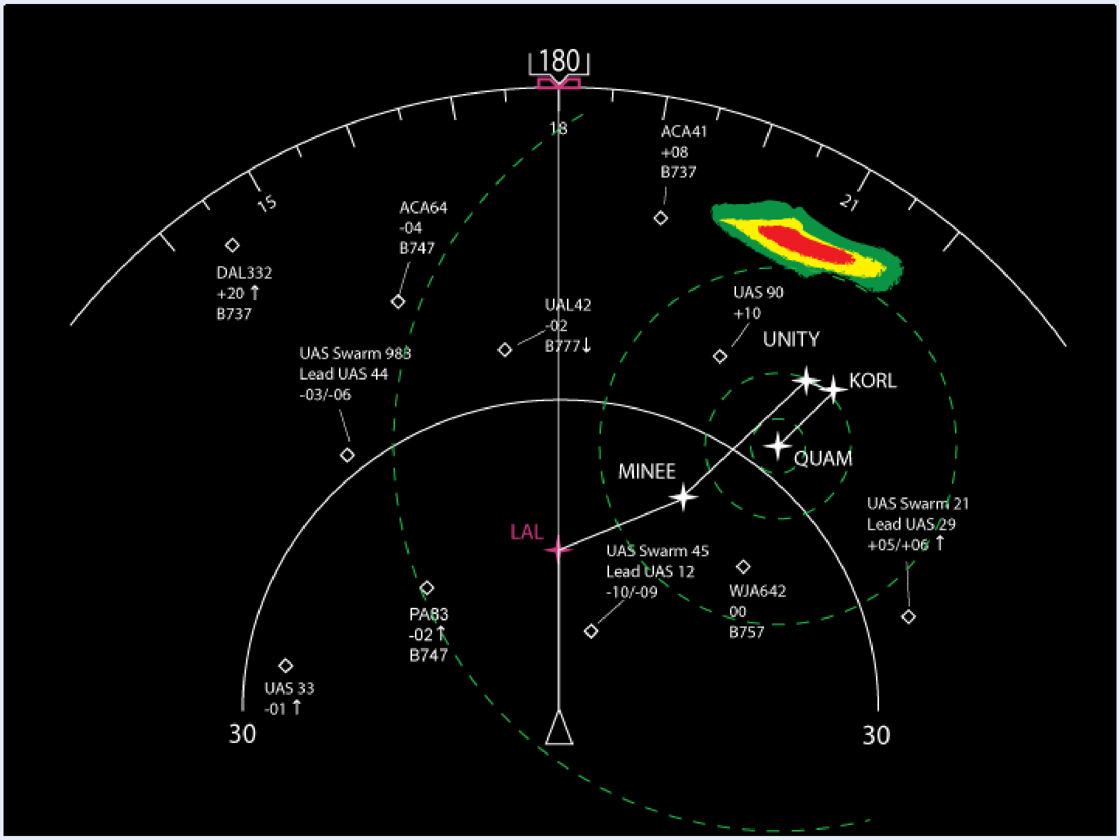


This page asks about your impressions of a presentation of a swarm where there is (see image below):

- One present position symbol for the position of a single "lead" UAS, and
- One data-block shown for the swarm as a whole



Shown below is an illustration of this type of presentation.



In answering the questions below, please assume that your task is to follow the pre-scheduled path and land at QUAM.

43. How effective is this type of presentation at providing the information needed to operate safely near a formation of UAS?

Very ineffective	Ineffective	Neutral	Effective	Very effective
○	○	○	○	○

44. Can you provide the 3 most appropriate keywords or short phrases to describe your impression of this type of presentation of a swarm of UAS?

Keyword 1 __________

Keyword 2 __________

Keyword 3 __________

45. Is there any critical information missing from this way of presentation of a formation/swarm of UAS? If yes, please specify in the comments below.

