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Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace

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UNMANNED AIRCRAFT SYSTEM (UAS) DELEGATION OF SEPARATION IN NEXTGEN AIRSPACE

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ABSTRACT

UNMANNED AIRCRAFT SYSTEM (UAS) DELEGATION OF SEPARATION IN NEXTGEN AIRSPACE

By Caitlin A. Kenny

The purpose of this thesis was to determine the feasibility of unmanned aircraft systems (UAS) performing delegated separation in the national airspace system (NAS). Delegated separation is the transfer of responsibility for maintaining separation between aircraft or vehicles from air navigation service providers to the relevant pilot or flight operator. The effects of delegated separation and traffic display information level were collected through performance, workload, and situation awareness measures.

The results of this study showed benefits related to the use of conflict detection alerts being shown on the UAS operator's cockpit situation display (CSD) and to the use of full delegation. Overall, changing the level of separation responsibility and adding conflict detection alerts on the CSD were not found to have an adverse effect on performance as shown by the low amounts of losses of separation. The use of conflict detection alerts on the CSD and full delegation responsibilities given to the UAS operator were found to create significantly reduced workload, significantly increased situation awareness and significantly easier communications between the UAS operator and air traffic controller without significantly increasing the amount of losses of separation.

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I dedicate this to my father Brian Kenny (rest in peace) who has always been supportive and enthusiastic about my research, reading every article I ever published. I hope that this thesis somehow reaches you. I love you and miss you.

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Introduction

A simple definition of Unmanned Aircraft Systems (UAS) is essentially an aircraft with the flight crew and support crew removed from the vehicle and placed at a ground control system with a connecting computer system and radio link used for command and control purposes (Austin, 2010). The demand for public access of UAS in the U.S. National Airspace (NAS) has grown dramatically. Since 2004, the number of public requests to fly UAS has increased over 900% (JPDO, 2012b). Projections of development from 2010 to 2019 predict over 20,000 UASs created in the United States and 35,000+ created worldwide (Teal Group, 2009). The FAA Modernization and Reform Act of 2012 addresses this increasing demand by requiring full integration of UASs into the NAS by 2015 (FAA, 2012a). Many concerns exist as to the best way to integrate UAS into the NextGen environment within the FAA mandated time frame.

The Next Generation Air Transportation System (NextGen)

The Next Generation Air Transportation System, or NextGen, is an overhaul of the NAS that is aimed to create a safer, more convenient, and dependable airspace system using satellite based information by 2025 (FAA, 2012b). The use of satellite information will allow for shorter routes, reduced delays due to traffic congestion, reduced fuel costs, increased amount of throughput to two to three times the amount of current day traffic, and It will create technology that will allow air traffic controllers to manage airspace traffic more safely and efficiently.

The air traffic management system used in current day operations will be unable to manage this growth. In 2011 alone, out of 3,567,652 flights, 20.46% were late arrivals, 19.13% were late departures, and 2.44% were cancelled, with only 76.83% of arrivals on time (Bureau of Transportations Statistics, 2012). These delays in the air traffic management system show how the transition from current day operations to the Next Generation Air Transportation System (NextGen) is vital for efficient airspace operations (JPDO, 2012a).

Fundamental changes in many of the technologies and procedures used today are projected to be seen in air traffic automation, communications, and navigation for accommodation of the expected two to three times increase in airspace traffic in the NAS (FAA, 2012b). As the NextGen airspace system will be required to do increasingly more tasks, the roles and responsibilities presently performed by the airspace management workforce will be required to change along with these new tasks. Research is being performed to develop decision support tools for both the pilots of the aircraft and the air traffic controllers, including testing of cockpit situation displays for use by pilots, as well as new merging and spacing procedures and algorithms (JPDO, 2011).

The increase in traffic density and change in the roles and responsibilities will create effects on the airspace users, such as an increase in workload and a reduction of availability in air traffic controllers (Galster, Duley, Masalonis, & Parasuraman, 2001). One proposed measure to reduce the amount of controller workload, increase their availability, and increase the amount of throughput per sector is the use of delegated separation.

Delegated Separation

Delegated separation is the transfer of responsibility for maintaining separation between aircraft or airspace vehicles from air navigation service providers to the relevant pilot or flight operator (JPDO, 2010). The high level tasks associated with separation assurance are the identification of potential conflicts and losses of separation, the identification of a solution for the problem (how the aircraft should maneuver to avoid conflicts), the implementation of the solution (change in heading, speed, altitude, etc.), and then monitoring for clear of conflict (Hoffman, Zeghal, Cloerec, Grimaud, & Nicolaon,1999).

Tasks associated with separation assurance are then delegated out to the aircraft pilot or flight operator in delegated separation. Three major levels of delegation have been defined: limited delegation, extended delegation, and full delegation (Zeghal & Hoffman, 2000). The exact tasks and responsibilities associated with delegated separation may vary depending upon airspace type, aircraft type, and phase of flight (Domino, Tuomey, Mundra, & Smith, 2010). When operating in oceanic airspace, delegated separation may be used for overtaking another aircraft. While in terminal areas, aircraft may be performing a longitudinal station keeping task or performing traffic merging. When operating in an airport, pilots may be performing runway incursions or avoiding obstacles while maneuvering on the ground.

Limited delegation places the controller in charge for identifying both the potential conflict and the appropriate solution. Pilots are responsible for implementing the solution and monitoring for their ownship to be clear of conflict so that they can request permission to return to their original flight path. Extended delegation places the controller in charge of identifying and notifying the pilot of potential conflicts. The pilot is then responsible for identifying the appropriate solution, implementing the solution, monitoring for clear of conflict, and requesting permission from the controller to return to their original flight path. In full delegation, the air traffic controller assumes more of a monitoring role as the pilot assumes responsibility for all tasks related to separation assurance: identification of conflicts and appropriate solutions, implementation of the solutions, monitoring for clear of conflict, and resuming the original flight path (Zeghal & Hoffman, 2000).

A concern with using delegated separation in the NextGen airspace environment is the possibility for fundamentally changing the air traffic controller roles and responsibilities, potentially reducing the controller’s situation awareness of the sector in their command, and creating a change in their workload. By handing off separation responsibilities to the aircraft flight crews, the controllers' task changes from being one of active control to a task predominately characterized by monitoring the aircraft in their sector (Galster, et al., 2001). The additional responsibilities to be delegated to pilots and flight crew cause concern as well. Pilots are not currently trained on traffic management (FAA, 2008a), and the amount of traffic information required to make successful deviations for avoiding conflicts needs to be researched further.

While the changing roles and responsibilities of air traffic controllers and pilots are of concern, the expected benefits of delegated separation are numerous. On the air traffic controller side, a reduction in workload, a reduction in the number of radio communications between aircraft and controllers, and a reduction in the amount of interventions by controllers are expected. A reduction in the amount of maneuvers performed by the aircraft is anticipated to also create a decrease in the amount and cost of fuel used per flight, an increase in traffic throughput per sector, and an increase in pilot and flight deck crew situation awareness (JPDO, 2012b).

Current day delegated separation. While delegated separation is viewed as being a largely NextGen concept, varying types of delegated separation are allowed in Class B, C, D, and E airspace in current day operations. Cockpit display of traffic information (CDTI) assisted visual separation allows pilots to maintain visual approach spacing even if visual contact is lost (JPDO, 2012b). This capability is incredibly useful in situations with low or poor visibility, such as stormy weather or night time flights. Since 2007, UPS has been performing CDTI assisted visual separation out of Lousiville, KY (Henden, 2008).

Visual separation is described in FAA Order JO 7110.65 U (2008b). There are two ways to perform visual separation; the controller identifies a conflict and issues instructions to the pilot as necessary, or the pilot identifies a conflict aircraft, calls in to air traffic control, and provides their own separation by maneuvering their aircraft as necessary. When a conflict is identified the air traffic controller will typically give the pilot information on the position, direction, and intention of the intruding aircraft. If the pilot notices the traffic first, the notification process may be reversed with the pilot notifying the controller of the intruder. After the pilot acknowledges the intruding aircraft is visually in sight, the controller will instruct the pilot to maintain visual separation. The pilot will then accept the order to maintain visual separation, and maintain separation from the aircraft.

Delegated separation in NextGen airspace. The use of delegated separation in NextGen airspace has been addressed by both the FAA and the Joint Planning and Development Office (JPDO) as part of Automatic Dependent Surveillance-Broadcast (ADS-B) uses. ADS-B consists of two parts, ADS-B In and ADS-B Out, and will be used as the primary surveillances method in NextGen airspace instead of radar (FAA, 2010). ADS-B Out broadcasts real-time information on aircraft state, such as identification information, altitude, and velocity through a transmitter located onboard the aircraft. ADS-B In receives the information sent from ADS-B Out, not only from the ownship but also from nearby equipped aircraft, and has the potential to receive additional transmitted data. In many cases, the data provided by ADS-B are more accurate than radar information, and will allow the aircraft to perform more precise maneuvers for spacing and conflict avoidance.

ADS-B Out will be required for aircraft operating in most of the NAS by 2020. With the precise information provided by ADS-B, an increase in traffic situation awareness and better conflict detection alerting will be possible. Through the use of ADS-B In, new spacing and separation capabilities will be possible starting as soon as 2017 (FAA, 2012c). Flight deck based interval management spacing is a capability to be used for managing spacing between aircraft while flying enroute. Cockpit display of traffic information (CDTI) assisted visual separation is an emerging use of ADS-B data that is planned for expansion. It allows pilots to maintain visual approach spacing even if visual contact is lost, such as in situations with stormy weather or night time low visibility.

The concept of delegated separation through use of ADS-B data is addressed as well. The defined interval concept discussed in the FAA NextGen Implementation Plan (2012b) is an example of extended delegation. In a defined interval task, the air traffic controller is seen to hold responsibility for maintaining separation while assigning pilots a spacing task that will be performed within defined boundaries. This use of pilot assigned spacing is believed to create a closer baseline for interval spacing than is currently possible through use of radar information. Delegated separation is again suggested through the Oceanic in-trail procedure (ITP) where a climb-through or descend-through maneuver is initiated by the flight crew of equipped aircraft in conflict. While performing this maneuver, pilots are to maintain the in-trail minimum separation. A full description can be seen in RTCA DO-312/EUROCAE ED-159 (RTCA, 2008).

The JPDO provides NextGen planning organizations with a view of mid-late and far-term (2025) operational capabilities expected to be in use in the NAS. Much of the work done by the JPDO is expected to be incorporated into the FAA NextGen Implementation Plan in the succeeding years as the FAA focuses on the near term aspects of a NextGen implementation. As part of the JPDO's NextGen Avionics Roadmap (2011), delegated separation is seen to provide an enhanced situation awareness that is shared between pilots in the air, and the controllers on the ground. This enhanced situation awareness will allow delegated separation practices to expand from those currently used in visual conditions, to non visual conditions in controlled airspace.

Unmanned Aircraft Systems (UAS)

Unmanned Aircraft Systems are more than just an aircraft with the crew removed and placed on the ground. UAS are typically comprised of the aircraft (also known as an unmanned aerial vehicle, or UAV), payloads, launch and recovery subsystems (when applicable), support sub-systems, the control station(s), communication devices (typically radio), vehicle operator, sensory operator(s), and support crew (Gertler, 2012). The system elements used to operate UAS are typically based upon those used in manned aircraft, though slightly different as they are created with the knowledge that the aircrew will not be onboard.

When talking about UAS, it is important to denote the differences between UAS, model aircraft and drones as they are easily confused (Austin, 2010). Model aircraft are typically designed to be operated for recreation, and restricted to use in sight of the operator through their command link. Drone aircraft typically contain no "intelligence," and no capabilities of sending or receiving any mission-pertinent information while in flight such as photographs, signal readings, or even vehicle location. Drones will often have a pre-planned flight path with a payload collecting data throughout their mission. This data is not accessible until after the drone is recovered and the operator removes the payload.