◯ Yes

◯ No

Comments

[ ]

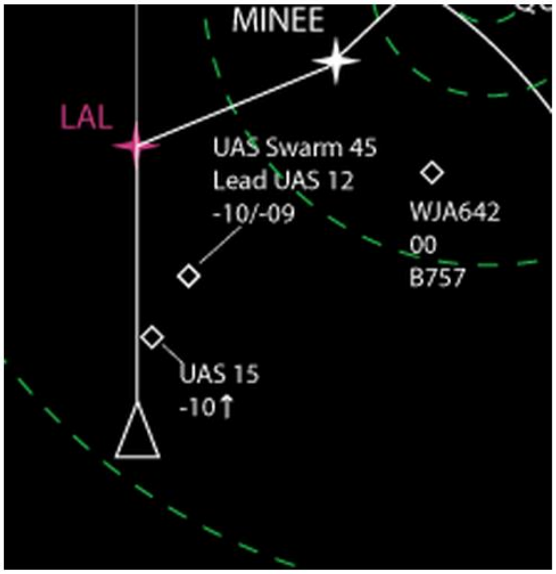
46. In the display below, assume one of the UAS (UAS 15) in the UAS Swarm 45 fails to maintain the intended formation flight and starts operating as an individual UAS.

Please rate the effectiveness of this type of presentation for managing this situation.

Very ineffective	Ineffective	Neutral	Effective	Very effective
◯	◯	◯	◯	◯

Comments

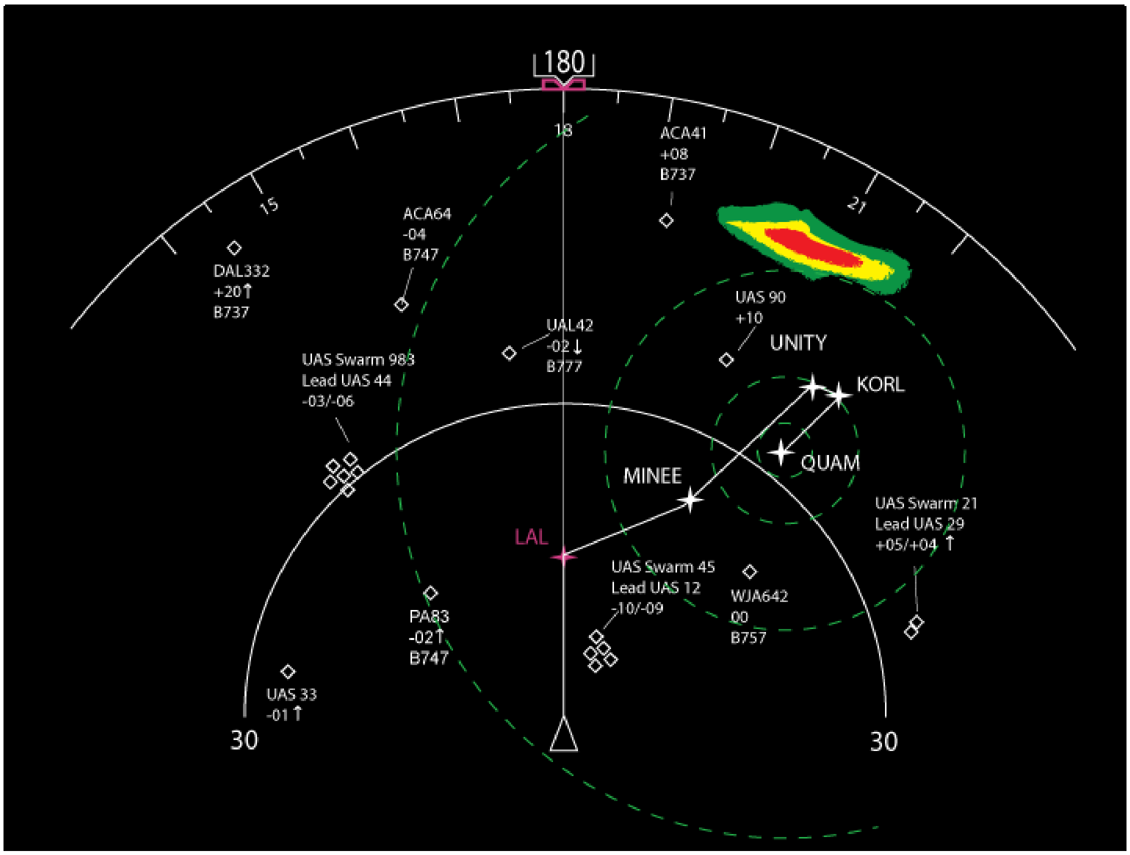
[ ]



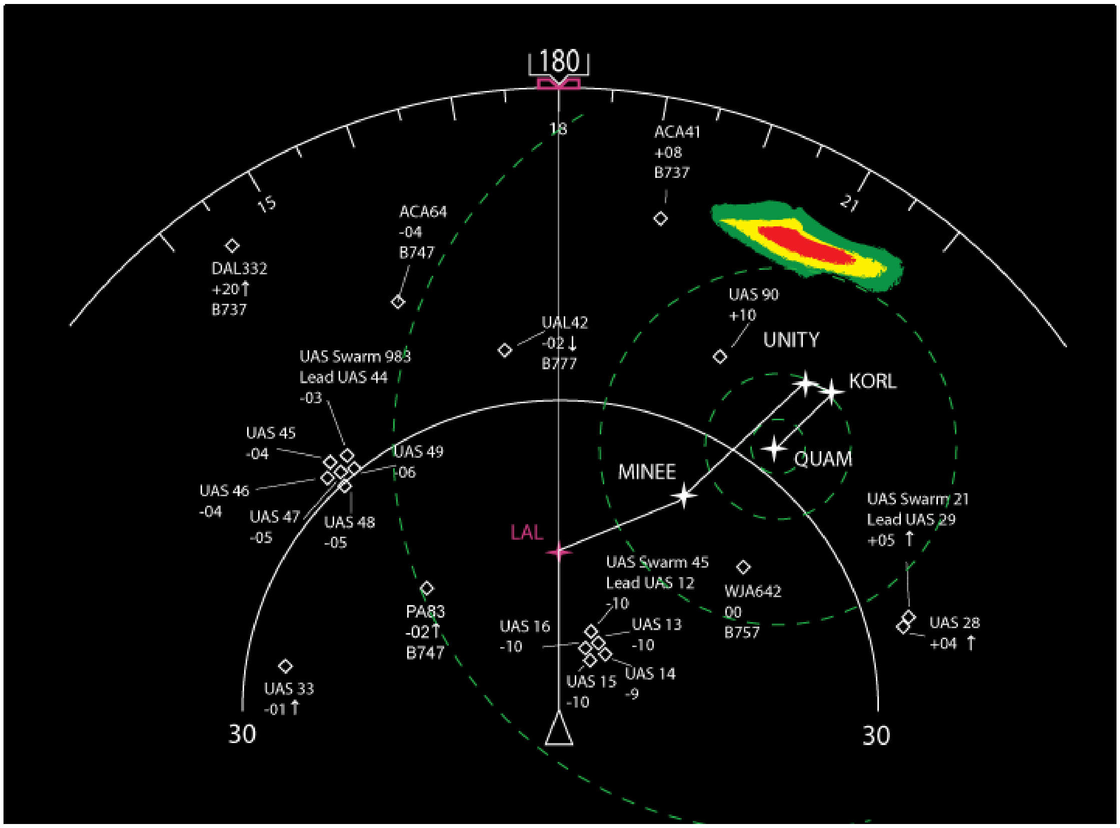
On the previous pages, you were presented with 4 different ways of showing a UAS swarm/formation.

The different types of presentation are shown again.