Unmanned aircraft systems can contain varying levels of intelligence, and are capable of communicating with the operator information such as payload data, flight state information (position, airspeed, heading, and altitude), and vehicle state information (amount of fuel, engine status, vehicle temperature, etc.) throughout their mission task. More intelligent UAS, such as the Global Hawk, can even be preprogrammed to perform contingency actions when specific off-nominal events, such as a loss of command and communication signal, occur (Mouloua, Gilson, & Hancock, 2003).

Types of Unmanned Aerial Vehicles. While UAS have many components besides the vehicle itself, the systems are typically categorized by the body type (such as fixed wing, turbo prop, or rotorcraft), size and capabilities (such as vertical takeoff and landing) of the vehicle used in the mission (Special Committee 203, 2010). The categories and specifications used to identify UAS can vary depending upon the agency, though a generic break down of UAV types may be used to describe them.

High Altitude Long Endurance, or HALE, UAVs can perform missions in high altitude (30,000+ ft), typically 24 hours or longer in duration. Typically HALE UAVs are used for missions that are long-range, require reconnaissance or surveillance, and have the potential to be armed and used for target acquisition and prosecution. The RQ-4 Global Hawk made by Northrop Grumman is an example of a HALE UAV (NASA, 2010).

Figure 1. Global Hawk UAS. Image reproduced with permission from NASA. Copyright 2010 by NASA.

Medium Altitude Long Endurance, or MALE, UAVs can perform missions from up to 30,000 ft in altitude and within 24 hours or less in duration. MALE UAVs are similar in many ways to HALE UAVs, and are often operated in a similar manner. An example of a MALE UAV is the MQ-9 Predator B made by General Atomics (NASA, 2007).

Figure 2. MQ-9 Predator B UAS. Image reproduced with permission from NASA Copyright 2007 by NASA.

Tactical or Medium Range UAVs (TUAVs), are smaller than MALE UAVs, and operate on simpler systems than the larger vehicles. TUAVs consist of both fixed wing and rotorcraft vehicles, with some aircraft having the capability to take off from and land on runways and airstrips. Aircraft may be accompanied by a ramp launching system to shoot the aircraft into the sky at flight speed. Examples include the Hunter RQ-5A made by Northrop Grumman, and the Shadow 600, made by AAI Unmanned Aircraft Systems (AAI Unmanned Aircraft Systems, 2009).

Figure 3. Shadow® Tactical Unmanned Aircraft System. Image reproduced with permission from AAI Unmanned Aircraft Systems. Copyright 2009 by AAI Unmanned Aircraft Systems.

Close Range UAVs are a prolific subset often used by groups that do not have a set location and are moving due to their smaller size. As Close Range

UAVs are often used in locations that are lacking in runways and airstrips, they are often accompanied by a launching system that typically uses a ramp mounted on a vehicle used in transport to shoot the aircraft from the ramp at flight speed, similar to those used by some TUAVs. Recovery of the Close Range UAVs is typically done through use of a parachute and airbag combination to lessen the damage of a fall, though methods may vary such as in the case of the sky-hook used for the Scan Eagle. Their use can range from reconnaissance, and target acquisition, to power line inspection, and crop spraying. Examples include the Scan Eagle made by Insitu, and the Aerosonde Small Unmanned Aircraft System made by Aerosonde Pty Ltd, (2012).

Figure 4. Aerosonde® Small Unmanned Aircraft System. Image reproduced with permission from AAI Unmanned Aircraft Systems and Aerosonde Pty Ltd. Copyright 2012 by Aerosonde Pty Ltd.

Mini UAV, or MUAV, is a class of UAVs that is not yet clearly defined. MUAVs are generally hand launched, and operated through the use of a laptop ground control station. Like Close Range UAVS, MUAVs are often used by groups that are mobilized due to their small size and portability. Examples include the Desert Hawk III made by Lockheed Martin, and the Skylite made by BlueBird Aero Systems.

Smaller UAVs have been created for use in urban terrains and research. The smaller sizes of these UAVs allow the vehicles to fly inside urban areas as opposed to flying over them. A desire for UAVs being used in urban terrains is to have the capability to hover and potentially perch on walls or window sills, creating unconventional configurations not commonly seen in the larger UAVS, such as the use of flapping wings (ornithopeters).

The Micro UAV, or MAV, was initially defined as having a wing span of less than or equal to 6 inches, though current definitions may vary. MAVs are preferred for use in urban terrains as their small size and maneuverability make them ideal for navigating between and within buildings. Examples include the Wasp made by AeroVironment Inc, and the Mosquito made by Israel Aerospace Industries.

Nano Air Vehicles, or NAV, is an emerging category populated by small vehicles less than 5 cm in any direction. The “nano,” in the name comes from the requirement that a vehicle so small will need nanotechnology for use in subsystems such as batteries, sensors and motors. NAVs may be used in a similar manner as MAVs, though they are also expected to be used in swarms, possibly for radar confusion or short range surveillance as most operate for only a few minutes at a time due to their small size. Examples include the Prox Dynamics Pico-flyer, Ornithopter, and Black Hornet (Prox Dynamics, 2012).

Figure 5. Nano Air Vehicles. Examples of NAVs include the Pico-flyer (top left), the Ornithopter (top right), and the PD-100 Black Hornet (bottom). Image reproduced with permission from Prox Dynamics. Respective copyrights 2005, 2007, and 2009 by Prox Dynamics.

Some of these categories may utilize rotorcraft vehicles, often called Remotely Piloted Helicopter (RHP), Vertical Takeoff UAV (VTUAV) or Vertical Takeoff and Landing (VTOL) UAV. These UAVs are valued for their ability to hover during missions, and for being less susceptible to turbulence than fixed wing aircraft. It is of interest to note that not all aircraft that are capable of a vertical takeoff are capable of vertical landing. Some examples include the Firescout made by Northrop Grumman, and the Camcopter made by Schiebel.

Combat UAS are split into two main categories. Unmanned Combat Aerial Vehicles (UCAV) are fixed wing aircraft designed to carry and launch weapons which may be used in aerial combat situations. Unmanned Combat Rotorcraft (UCAR) are also in development. Examples include the X-45A made by Boeing, and the X-47 Pegasus made by Northrop Grumman (NASA, 2002).

Figure 6. The X-45A UCAV. Image reproduced with permission from NASA. Copyright 2002 by NASA.

Civilian UAS use. Unmanned systems are often used for duties that are deemed to be too dull, dirty or dangerous for human completion (Takayama, Ju, & Nass, 2008). In addition to the known military use of UAS for training, transit, surveillance, and reconnaissance, there is a wide variety of civil applications. Proposed uses include research, disaster monitoring and aid, agriculture, surveillance, and conservation among others.

Research applications include geological and meteorological aspects. Meteorological applications often include the sampling of atmospheric components that can be used to further understand weather phenomena and create more accurate weather forecasting. Weather monitoring data can include information on air temperature, dewpoint, atmospheric pressure, winds, global warming monitoring, and atmospheric pollutions ratings (NOAA, 2012b).

Currently UAS are utilized for research missions, including the Global Hawk used by NASA and National Oceanic and Atmospheric Administration (NOAA) primarily focused on collecting information about storm development and tracking (NOAA, 2012a). This Global Hawk utilizes a special payload called the DropWindSonde System (Figure 7) designed to be dropped into the top of the storm and continuously collect data until the weather dissipates (NOAA, 2012b).

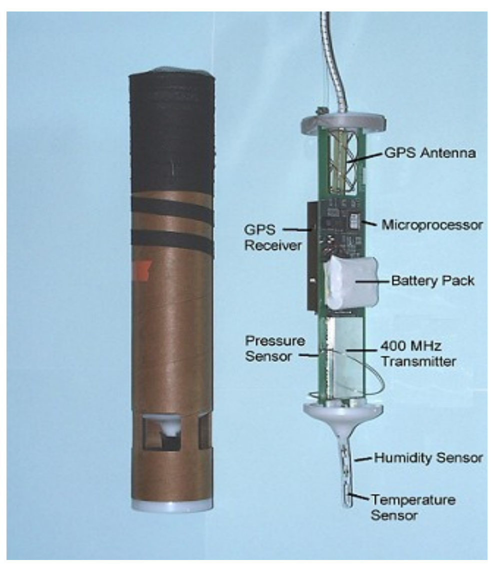

Figure 7. The NOAA DropWindSonde System Probe. Image reproduced with permission from NOAA. Copyright 2012 by NOAA.

The use of UAS for disaster monitoring and aid is done through the use of video and infrared search within specific restrictions defined by the FAA (Aviation Unmanned Aircraft Program Office, 2008). The first time that UAS were requested for search and rescue operations was in 2005, in the wake of Hurricane Katrina (Waharte & Trigoni, 2012). At the time, the FAA did not have any regulations in place for this type of UAS use, and no way to authorize the mission for flight in the national airspace. Regulations have since been passed to grant authorization for relief missions in a matter of hours.

The MQ-1 Predator is now authorized to fly in search and rescue missions in support of disaster relief as the UAS has an infrared camera that is able to identify heat source emissions small enough to come from a human body up to approximately 10,000 ft away (Waharte & Trigoni, 2012). This infrared camera can assist rescuers to identify and locate survivors quickly, as well as increase the efficiency of search patterns and crew organizations. The infrared camera is especially useful during wildfire flares, and has been used to assist firefighters in locating hidden pockets of fire and mapping the movement of fires across extended periods of time (NASA, 2007). An infrared image created by the Ikhana Predator of the Harris Fire in San Diego County (2007) can be seen in Figure 8.

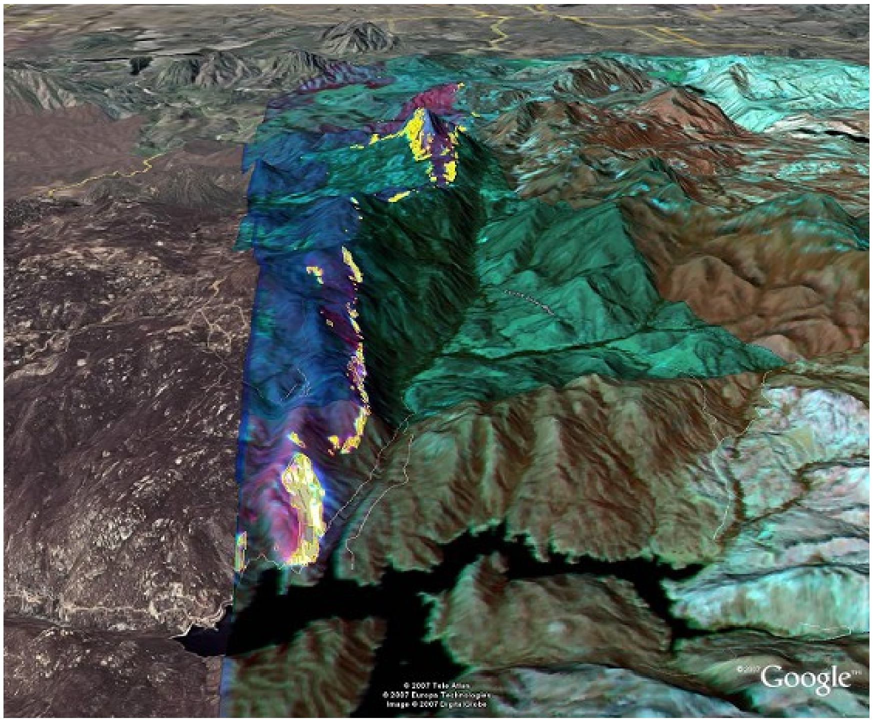

Figure 8. UAS Wildfire Infrared Imaging. Thermal infrared image scans from NASA's Ikhana Predator UAS of the Harris Fire in San Diego County Oct. 24, 2007. Image shows wildfire hot spots in yellow along the ridgeline. Image reproduced with permission from NASA. Copyright 2007 by NASA.

Agricultural and fisheries uses are varied and can include crop monitoring and spraying, livestock monitoring and herd driving, fisheries protection and water stress, as well as habitat monitoring. Using UAS for these purposes creates a number of potential advantages, such as with the cost of aerial imagery. Aerial imagery is typically collected from either satellite data which is often not up to date and can often have a low resolution, or from data collected by having a light aircraft fly over the specified lands. Both options are relatively expensive, and the use of Micro UAS imaging could potentially cut down the cost of acquiring the imagery (Austin, 2010). The FAA currently does not allow the use of UAS for agricultural or fisheries purposes, though other countries have used them for years. Farmers in Japan, for example, have used small UAS for approximately 10 years to perform monitoring and crop spraying tasks.

While surveillance and monitoring is typically associated with military tasks, there are many civil uses. Aerial photography and video recordings are used in a variety ways from land surveying, power and gas line inspections, oil pipeline security, news and media use, monitoring and control of traffic on roads and highways, and ordinance surveys for creation of detailed maps. Perhaps one of the more well known surveillance and monitoring tasks UAS are used for is police and customs work. The UAS are capable of searching for mission persons and suspects, checking coastline and land bound borders for illegal immigration suspects, illegally imported goods and search and rescue missions at sea (DoD, 2011). Currently both the U.S. Border Patrol and the U.S. Coast Guard have multiple UAS in use, including the fixed wing Predator B and the Eagle Eye tilt rotor helicopter.

There also exists the capability for UAS to assist in conservation efforts. Through the use of UAS, conservationists are able to monitor atmospheric and land based pollution, forestry services are capable of identifying and controlling fires, monitoring deforestation patterns, and wildlife monitoring. The use of UAS is especially helpful when observing endangered or threatened species that have extensive migratory patterns, or live in hard to access regions. UAS have been successfully used in conservation efforts for estimating shrub utilization, identifying and locating invasive species, measurement of the biomass and nitrogen levels present in various plan species, identification of crop water stress, and mapping various rangeland plant species (Austin, 2010).

Unmanned Aircraft System Integration into the National Airspace

The integration of UAS into the NAS is seen to be one of the critical issues existing between now and the mid-term vision of NextGen (JPDO, 2012b). The demand for public access of UAS in the U.S. National Airspace (NAS) has grown dramatically. Projections of development from 2010 to 2019 predict over 20,000 UAS created in the United States and 35,000+ created worldwide (Teal Group, 2009). The FAA Modernization and Reform Act of 2012 addresses this increasing demand by requiring full integration of UAS into the NAS by September 30, 2015 (FAA, 2012a).

As part of this bill, the FAA is required to create a plan in order to successfully integrate UAS into the national airspace without compromising the safety and efficiency of the existing air traffic management system and its users (FAA, 2012a). The plan is required to have at minimum recommendations on how to define acceptable operational standards for flight and certification of UAS. The purpose of this section of the bill is to ensure that all UAS will have a sense and avoid system, and to create the standards for what would be required to act as a UAS operator in the NAS as well as the process to achieve certification.

Sense and avoid. Sense and avoid is the capability to maintain separation from intruding aircraft. Sense and avoid systems may include a suite of surveillance sensors, trackers, threat detection and/or resolution algorithms, a traffic display for the pilot, and potentially resolution guidance or advice (Prinzel, et al., 2011). The addition of a sense and avoid suite on a UAS would create the ability for the UAS to avoid collisions through a combination of self separation and collision avoidance.

The capability for a UAS to self separate is deemed to be an essential component of the sense and avoid system, and may be the only function required in the sense and avoid system provided a safety analysis can demonstrate the target level of safety is met (JPDO, 2012b). While operating in positively controlled airspace, separation responsibilities may be delegated to the UAS operator. Conflict avoidance alone on a UAS is not an acceptable means to remain well clear as stated in 14CFR Part 91 (FAA, 2001); even if the target level of safety was met, a self separation capability would be required.

Challenges and Concerns of UAS Integration

The NAS was originally designed for use of manned aircraft, and while many procedures and general principles from manned aircraft can apply for UAS, there are significant differences is capabilities, advances in technology, and operational experience. These performance differences between UAS and manned aircraft may cause disruption in the NAS. Four challenges have been identified for UAS integration into the NAS; communication, airspace operations, internal systems onboard the aircraft, and human systems integration (JPDO, 2012b).

Communication concerns exist about the transfer of information between the aircraft, the operator, and the satellite/technology providing communications relay. Currently, communications relays can take on average two to eight seconds to send information from the aircraft to the operator. In a time sensitive situation, such as when avoiding a collision, this delay may be the difference between a crash and successful conflict avoidance. The security of the communications link is also of great concern as this could be hacked into, and control of the unmanned vehicle lost (DoD, 2001).

Airspace operations concerns are associated with the UAS operating in the same airspace as manned aircraft. The quality and availability of surveillance data needs to be assessed. Integrated separation concepts need to be developed, requiring an evaluation of performance of different potential human and machine roles and responsibilities, and how to properly integrate the varying self separation, separation assurance and conflict avoidance functions. With the need for a sense and avoid system capable of self separation, the differences in unmanned and manned aircraft flight become points of note. Concerns exist about UAS performing self separation due to the lack of the out-the-window view that manned aircraft pilots have (Gawron, 1998). Without this visual means of traffic acquisition, a sense and avoid solution becomes vital for safe UAS flight. UAS self separation is an essential component of the sense and avoid solution, and may be the only function provided safety analysis demonstrates the target level of safety is met (JPDO, 2011).

The unmanned aircraft itself, and systems located onboard, are also items of concern. Airframe certification, location and navigation systems, UAS avionics and control systems certification, as well as the ability for the UAS operator to have an accurate awareness of vehicle state and be capable of real time management are all items that need to be further researched (McCarley, & Wickens, 2005). The flight characteristics of UAS are different from manned aircraft in many ways, such as being operated at speeds slower than those typically used for manned aircraft and being able to fly at higher altitudes than many manned aircraft.

The overall flight paths of manned and unmanned aircraft are also quite different and important to note. Manned aircraft typically aim to fly the shortest distance from Point A to Point B through the use of specified routes and arrival corridors. Unmanned aircraft are often required to operate in a grid or corkscrew pattern, loiter, hover, and perform frequent heading and altitude changes, as well as unplanned aerial work around areas of interest while performing mission roles

(Special Committee 203, 2010). An example of a UAS flight path can be seen in Figure 9. The differences in mission behavior have the potential to cause congestion and an increase of potential conflict in sectors as the flight path of a UAS may appear to be erratic and unpredictable when compared to that of a manned aircraft. The differences in flight path configuration and mission roles are important to take into consideration as they may increase the workload of air traffic controllers managing the sector the UAS is flying in.

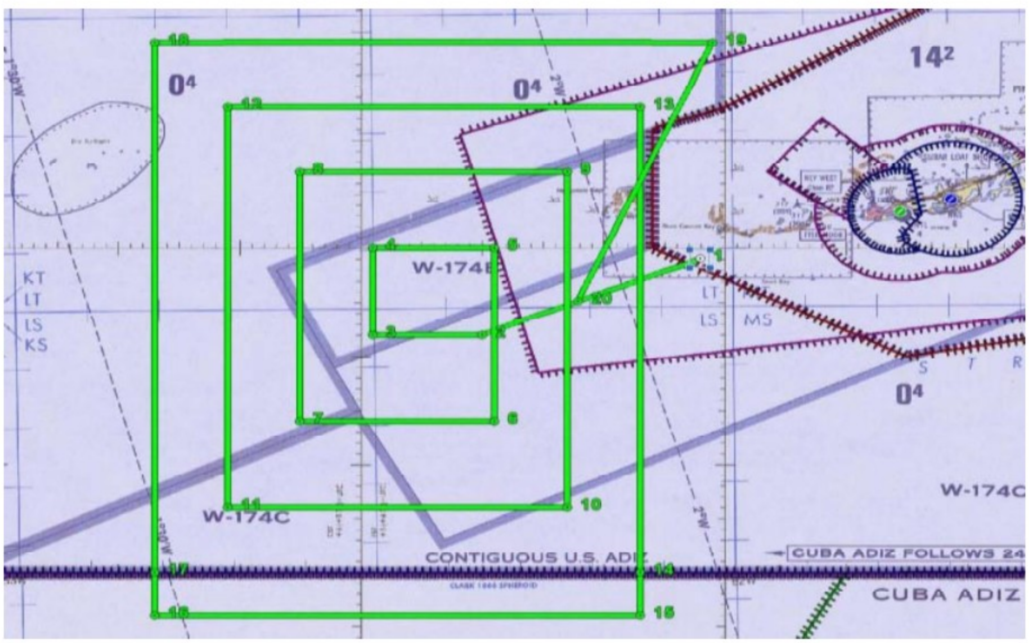

Figure 9. UAS Flight Path Example. This image shows the planned route of a ScanEagle UAS in a green corkscrew pattern performing a marine fisheries protection and monitoring operation. Image reproduced with permission from RTCA, Inc. Copyright 2010 by RTCA, Inc.[1]

[1] The complete document referenced, DO-320 Operational Services and Environmental Definition (OSED) for Unmanned Aircraft Systems (UAS), may be purchased from RTCA, Inc. 1150 18th Street NW, Suite 910, Washington, DC 20036. (202) 833-9339 www.rtca.org

Human system integration concerns focus on the interaction between the operator and the ground control station's interfaces and systems (JPDO, 2012b). Currently there is no universal ground control station used for unmanned aircraft, nor are there any guidelines for what should be required in a ground control station, or of the UAS operator. Research must be conducted to determine the optimal performance needs. Areas needing research include: the display of traffic, aircraft and airspace information, focusing on the presentation method and quantity of information available; how to promote optimal human and automation interaction; system level issues for any interfaces or algorithms being utilized; a pilot centric station that includes an ergonomic evaluation for optimal placement of displays and controls; a clear definition of roles and responsibilities given to the UAS operator and the air traffic controller; and a set of qualification and training requirements needed to operate safely in the NAS (DoD, 2011).

The NextGen airspace will be required to provide a NAS that is flexible and robust enough to support routine use of UAS instead of as the exception. This could be accomplished through a combination of automation, more precise airspace information provided by ADS-B, and delegated separation given to the pilot within positively controlled sectors (Special Committee 203, 2010). It is theorized that much of the activity would occur in air traffic controller systems using automation, and on systems located in manned aircraft and unmanned ground control stations to advise pilots of relevant flight path changes. This will help to maximize airspace efficiency and safety.

Through use of self separation, aircraft exchanges would be accepted or rejected based upon the situation awareness of the UAS operators and manned pilots. The role of the air traffic controller would be changed into one predominated by monitoring, with intervention only when necessary (Grimaud, Hoffman, & Zeghal, 2001). Self separation is planned to initially take place in areas with low traffic density, with a gradual progression to high density airspace. The UAS flying in NextGen airspace could benefit greatly from delegated separation as they will also begin to operate in low density areas and perform flight paths and mission tasks in a manner that is not typical for manned aircraft (Special Committee 203, 2010). The use of delegated separation by UAS operators could reduce the workload of air traffic controllers when monitoring for unexpected maneuvers and aircraft flying atypical routes.

The Current Experiment

The purpose of the current experiment was to determine the feasibility of UASs performing delegated separation in the NAS. The study used a 2 x 2 within-subjects design, with level of delegation (extended delegation vs. full delegation) and traffic display information level (basic, traffic only vs. conflict detection present) as independent manipulations. The effects of delegated separation and traffic display information level were assessed through objective and subjective measures of performance, workload, and situation awareness. Experimental data were collected in the Flight Deck Display Research Laboratory (FDDRL) at NASA Ames Research Center from the experimental participants consisting of 13 pilots and two retired air traffic controllers acting as pseudo-controllers. Three pseudo-pilots were used in a confederate role to create sector traffic with no data collected on their performance.

The expected results for air traffic controllers in the full level of delegation included: reduced workload, radio communications with the UAS operator to be perceived as easier, and less frequent communications would occur between the ATC and UAS pilot. The expected results for the UAS operator included an increased (but manageable) workload in the full level of delegation, and increased situation awareness within both the full level of delegation and the conflict detection present mode of the CSD. It was expected that both the air traffic controller and the UAS pilot would have higher levels of workload in extended delegation, and subjective scores rating their perception of difficulty in communication would increase as well. The amounts of losses of separation were expected to be lower in full delegation and in the conflict detection present CSD mode. The overall amount of losses of separation levels were expected to be low.