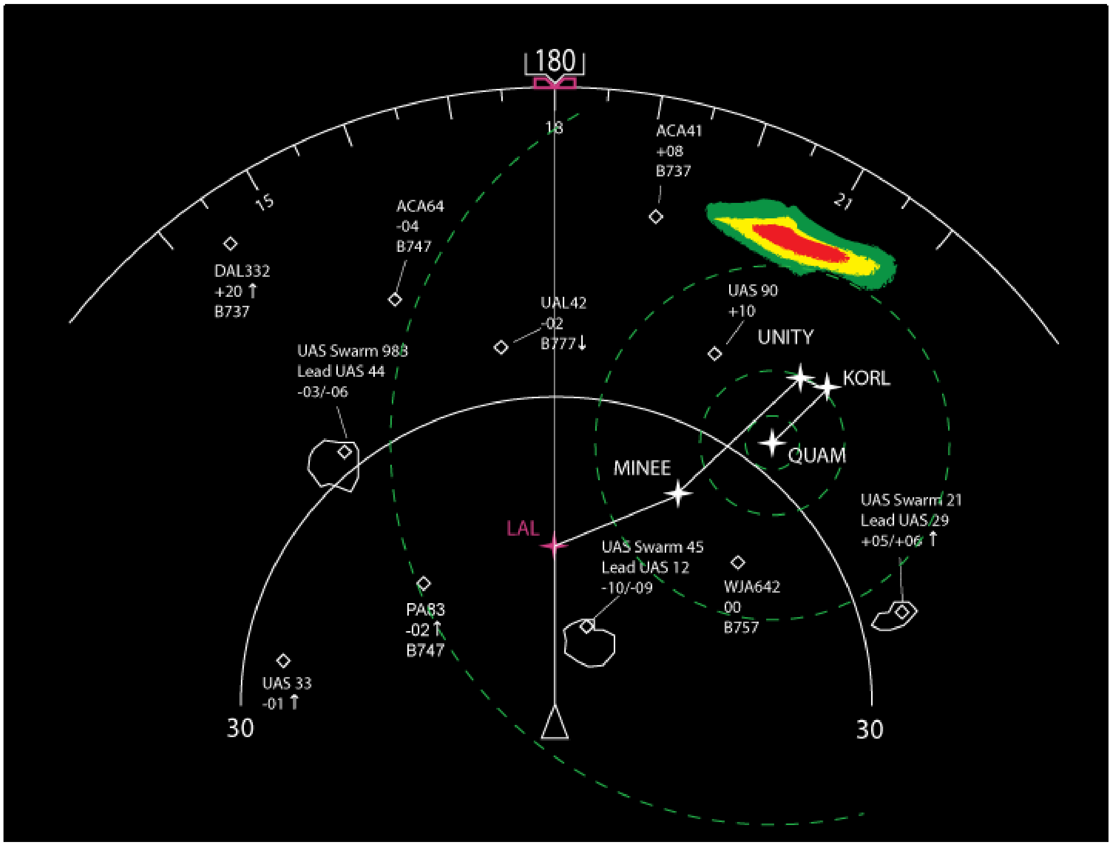
Presentation 1. Present position symbol of each UAS is shown with one datablock for the swarm as a whole.



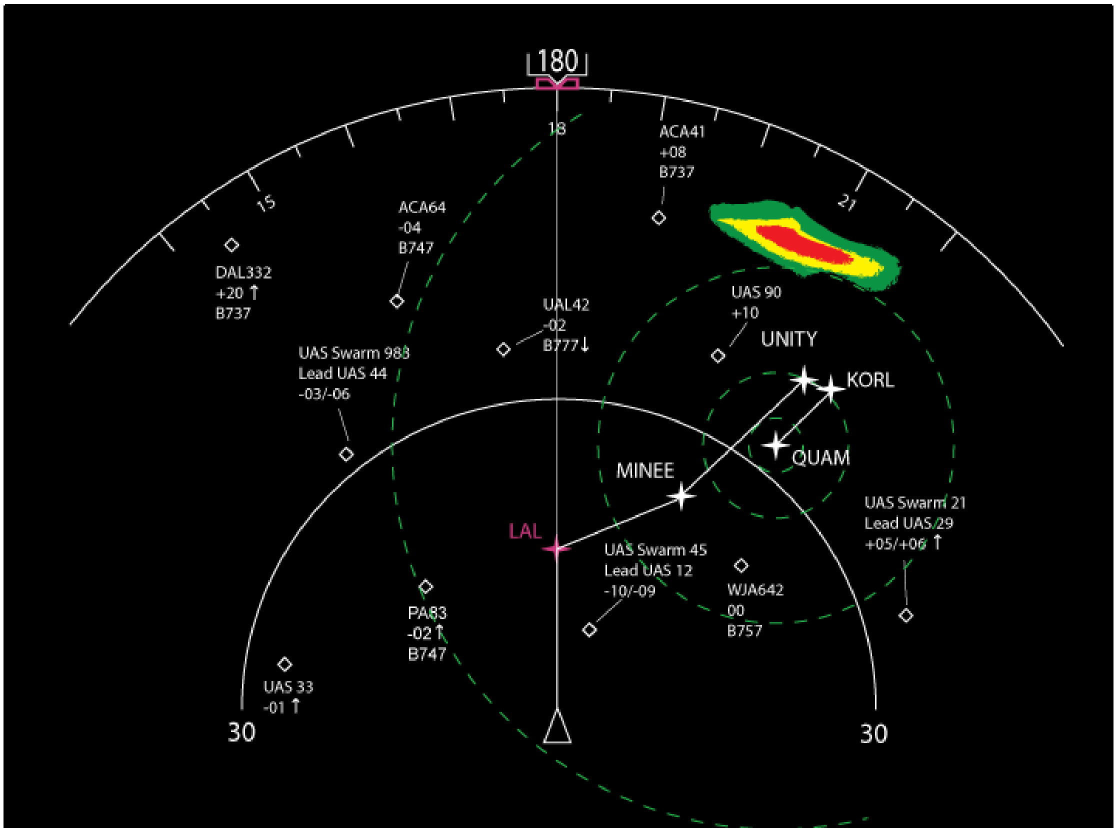
Presentation 2. Present position symbol and datablock of each and every UAS is shown as well as one datablock for the swarm as a whole.