Methods

Participants

Experimental participants. A total of 15 experimental participants were used for this study; 13 pilots acting as UAS operators and two retired air traffic controllers acting as pseudo controllers. Data were collected from the 13 pilots and the two pseudo controllers. UAS operator participation was limited to pilots who were 18-40 years old, had normal or corrected to normal vision, and held at minimum a Private Pilot Certificate with preference towards those with an Instrument Rating. Pseudo controller participation was limited to retired air traffic controllers with previous experience using the Mutli-Aircraft Control System (MACS) controller mode software (AOL, 2008). Each air traffic controller worked with approximately half of the UAS operator participants throughout the simulation.

Confederate participants. Three pilots acted as confederate pseudo pilots to create the background airspace traffic and radio chatter. Pseudo-pilot participation was limited to pilots who were between 18-40 years old, had normal or corrected to normal vision, held at minimum a Private Pilot Certificate, and had previous experience using the pseudo-pilot mode of MACS. No data were collected from the pseudo pilots as they were acting in a confederate role.

Experimental Design

The current study was a 2 x 2 within-subjects design with level of delegation (extended delegation vs. full delegation) and traffic display information level (basic, traffic only vs. conflict detection present) as independent variables. Counterbalancing was used to control for order effects across the four experimental scenarios created as the result of the factorial combination of the two levels of delegation and two levels of traffic display information. The scenarios were blocked by traffic display condition; the first traffic display condition was presented with the two levels of delegation before the second traffic display condition was presented with the two levels of delegation. Order of presentation of the traffic display condition (basic or conflict detection) was counterbalanced across participants. All experimental data were collected in the Flight Deck Display Research Laboratory (FDDRL) at NASA Ames Research Center.

Data on the effects of delegation and traffic display information level was collected through objective and subjective measures of performance, workload, and situation awareness. The level of delegation manipulation was used to uncover the effects of delegating the roles and responsibilities for maintaining separation partially or fully from the air traffic controller to the UAS operator. The level of traffic display information was used to uncover the effects of increasing information available about the surrounding airspace on operator performance when delegated with separation responsibility. As there were only two air traffic controllers in this experiment, it is important to note the analyses performed on their data have low statistical power.

Level of delegation. The level of delegation was separated into two conditions, extended delegation and full delegation, which were counterbalanced across missions. In both scenarios, only the UAS was given delegated separation and the air traffic controllers maintained positive control of all surrounding aircraft. At any point in time throughout the scenarios, the UAS Operator was allowed to request help from the air traffic controller by giving the direction, flight level, and callsign of the intruder aircraft.

- Example of a UAS Operator requesting help:
  - **UAS Operator:** *"L.A. Center, this is PD-1. Traffic north bound, FL 280, callsign SWA242. Cannot perform separation, please advise."*
  - **ATC:** *"PD-1, traffic acquired."*
    - ATC orders a reroute to avoid collision

In extended delegation, the air traffic controller was responsible for problem identification and notifying the UAS operators of the potential conflict. The UAS operators then located the intruder aircraft on their traffic display and told the air traffic controller that the traffic was acquired. The controller would then tell the UAS operators to maintain separation from that aircraft. The UAS operators then accepted the separation order, and were responsible for identification and implementation of conflict solutions and monitoring for clear of traffic after rerouting.

- Extended Delegation Example:
  - **ATC:** *"PD-1, traffic SWA749 at 2 o'clock, north bound, FL 280. Advise tracking"*
  - **UAS Operator:** *"PD-1, traffic acquired."*
  - **ATC:** "*PD-1, maneuver to maintain separation from SWA749."*
  - **UAS Operator:** "*PD-1, maintaining separation with SWA749."*
    - UAS makes a reroute to avoid collision and monitors until clear of conflict
  - **UAS Operator:** "*L.A. Center, this is PD-1. Clear of traffic, request to return to original flight path."*
  - **ATC:** "*Roger, PD-1. Permission to return to original flight path approved."*
    - UAS returns to original flight path

Full Delegation gave responsibility to the UAS operator for all tasks related to separation assurance, including identification of problems and solutions, implementation of solutions and monitoring for clear of traffic after rerouting. Air traffic controllers only reclaimed separation responsibilities from the UAS operator if collisions became imminent or the operators requested assistance. No communication with air traffic control was required to complete these scenarios.

- Full Delegation Example:
  - UAS operator monitors CSD for potential conflicts
  - UAS operator identifies a potential conflict
  - UAS operator makes a reroute to avoid collision and monitors until clear of conflict

– UAS operator identifies clear of conflict and resumes original flight path

Level of traffic display information. The level of traffic display information was split into two conditions, basic and conflict detection present, and counterbalanced across missions. The basic conditions provided a 2-D display of the surrounding traffic in an ownship centric manner. Basic information included aircraft call sign, altitude and airspeed, as well as the use of color coding to denote altitude (green for 500+ ft below ownship, white for within 500 ft below or above ownship, and blue for 500+ ft above ownship). No conflict detection was available in the basic conditions. The conflict detection present conditions included the information available in the basic conditions and provided conflict detection alerts in a visual and aural manner that was based upon ballistic information. Once the UAS operator successfully rerouted to avoid the conflict, the ownship and intruder aircraft stopped glowing yellow.

Missions. Two training and four experimental scenarios were used in this experiment. The training scenarios were five minutes long and provided practice for all participants. The UAS operators learned how to operate their aircraft and how to use their ground control station to perform flight path reroutes while practicing under the assigned level of delegated separation. Air traffic controllers practiced delegating separation responsibility to the UAS operator in the assigned level of delegated separation.

Experimental scenarios were each 30 minutes long, and consisted of a CO^2 emissions monitoring task. No conflicts were pre-scripted, though the flight paths of the UAS throughout the trials were designed to cross over and through traffic streams so as to increase the chance of a conflict occurring. All scenarios began with the UAS in a preprogrammed flight path and included five mission messages that required the UAS operators' attention and flight path reroutes. The timing of the mission messages and the four flight paths differed between scenarios and were counterbalanced as a means to reduce predictability.

Mission objectives. The UAS operators were instructed to fly a CO^2 emissions monitoring task in southern California based upon scenario 3 in RTCA SC-203's Operational Services and Environmental Definition (OSED) for UAS (2012). The mission objectives that were given to the UAS operator included: follow the appropriate level of delegated separation while flying the mission routes, reroute in response to mission messages, reroute to maintain separation from the surrounding traffic, and maintain communications with ATC as necessary. Air traffic controllers were also informed of the level of separation delegated to the UAS operator, and notified of the corresponding responsibilities in each of the scenarios. Air traffic controllers always maintained positive control over the surrounding aircraft; only the UAS received delegated separation responsibilities.

Experimental Environment

The experimental environment was a simulated LA Center airspace. UAS operators and air traffic controllers had access to a list of currently used navaids and fixes for use in communications and route modifications. The current day air traffic controller will accept and hand off aircraft entering or exiting their sector and maintain separation between aircraft to avoid mid-air collisions. Separation standards for aircraft are typically a 5 nm mile horizontal distance, and 1000 ft in vertical distance in current day operations (FAA, 2008b). If the controller fails to maintain this level of separation, a loss of separation (LOS) occurs; collisions may or may not occur depending upon how far the intruder penetrates the separation standard.

In half of the trials, separation responsibilities were partially delegated to the UAS operator, and in the other half separation responsibilities were fully delegated to the UAS operator. In all experimental conditions, the air traffic controller maintained positive control of the surrounding aircraft; only separation responsibilities for the UAS were delegated away from the controllers. The UAS operators used a ground control station composed of the U.S. Army Aeroflightdynamics Directorate's Multiple UAS Simulator, MUSIM (Fern & Shively, 2009), and the Ames 3D Cockpit Situation Display, CSD (Granada, Dao, Wong, Johnson & Battiste, 2005) to display traffic. The air traffic controllers and confederate pseudo pilots used the Multi-Aircraft Control System (MACS) in their respective air traffic controller and pseudo pilot modes.

All experimental participants additionally had a touch screen monitor used to collect workload ratings through probes. Workload probes were presented with an auditory chime to alert the participants of their presence. UAS operator probes were presented every three minutes with a scale from one (low) to seven (high), while air traffic controller probes were presented every three minutes on a scale from 1 (low) to 7 (high). UAS operators were given six situation awareness probes per trial presented in a chat box that was located on MUSIM. Communications between participants and pseudo pilots were given by voice through a simulated radio frequency.

Apparatus

MUSIM. MUSIM (Figure 10) is a Linux based UAS ground control station simulation environment; a full description of its capabilities can be found in Fern & Shively (2009). The configuration of MUSIM for this experiment was in a 1:1 operator to vehicle interface with no sensor video as the focus was on the basic flight operation of the UAS and not sensor tasks. A generic fixed wing flight control model with generic Mid-Altitude Long Endurance (MALE) UAS parameters was used. Ownship speed for the UAS was fixed at 110 knots throughout all missions. Shutter screen capture software was utilized to record video of all events occurring on MUSIM.

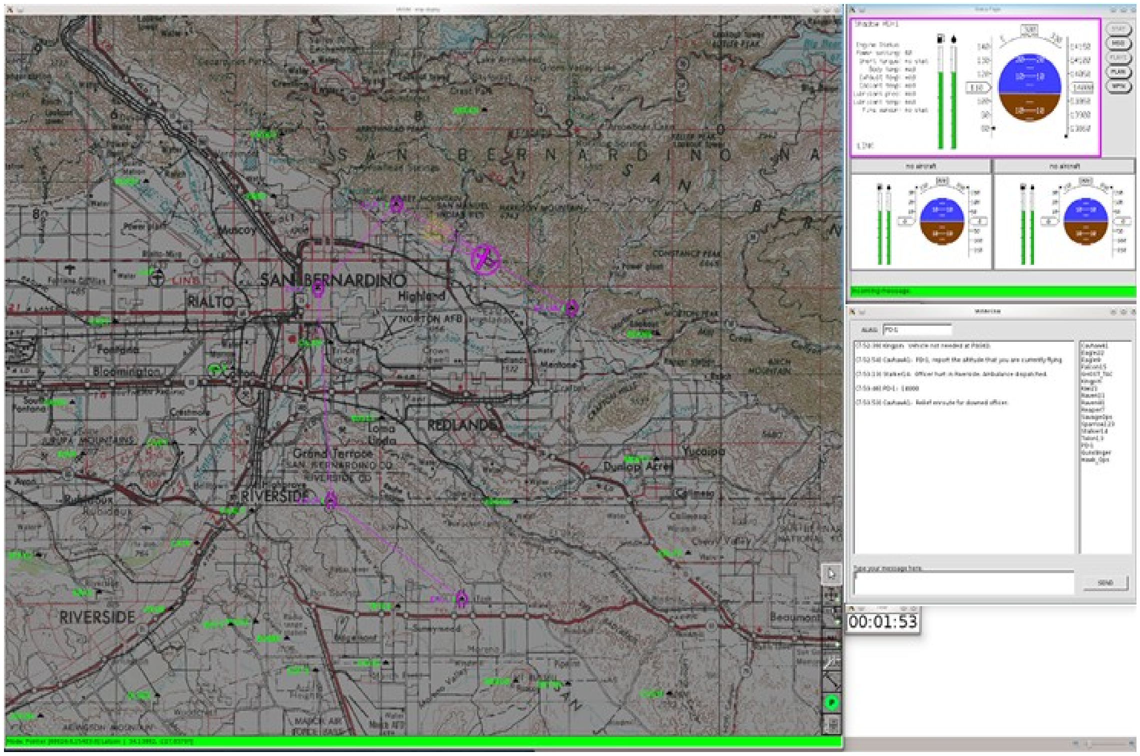

Figure 10. The MUSIM Ground Control Station. The ground control station was separated into four sections. A map display used to indicate the position and flight path of the UAS, the available navaids for route modifications, and where the UAS operator performed route modifications (left). A multi-function display to display the UAS primary flight display and mission messages (top right). The mIRC Chat box used to display a simulated UAS chat group and the operator's situation awareness probes (middle right), and a timer (bottom right).

Ames 3D CSD. The Ames 3D CSD (Figure 11) is a 3D volumetric display designed to provide pilots with an increased situation awareness of the surrounding traffic. A full description can be found in Granada, Dao, Wong, Johnson & Battiste (2005).

Figure 11. The Ames 3D CSD. Green aircraft were 500+ ft below ownship's altitude, white aircraft were within 500 ft above or below ownship's altitude, and blue aircraft were 500+ ft above ownship's altitude. The visual alert of the yellow glowing ownship and intruding aircraft can be seen indicating a conflict.

In this experiment, the Ames CSD was used in its basic 2D planar view to display traffic information. The CSD has an ownship-centric view of the surrounding traffic that was color coded. Green aircraft were over 500 ft below the ownship's altitude, white aircraft were within 500 ft above or below the ownship's altitude, and blue aircraft were over 500 ft above the ownship's altitude.

Participants were allowed to adjust the horizontal viewing distance from 10-640 nm, and were provided with conflict detection alerts in half of the conditions. UAS operators were notified of traffic as far as 20 minutes into the future through alerts given in the form of an auditory chime, and a visual of their aircraft and the intruding aircraft glowing yellow on the cockpit situation display. Camtasia screen capture software was utilized to record video of all events occurring on the CSD.

MACS. MACS (Multi Aircraft control System) is a JAVA program created by the Airspace Operations Laboratory (AOL) at NASA Ames for simulation of airspace to be used in air traffic management and operations research (AOL, 2008). In the current experiment, the MACS pseudo pilot (Figure 12) and air traffic controller (Figure 13) modes were used. The sector controlled by the air traffic controllers was between 13,000 and 24,000 ft, with the navaids and fixes that were available to the UAS operator displayed and boundaries denoted by highlighted lines. Camtasia screen capture software was utilized to record video of all events occurring on the pseudo pilot and air traffic controller monitors.

Figure 12. MACS in Pseudo Pilot Mode. MACS allowed the pseudo pilots to control multiple aircraft at a time through the use of automation. The monitor on the left displays the sector, and the monitor to the right displays aircraft controls.

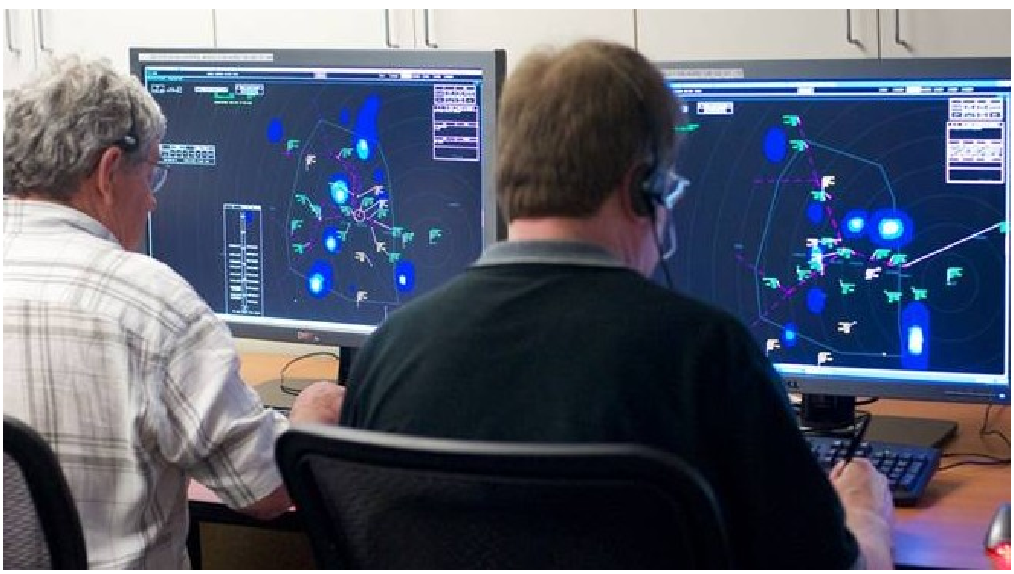

Figure 13. MACS in Air Traffic Controller Mode. MACS allowed the air traffic controllers to observe their sector and manipulate the traffic flow. The sector was between 13,000 and 24,000 ft, with navaids and fixes displayed, and boundaries denoted by highlighted lines.

Procedure

After arrival in the lab, all participants were briefed on the purpose of the study, and given informed consent and demographic forms to complete. Participants were split into two groups: UAS operators and pseudo participants. The pseudo participants (including pseudo controllers and pseudo pilots) received their initial briefing and training before the experimental data were collected. This was done to reduce the amount of time spent on training as the pseudo participants rotated throughout the experiment. The UAS operator participants were briefed on the purpose of the study and provided with instructions on how to operate MUSIM and respond to online workload and situation awareness probes.

UAS operator participants were then run through a 5 min practice scenario focusing only on the use of MUSIM and responding to probes without the presence of the pseudo controllers or pseudo pilots. After completion of the initial MUSIM practice scenario, participants received training appropriate to their first experimental scenario block through the use of self-paced PowerPoint slides. After the training was completed, all participants completed a full five minute practice scenario in the appropriate condition containing mission reroute messages and probes.

After the training scenario was completed, participants then began their first 30 min experimental scenario. After each experimental scenario, UAS operator and pseudo controller participants were given a NASA-TLX to assess their level of workload. The experimental participants also responded to post-trial subjective questions asking about workload associated with communications and negotiations between the pseudo air traffic controllers and the UAS operators. After the questionnaires were completed, participants were given a 10 min break. There were two delegated separation scenarios (extended delegation vs. full delegation) performed for each CSD experimental block (basic traffic information vs. conflict detection present).

After each experimental block, the UAS operator participants completed a subjective questionnaire asking about situation awareness. After the first experimental block, the UAS operator participants were given the appropriate training for the next two scenarios through a self-paced PowerPoint slide presentation. The training was then followed by a 5 min practice scenario with all elements associated with the experimental scenario given to the UAS operator, pseudo air traffic controllers and pseudo pilots.

Post scenario and post block questionnaires were provided in the same order as given with the first experimental block. After the last scenario and associated paperwork was completed, the UAS operator and pseudo controller participants were given a post-simulation questionnaire asking questions on workload, situation awareness, pseudo controller to UAS operator interactions, as well as acceptability, preference and usability ratings. Participants were then debriefed, and the experimenter answered any questions the participants had.

Metrics

The effects of delegation and traffic display information level were assessed through objective and subjective measures of performance, workload and situation awareness.

Objective metrics. The objective metrics that were collected focused mainly on the UAS operator. Current separation standards are defined as having a minimum required distance of 1,000 ft vertical and 5 miles lateral (FAA, 2008b). When aircraft are separated by a distance less than this, a loss of separation (LOS) has occurred. Situation awareness probes were provided to the UAS operator through queries provided in the MUSIM chat client. Operators were required to monitor the chat window for their callsign (PD-1) and respond to any queries addressed to them. Responses were judged based upon the accuracy of the response, with the assumption that correct responses indicate high situation awareness. UAS operator response times were also analyzed.

Subjective metrics. The subjective metrics collected included situation awareness ratings and multiple workload ratings from both the UAS operator and the pseudo controller. The UAS operators were provided with online workload probes every three minutes on a scale from one (low) to seven (high), and the pseudo air traffic controllers received online workload probes every three minutes on a scale from one (low) to nine (high). Both the UAS operators and the pseudo air traffic controllers were provided with a post-trial NASA TLX.

The NASA TLX is a self-assessed workload measure that includes ratings on six dimensions; mental, physical, temporal, performance, effort and frustration (Hart, & Staveland, 1988). Along with the NASA TLX, both UAS operators and pseudo controllers were given post-trial and post-simulation questions pertaining to their overall workload associated with their interactions with each other (UAS operator to pseudo controller) on a scale from one (low) to seven (high), and additional information on UAS operator and pseudo-controller workload, situation awareness, and acceptability and preference ratings.

Results

Multiple 2x2 repeated measures ANOVAs were performed on the data collected in this experiment. The repeated measures ANOVA is used to test the equality of means when the participants are exposed to all treatments (Howell, 2011). This test indicates a real difference between the means in the datasets compared to a difference found by chance or sampling error.

ANOVAs were performed on the following data sets:

- Loss of separation (within 5 nm horizontal and 1,000 ft vertical)
- Pilot workload probes (ratings and response times)
- Pilot NASA TLX (individual subscales and overall)
- Pilot situation awareness probes (accuracy and response times)
- ATC workload probes (ratings and response times)
- ATC NASA TLX (individual subscales and overall)
- Subjective questions on:
    - Difficulty of interaction between ATC and UAS operator
    - Acceptability of final flight path
    - Acceptability of traffic reroutes
    - Difficulty for ATC to maintain flow and separation with UAS present
    - ATC level of delegation preference

Loss of Separation

Loss of separation data were analyzed by looking at the closest horizontal and vertical distances intruding aircraft reached with regards to the UAS per trial. A loss of separation was determined to have occurred when the minimum distances reached between the UAS and the intruder were within a distance of 5 nm horizontal and 1,000 ft vertical.

A 2 x 2 repeated measures ANOVA was used to determine if there were any significant differences between the level of delegation and the level of information shown on the traffic display. Results showed no significant differences between the basic and conflict detection present CSD condition, $F(1, 12) = .274$, $p = .610$, $d = -0.327$; no significant differences between the extended and full levels of delegation, $F(1,12) = .085$, $p = .776$, $d = 0.111$; and no significant interaction between the CSD and delegation conditions was found, $F(1, 12) = .316$, $p = .584$. For mean losses of separation and standard error per condition, see Table 1.

Table 1

Loss of Separation Means and Standard Errors

	Losses of Separation	
Condition	Mean	S.E.
Basic CSD, Extended Delegation	0.462	0.215
Basic CSD, Full Delegation	0.308	0.133
Conflict Detection CSD, Extended Delegation	0.462	0.183
Conflict Detection CSD, Full Delegation	0.538	0.268

UAS Operator Workload Probes

UAS operator workload probes were analyzed by their ratings and by the response times of the pilots. The workload ratings were collected on a scale of one (low) to seven (high). When analyzing probe ratings, if the pilot did not respond to the probe within the allotted time span of three minutes, the blank scores were adjusted to a score of seven (high). When analyzing probe response times, time outs (participant did not answer probe before the next probe was presented) were not included in the analysis.

Probe ratings. Results showed no significant differences in the ratings between the basic and conflict detection present CSD condition $F(1, 12) = 3.390$, $p = .090$, $d = -1.107$, though ratings did trend towards significance with conflict detection present condition ($M = 4.012$, $SE = .247$) having higher workload ratings than the basic condition ($M = 3.527$, $SE = .218$). No significant differences were found between the extended and full levels of delegation, $F(1,12) = 1.880$, $p = .195$, $d = 0.632$; and no significant interaction between CSD and delegation conditions was found, $F(1, 12) = .282$, $p = .605$. Across all conditions, the overall workload probe scores were just below the average rating of four ($M = 3.77$, $SD = 1.65$).

Response times. Results showed no significant differences in the response times to workload probes between the basic and conflict detection present CSD condition $F(1, 12) = .015$, $p = .906$, $d = -2.105$; no significant differences were found between the extended and full levels of delegation, $F(1,12) = .195$, $p = .667$, $d = 7.314$; and no significant interaction between CSD and delegation conditions was found, $F(1, 12) = 1.305$, $p = .276$.

UAS Operator NASA TLX

The NASA TLX is a self-assessed workload measure that includes ratings on six dimensions; mental, physical, temporal, performance, effort, and frustration (Hart, & Staveland, 1988). The overall and individual subscales of the NASA TLX were analyzed.