Presentation 3. Outline circling positions of all UAS is shown with one datablock for the swarm as a whole



Presentation 4. Present position symbol of **only** the lead UAS is shown as well as one datablock for the swarm as a whole



47. For the situation illustrated above, please rank the 4 types of presentation from most preferred to least preferred.

Please use the mouse to drag the options to the box on the right side.

The option you put in the first place would be the one you prefer the most. The one at the end would be the least desired type of presentation.

We ask you to please carefully examine the pictures above. **The order may not be the same as the order you answered questions about the individual presentation types**

Drag items from the left-hand list into the right-hand list to order them.

- Present position symbol of each UAS is shown with one datablock for the swarm as a whole (Presentation 1)
- Present position symbol and datablock of each and every UAS is shown as well as one datablock for the swarm as a whole (Presentation 2)
- Outline circling positions of all UAS is shown with one datablock for the swarm as a whole (Presentation 3)
- Present position symbol of Only the lead UAS is shown as well as one datablock for the swarm as a whole (Presentation 4)

48. Could you briefly explain your choice for the ranking question?

Section 5

In a next-generation surveillance environment, additional information about "non-cooperative" objects will become available (e.g. "non-cooperative" objects). For example, individual birds could be reliably identified, and species information used to filter which birds are shown or not shown.

More importantly, this enhanced surveillance information could also be made available directly to pilots in their cockpit.

The following questions ask about your perspective on current challenges communicating with controllers about objects that pose potential hazards, and the communication challenges that might be created by having additional ground-surveillance information shared with both pilots and controllers.

49. What are the 3 most important advantages you can see occurring if surveillance information about non-cooperative targets (e.g. birds) was available to both pilots in the cockpit and to controllers on the ground?

Advantage #1

Advantage #2

Advantage #3

50. What are the 3 most important concerns you might have if surveillance information about non-cooperative targets (e.g. birds) was available to both pilots in the cockpit and to controllers on the ground?

Concern #1

Concern #2

Concern #3

Sometimes there are differences in how long it takes surveillance information about a common "non-cooperative" object to reach a pilot and the controller.

For example, controllers and pilots each have access to weather radar displays, but the data is collected in different ways and at different points in time. Therefore, there might be a difference in the information age.

51. Please assume you are on a final approach in a busy terminal area.

On your navigation display there are several non-cooperative objects (birds and/or UAS).

One of the non-cooperative objects is crossing your flight path on the final approach, creating the need for a non-emergency evasive maneuver.

The controllers in the terminal area have a display that also shows the non-cooperative objects. However, the controller's display may have more up-to-date or less up-to-date positions of the non-cooperative objects than the positions shown on your display.