Overall workload. Results showed no significant differences in the overall workload ratings between the basic and conflict detection present CSD conditions $F(1, 12) = .003$, $p = .960$, $d = 0.162$. No significant differences were found between the extended and full levels of delegation, $F(1,12) = 3.408$, $p = .090$, $d = 2.748$, though results trended towards significance with the extended delegation condition ($M = 3.122$, $SE = .228$) having higher workload ratings than the full delegation condition ($M = 2.782$, $SE = .211$). No significant interaction was found between CSD and delegation conditions, $F(1, 12) = .041$, $p = .842$. While no significant differences were found for overall workload, the scores were on average low; $M = 2.95$, $SE = .199$ (Figure 14).

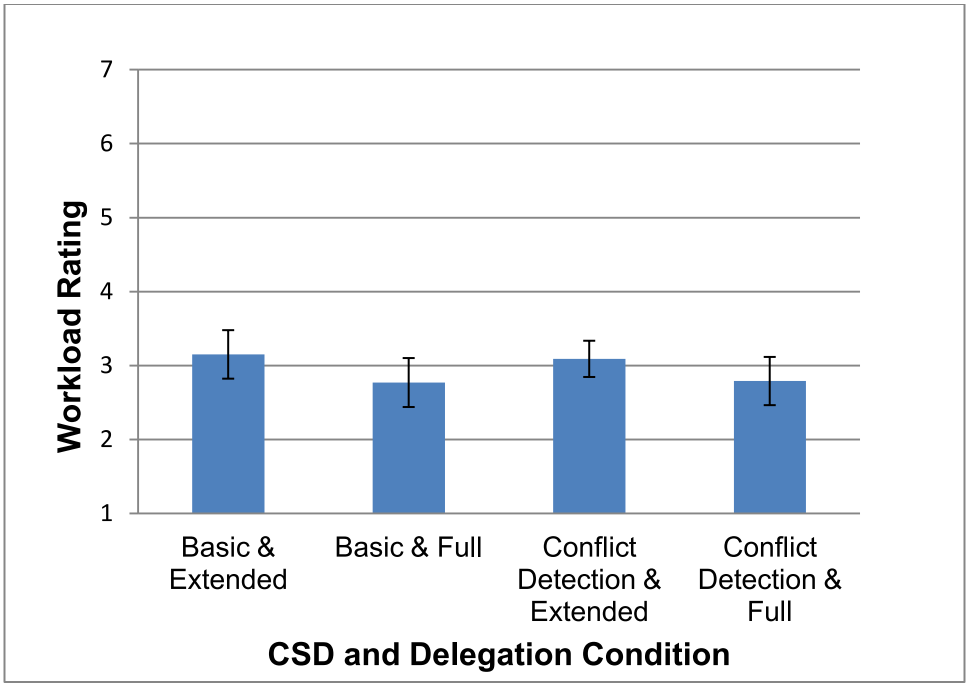

Figure 14. UAS Operator Overall Workload NASA TLX. While no significant differences were found for overall workload, the scores were on average low; *M* = 2.95, *SE* = .199.

Individual subscale. The NASA TLX is separated into six individual subscales: mental, physical, temporal, performance, effort and frustration. The level of delegation had a significant effect on temporal workload, $F(1, 12) = 10.958$, $p = .006$, $d = 1.634$, with full delegation ($M = 2.962$, $SE = .302$) having significantly lower workload scores than extended delegation ($M = 3.808$, $SE = .292$). See Figure 15.

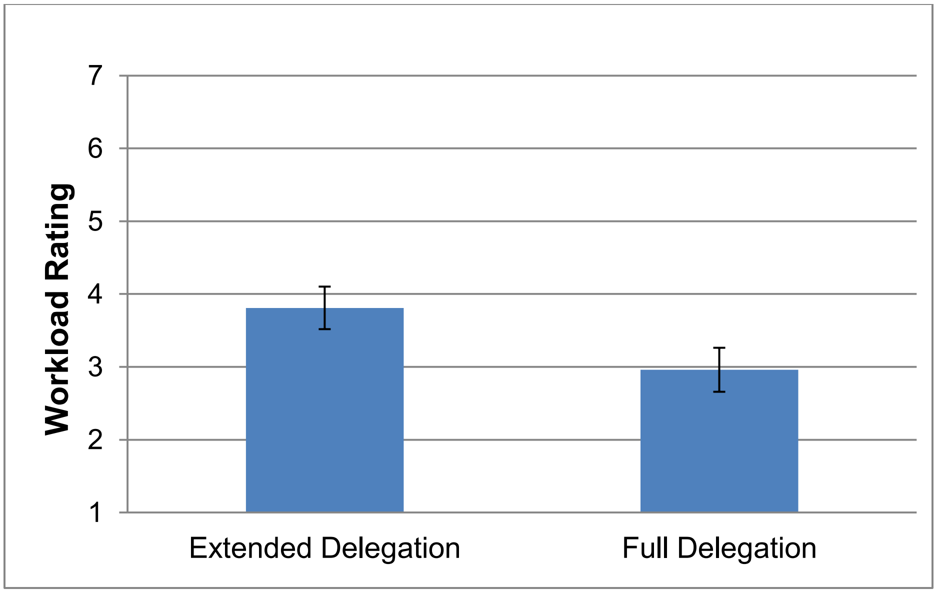

Figure 15. Mean UAS Operator Temporal Workload. The level of delegation had a significant effect on temporal workload, $F(1, 12) = 10.958$, $p = .006$, with full delegation having significantly lower workload scores than extended delegation.

The effect of the level of delegation approached significance for frustration, F(1, 12) = 3.770, $p = .076$, $d = 1.125$, with full delegation ($M = 2.038$, $SE = .302$) having lower workload scores than extended delegation ($M = 2.696$, $SE = .440$). All other subscale results were not significant (see Table 2).

Table 2

UAS Operator NASA TLX Significance Summary Table

	NASA TLX Subscale					
	Mental	Physical	Temporal	Performance Degradation	Effort	Frustration
CSD	$p = .947$	$p = .488$	$p = .719$	$p = .715$	$p = .802$	$p = .706$
Delegation	$p = .157$	$p = .137$	$p = .006$	$p = .730$	$p = .279$	$p = .076$
CSD* Delegation	$p = .895$	$p = .273$	$p = .656$	$p = .750$	$p = .899$	$p = .917$

While the ratings for mental, physical, effort and performance degradation were not found to be significant, the workload scores were found to be on average low to normal. Mental (*M* = 4.13, *SE* = .256), physical (*M* = 1.36, *SE* = .299), effort (*M* = 4.09, *SE* = .269) and performance degradation (*M* = 2.36, *SE* = .353) respectively.

UAS Operator Situation Awareness Probes

UAS operator situation awareness probes were analyzed for response accuracy and response time using 2x2 within subjects design ANOVAs. When analyzing probe response times, time outs (participant did not answer a probe question before the next probe was presented) were removed from analysis.

Probe accuracy. There were six probes presented to the UAS operator in each trial. Results were coded by accuracy with a score of one given to accurate responses, and a score of zero given to incorrect responses. The total amount of accurate responses per trial was then used in analysis.

Results showed highly significant differences in probe accuracy between the basic and conflict detection present CSD conditions $F(1, 12) = 452.107$, $p < .001$, $d = -11.62$, with the conflict detection present condition (*M* = 4.423, *SE* = .178) having significantly higher accuracy ratings than the basic condition (*M* = .840, *SE* = .026). See Figure 16.

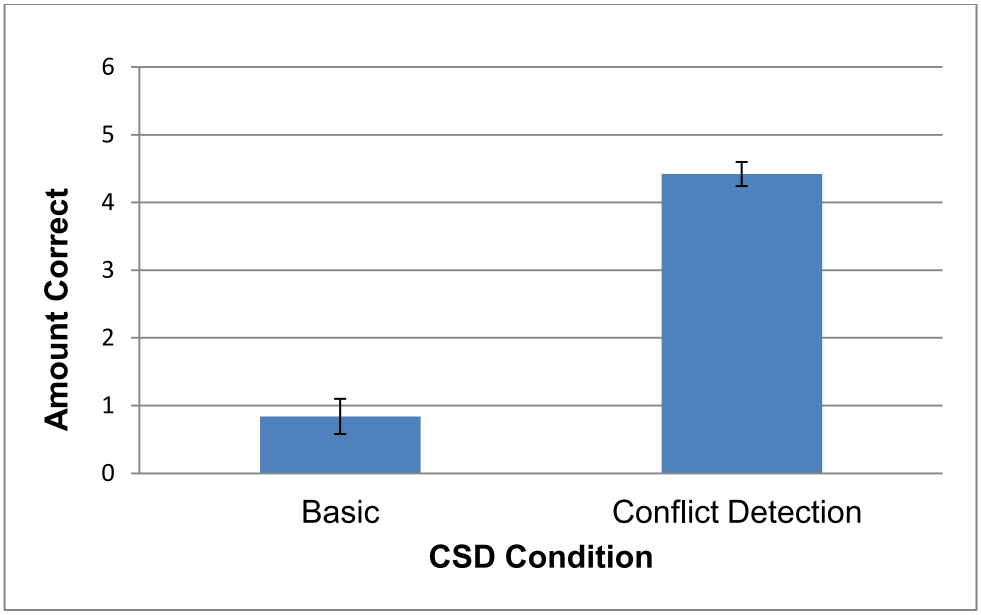

Figure 16. Situation Awareness Probe Accuracy. The conflict detection present condition was found to have a significantly higher amount of accurate probe responses than the basic condition, $F(1, 12) = 452.107$, $p = .000$.

No significant differences were found between the extended and full levels of delegation, $F(1,12) = .082$, $p = .779$, $d = -0.146$; and no significant interaction between CSD and delegation conditions was found, $F(1, 12) = .033$, $p = .859$.

Probe response time. Results showed no significant differences in the response times between the basic and conflict detection present CSD condition $F(1, 12) = 3.851$, $p = .073$, $d = -0.618$, although response times did approach significance with the conflict detection present mode ($M = 25.994$ seconds, $SE = 3.889$) having quicker response times than the basic mode ($M = 33.631$, $SE = 5.144$). No significant differences were found between the extended and full levels of delegation, $F(1,12) = .167$, $p = .690$, $d = 0.891$; and no significant interaction between CSD and delegation conditions was found, $F(1, 12) = .136$, $p = .719$.

UAS Operator Situation Awareness Questionnaires

As the experimental blocks were based on CSD condition, situation awareness questionnaires were given out after each block on a scale from 0 (low) to 7 (high). In each block (basic or conflict detection present), participants performed one trial each of extended and full delegation. Situation awareness scores were analyzed using a 2x2 repeated measures design examining the effect of the CSD condition and the order of CSD presentation (condition presented first or second).

Results showed no significant differences were found between the CSD condition, $F(1,5) = .649$, $p = .457$, $d = 1.17$; and no significant interaction between order presented and CSD conditions was found, $F(1, 5) = .361$, $p = .574$. Significant differences in pilot perceived situation awareness between the order of CSD presentation $F(1, 5) = 9.826$, $p = .026$, $d = -0.444$ were found, with the first experimental block presented ($M = 5$, $SE = .302$) having significantly lower perceived situation awareness ratings than the second experimental block presented ($M = 5.241$, $SE = .290$). This is not a surprising result as the UAS operators had more practice with the simulator by the second experimental block, and had better knowledge on procedures associated with the use of the CSD and delegated separation. See Figure 17.

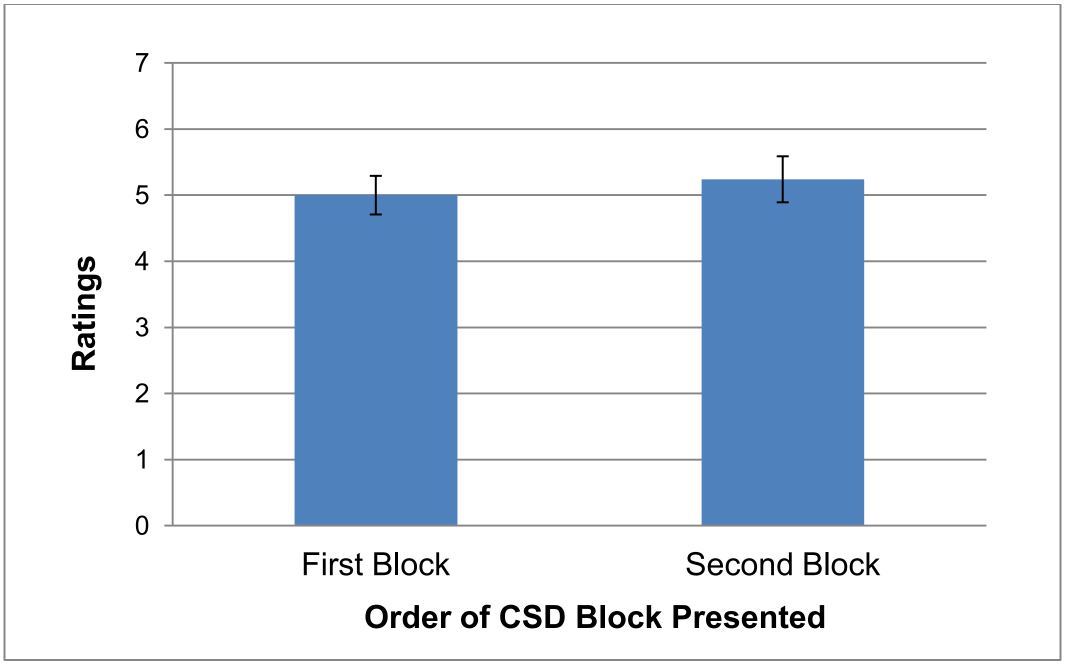

Figure 17. Post-Block Situation Awareness Ratings. The first experimental block presented (the first and second scenarios) was found to have significantly lower ratings for perceived situation awareness than the second experimental block presented (the third and fourth scenarios), $F(1, 5) = 9.826$, $p = .026$.

Air Traffic Controller Workload Probes

Air Traffic Controller workload probes were analyzed by their ratings and by the response times of the ATC per trial. The workload ratings were collected on a scale of one (low) to nine (high). All workload probes were responded to within their allotted time span, so no adjustments were made on the scores, and no response times were discarded during analysis. It is of note to point out that since there were only two air traffic controllers in this experiment, each controlling for roughly half the UAS operator participants, the analyses have low statistical power.

Probe ratings. Results showed no significant differences in the ratings between the basic and conflict detection present CSD conditions $F(1, 1) = .132$, $p = .778$, $d= 0.023$. No significant differences were found between the extended and full levels of delegation, $F(1,1) = 1$, $p = .50$, $d= 0.132$. No significant interaction between the CSD and delegation conditions was found, $F(1, 1) = 5.183$, p =..263. While workload probe ratings were not found to be significantly different, the overall workload ratings were manageable ($M = 5.913$, $SE= .220$) and on par with typical workload probe ratings from previous studies performed in the FDDRL with air traffic controller participants (Johnson el al., 2012; Battiste et al. 2012). See Figure 18.

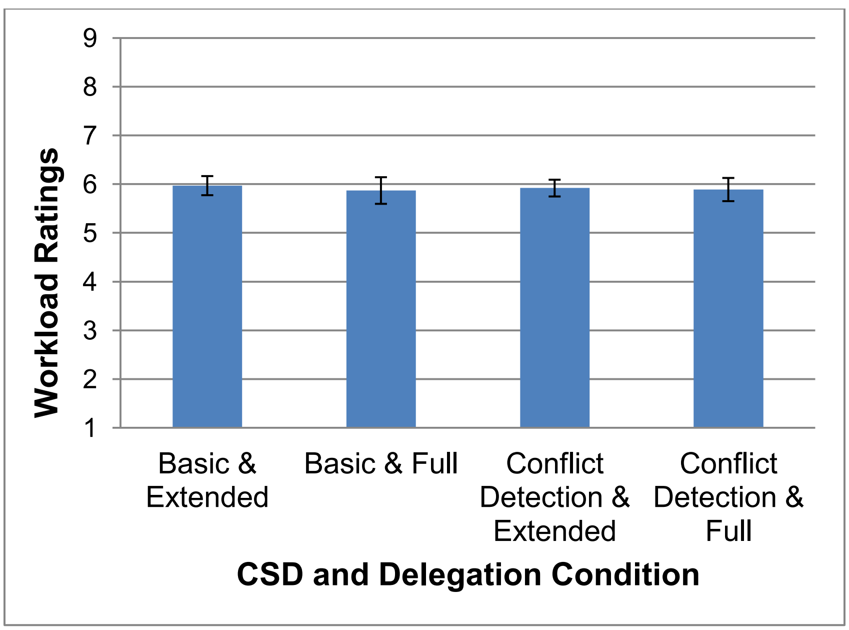

Figure 18. ATC Workload Probe Ratings. While not significant, the overall workload probe ratings for the air traffic controllers were manageable.

Probe response times. Results showed no significant differences in the response times between the basic and conflict detection present CSD conditions $F(1, 1) = 3.817$, $p = .301$, $d = 0.212$. Results showed no significant differences in the response times for the levels of delegation $F(1, 1) = .037$, $p = .879$, $d = -0.1$. No significant interaction between the CSD and delegation conditions occurred, $F(1, 1) = .011$, $p = .933$.

Air Traffic Controller NASA TLX

The NASA TLX is a self-assessed workload measure that includes ratings on six dimensions; mental, physical, temporal, performance, effort and frustration (Hart, & Staveland, 1988). The overall and individual subscales were analyzed. It is noteworthy that since there were only two air traffic controllers in this experiment, each controlling for roughly half the UAS operator participants, the analyses had low statistical power.

Overall workload. No significant differences occurred in the overall workload ratings between the basic and conflict detection present CSD conditions $F(1, 1) = 29.388$, $p = .116$, $d = -0.2$. No significant differences were found between the extended and full levels of delegation, $F(1,1) = 25.733$, $p = .124$, $d = 0.543$. No significant interaction between the CSD and delegation conditions was found, $F(1, 1) = .801$, $p = .535$. While NASA TLX workload ratings were not significantly different, the overall workload ratings were manageable ($M = 4.788$, $SE = .260$). See Figure 19.

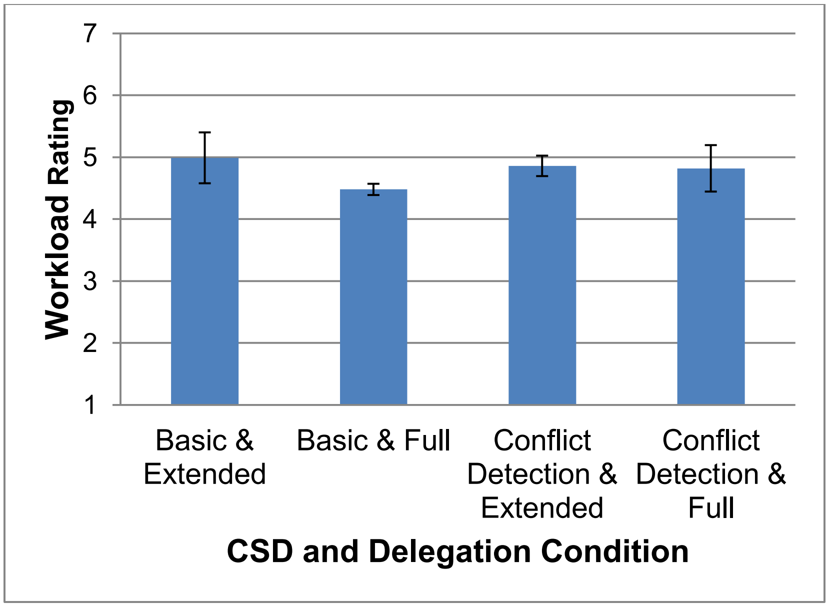

Figure 19. ATC Overall Workload NASA TLX. While not significant, the overall workload probe ratings for the air traffic controllers were manageable.

Individual subscale. The effect of CSD condition approached significance for temporal workload, $F(1, 1) = 64$, $p = .079$, $d = -0.195$, with the basic condition ($M = 4.982$, $SE = .232$) having lower workload scores than the conflict detection present condition ($M = 5.077$, $SE = .244$). All other subscale results were found to be not significant (see Table 3).

Table 3

ATC NASA TLX Significance Summary Table

	NASA TLX Subscale					
	Mental	Physical	Temporal	Performance Degradation	Effort	Frustration
CSD	$p = .126$	$p = .500$	$p = .079$	$p = .830$	$p = .357$	$p = .677$
Delegation	$p = .304$	$p = .500$	$p = .179$	$p = .170$	$p = .390$	$p = .279$
CSD* Delegation	$p = .667$	$p = .500$	$p = .578$	$p = .371$	$p = .637$	$p = .616$

While the ratings for mental, physical, temporal, performance degradation, effort and frustration were not significant, the workload scores were on average normal to manageable. Mental (*M* = 5.76, *SE* = .467), physical (*M* = 4.02, *SE* = 1.02), temporal (*M* = 5.03, *SE* = .238), performance degradation (*M* = 4.15, *SE* = .179), effort (*M* = 5.27, *SE* = .63) and frustration (*M* = 4.49, *SE* = .05) respectively.

Subjective Questions

The UAS operators and pseudo air traffic controllers were given post-trial questions pertaining to their overall workload, acceptability of reroutes, acceptability of final flight path, and workload associated with their interactions with each other (UAS operator to pseudo controller) on a scale from zero (low) to seven (high). Ratings were analyzed using 2 (CSD condition) x 2 (level of delegation) ANOVAs.

Additional questions on UAS operator and pseudo-controller workload, situation awareness, and acceptability and preference ratings were given to the participants at the end of the simulation. The post-simulation subjective questions were given on a scale from 0 (easy or acceptable) to 7 (hard or unacceptable). As the post-simulation questionnaires were collected at the end of the day after all trials were completed, analyses could not be performed to determine the effect of CSD condition and level of delegation experienced in each trial. The UAS operator responses are provided with the percentage of participants who rated that answer provided.

UAS operator subjective post-trial questions. Level of delegation was seen to have a significant effect on the difficulty to interact with air traffic control, $F(1, 12) = 6.789$, $p = .023$, $d = 2.369$, with full delegation ($M = .577$, $SE = .195$) having significantly lower difficulty scores than extended delegation ($M = 1.808$, $SE = .469$). While there is a significant difference in the mean, it is of note that both conditions have relatively low difficulty ratings. See Figure 20.

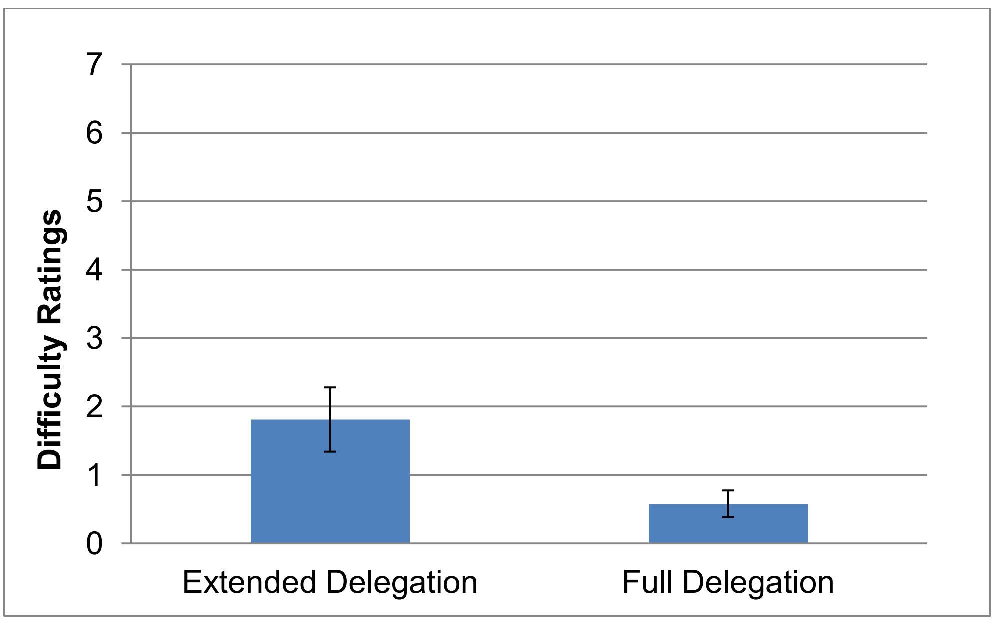

Figure 20. UAS Operator Difficulty Interacting with ATC. UAS operators were asked on a scale from zero (low) to seven (high) how difficult it was for them to interact with the air traffic controllers. Full delegation was found to have significantly lower difficulty ratings than extended delegation, $F(1, 12) = 6.789$, $p = .023$.