Please answer the following questions based on your own experiences and with respect to what you feel would be **operationally acceptable differences.**

For this situation, what is the maximum time delay (in seconds) between your display and the controller's display? [ ]

Would your answer change if the controller's display is the one that is more up-to-date or if it is your display that is more-up-to-date? [ ]

For this situation, what is the maximum distance (in nautical miles) between the actual (real world) position of the non-cooperative objects and the position of the non-cooperative objects shown on your navigation display? [ ]

Section 6

If objects are operating near the limits of detectability for a surveillance system, the object may not be continuously detected. This "**intermittency effect**" can cause an object to appear and disappear from a navigation display and/or collision avoidance display.

We are interested in learning more about the consequences of this characteristic of any surveillance system and how it may impact the integration of UAS into airspace in the future.

52. In your last year of experience as a pilot, how often have you observed the "intermittency effect" occurring for an aircraft shown on a primary navigation display and/or collision avoidance display? Please select the best answer. *

- ◯ I don't understand what is meant by the "intermittency effect".
- ◯ Never. I have never operated an aircraft equipped with a navigation display or other form of collision avoidance display showing the relative position of other aircraft.
- ◯ Never. I have never observed the "intermittency effect".
- ◯ Very rarely. I have observed the "intermittency effect" but it happens very infrequently.
- ◯ Rarely. I have observed the "intermittency effect" about every month.
- ◯ Sometimes. I have observed the "intermittency effect" about once a week.
- ◯ Often. I have observed the "intermittency effect" at least once a day.
- ◯ Very often. I have observed the "intermittency effect" hourly.

53. Have you observed the "intermittency effect" with any UAS shown on a primary navigation display and/or collision avoidance display?

- ◯ Yes
- ◯ No

54. When the "intermittency effect" occurs for an aircraft in your navigation display, on average, how long are the periods of time during which no surveillance data is available? Please select the best response below, or use the blank box to provide your own estimate.

- ◯ 0 to 5 seconds
- ◯ 6 to 10 seconds
- ◯ 11 to 30 seconds
- ◯ 31 to 60 seconds
- ◯ More than 1 minute
- ◯ Other [ ]

55. Please rate your level of satisfaction with how the current technology in your most frequently flown aircraft handles the "intermittency effect" for aircraft under your control.

- ◯ Not very satisfied
- ◯ Not satisfied
- ◯ Neutral
- ◯ Satisfied
- ◯ Very satisfied
- ◯ Don't know / Not enough experience to answer

56. Which of the following are examples of challenges with how the "intermittency effect" is handled for an aircraft displayed on your current navigation and/or collision avoidance screen(s)? Please select any and all that apply.

If there are important challenges that you have experienced but they are not listed below, please add them in the boxes provided.

- ☐ The only change on my display is in the type of symbol used to indicate the position of the aircraft. This is difficult to notice.
- ☐ Aircraft disappear completely from the screen, forcing me to remember where the aircraft were.
- ☐ There is no indication that the present position is estimated or projected rather than an actual position.
- ☐ "Intermittency effect" appears to occur randomly, in locations and at times that cannot be predicted.
- ☐ Alerts and warnings that surveillance tracking has been lost are distracting and draw my attention away from more critical tasks.
- ☐ Other [ ]
- ☐ Other [ ]
- ☐ Other [ ]

57. Are there any differences in how the "intermittency effect" for a UAS affects your decision making as compared to the "intermittency effect" for a traditional, piloted, aircraft? If you have not observed the "intermittency effect" with any UAS, please click "Not Applicable" to proceed to the next page.

- ◯ Yes
- ◯ No
- ◯ Not Applicable

Comments

58. Do you think there will be any differences in how the "intermittency effect" for a UAS affects your decision making as compared to an "intermittency effect" for a traditional aircraft? Please comment or explain.

- ◯ Yes
- ◯ No

Comments

One final question....

59. Would you like to share with us any more thoughts? Any comments and feedback are welcome!

Congratulations! You have just finished the survey.

Thank you for taking our survey. Your response is very important to us.