All other UAS operator post-trial subjective question results were found to be not significant (see Table 4).

Table 4

UAS Operator Subjective Questions Significance Summary Table

	UAS Operator Subjective Questions			
	Difficulty to interact with ATC	Acceptability of traffic reroutes	Acceptability of final flight path	Overall Workload
CSD	*p* = .201	*p* = .797	*p* = .517	*p* = .814
Delegation	*p* = .023	*p* = .235	*p* = .337	*p* = .119
CSD* Delegation	*p* = .487	*p* = .919	*p* = .645	*p* = .897

While the ratings for both the acceptability of the UAS operators' final flight path, and the acceptability of their reroutes to avoid traffic conflicts were not significant, this was due to overall ratings of acceptability; *M* = 2.59, *SE* = .30 and *M* = 2.63, *SE* = .28, respectively.

UAS operator post-simulation subjective questions. UAS operator post-simulation ratings are discussed by question type: perceived safety, workload associated with UAS, CSD usefulness and ease of use, CSD workload and willingness to use, and the amount of information displayed on the CSD. The tables show the responses given by the UAS operators and the percentages of participants who gave that response.

While the UAS operators were mixed on their opinions of flying in a shared environment with UAS in the current NAS, over 60% of the participants were willing to share the airspace with properly trained unmanned vehicle operators.

The importance of training was further emphasized with all participants rating that they gained more confidence operating the UAS and working in delegated separation conditions as they gained more practice. See Table 5 for all safety ratings and response percentages (rounded to the tenth).

Table 5

UAS Operator Post-Simulation Perceived Safety Ratings

Subjective Question	Response Percentages
I believe flying in a shared environment with UAS would be acceptable in the current environment	7.7 % Strongly Disagree 23.1% Somewhat Disagree 15.4% Neither Disagree nor Agree 30.8% Somewhat Agree 23.1% Strongly Agree
With appropriate training for UAS pilots, I would be willing to fly in an airspace that included UAS	23.1% Somewhat Disagree 15.4% Neither Disagree nor Agree 53.9% Somewhat Agree 7.7% Strongly Agree
I gained comfort with my ability to respond to the reroute orders as I gained more practice	15.4% Somewhat Agree 84.6% Strongly Agree
I gained comfort with my ability to operate the UAS under the extended delegated separation as I gained more practice	69.2% Somewhat Agree 30.8% Strongly Agree
I gained comfort with my ability to operate the UAS under full delegated separation as I gained more practice	38.5% Somewhat Agree 61.5% Strongly Agree

The post-simulation workload ratings reflect those collected via probes and the NASA TLX with overall ratings found to be low to manageable. A trend in level of delegation can be seen in the post-simulation ratings that match with other workload measures; full delegation was found to create lower UAS operator workload than extended delegation. See Table 6 for all workload ratings and response percentages (rounded to the tenth).

Table 6

UAS Operator Post-Simulation Workload Ratings

Subjective Question	Response Percentages
I believe the overall WL associated with the concept of UAS in the NAS is manageable	7.7% Strongly Disagree 7.7% Somewhat Disagree 23.1% Neither Disagree nor Agree 30.8% Somewhat Agree 30.8% Strongly Agree
Flying a UAS in extended delegated separation would not be possible due to high WL	7.7% Strongly Disagree 46.2% Somewhat Disagree 7.7% Neither Disagree nor Agree 23.1% Somewhat Agree 15.4% Strongly Agree
Flying a UAS in full delegated separation would not be possible due to high WL	30.8% Strongly Disagree 15.4% Somewhat Disagree 15.4% Neither Disagree nor Agree 23.1% Somewhat Agree 15.4% Strongly Agree
I was unable to successfully perform my mission due to the high WL associated with the rerouting events	23.1% Strongly Disagree 30.8% Somewhat Disagree 46.2% Somewhat Agree
I was unable to successfully perform my mission due to the high WL associated with avoiding conflicts	23.1% Strongly Disagree 15.4% Somewhat Disagree 30.8% Neither Disagree nor Agree 23.1% Somewhat Agree 7.7% Strongly Agree

The willingness to use CSD ratings shows that the UAS operators are more willing to fly a UAS in the NAS when using the CSD, with about 76% of the pilots being unwilling to fly a UAS without one. UAS operators are also more willing to fly a UAS in the NAS when conflict detection is present on the CSD.

See Table 7 for CSD use ratings and response percentages (rounded to the tenth).

Table 7

UAS Operator Willingness to Use CSD Ratings

Subjective Question	Response Percentages
I would be willing to fly center airspace with a UAS without using the CSD	53.9% Strongly Disagree 23.1% Somewhat Disagree 15.4% Neither Disagree nor Agree 7.7% Somewhat Agree
I would be willing to fly center airspace with a UAS using the basic mode of the CSD	15.4% Strongly Disagree 30.8% Somewhat Disagree 23.1% Neither Disagree nor Agree 30.8% Somewhat Agree
I would be willing to fly center airspace with a UAS using the conflict detection present mode of the CSD	7.7% Strongly Disagree 7.7% Somewhat Disagree 23.1% Neither Disagree nor Agree 23.1% Somewhat Agree 30.8% Strongly Agree 7.7% N/A
Use of the CSD will enhance the safety of flying UAS in the NAS	23.1% Moderate Enhancement 46.2% Intermediate Enhancement 30.8% Large Enhancement

The CSD usability ratings show an overall favorable view towards the use of the CSD. Across all participants, the CSD was used to determine reroutes and the information displayed on the CSD in both the basic and conflict detection modes was found to be useful. Overall, more participants found the conflict detection mode to be very useful when compared to the basic mode. Over 50% of the participants found their workload to be lower in the conflict detection mode than in the basic mode. See Table 8 for all CSD usability ratings and response percentages (rounded to the tenth).

Table 8

UAS Operator CSD Usability Ratings

Subjective Question	Response Percentages
Did you use the CSD when determining reroutes	100% Yes
How useful was the display for extracting airspace information in basic mode	15.4% Neither Useless or Useful 76.9% Somewhat Useful 7.7% Very Useful
How useful was the display for extracting airspace information in conflict detection present mode	7.7% Somewhat Useless 7.7% Neither Useless or Useful 61.5% Somewhat Useful 23.1% Very Useful
How useful was the conflict detection mode compared to the basic mode in supporting interactions with ATC	15.4% Somewhat Useless 38.5% Neither Useless or Useful 46.2% Somewhat Useful
How easy was the display to use in the basic mode given the mission requirements	15.4% Somewhat Difficult 38.5% Neither Difficult or Easy 46.2% Somewhat Easy
How easy was the display to use with conflict detection present given the mission requirements	7.7% Somewhat Difficult 38.5% Neither Difficult or Easy 30.8% Somewhat Easy 23.1% Very Easy
What was your WL when using the conflict detection present CSD mode vs. the basic mode	23.1% Somewhat More Difficult 23.1% Neither Difficult or Easy 30.8% Somewhat More Easy 23.1% Much More Easy

Questions were also asked of the UAS operator participants on the information displayed via the CSD. Overall, participants found more necessary information displayed in the conflict detection present mode than in the basic mode. See Table 9 for CSD information displayed ratings and response percentages.

Table 9

UAS Operator CSD Information Displayed Ratings

Subjective Question	Response Percentages
Was all of the necessary information available from the CSD in basic mode	15.4% Somewhat Less Available 30.8% Neither Missing or Available 46.2% Somewhat Available 7.7% Completely Available
Was all of the necessary information available from the CSD in the conflict detection present mode	15.4% Somewhat Less Available 23.1% Neither Missing or Available 30.8% Somewhat Available 30.8% Completely Available

Open ended questions were also asked of the UAS operators for the type of information they would have liked to see that was not available in the scenarios presented. The most common responses were to have the full flight plan of the surrounding aircraft available for assistance in conflict detection and avoidance and to have an overlay of instrument and approach airways. While not used in this experiment in order to create a simulation environment closer to the airspace systems used in the current environment, it is worth noting that both of these capabilities are available on the Ames 3D CSD and have been found to greatly assist in separation assurance.

Air traffic controller post-trial subjective questions. It is of note to point out that since there were only two air traffic controllers in this experiment, each controlling for roughly half the UAS operator participants, the analyses have low statistical power.

The level of delegation was seen to have a highly significant effect on how acceptable air traffic controllers found the UAS operators' reroutes to be, $F(1, 1) = 5041$, $p = .009$, $d = 7.723$, with the extended delegation condition's reroutes ($M = 1.42$, $SE = .006$) being rated as less acceptable to air traffic controllers than the full delegation condition ($M = 1$, $SE = .000$). See Figure 21.

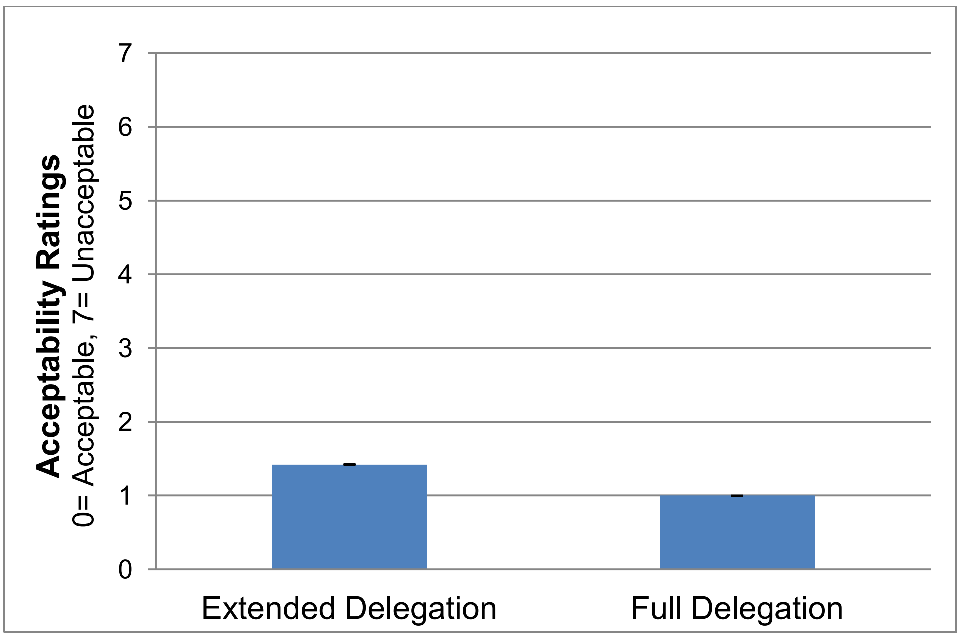

Figure 21. ATC Reroute Acceptability Ratings. Air traffic controllers were asked on a scale from zero (acceptable) to seven (unacceptable) how acceptable the reroutes made by the UAS operators were. Full delegation was found to have significantly higher acceptability than extended delegation, $F(1, 1) = 5041$, $p = .009$.

Across all participants and 100% of the trials, both air traffic controllers preferred full delegation to extended delegation and current day operations. All other subjective question results were found to be not significant (see Table 10).

Table 10

ATC Subjective Questions Significance Summary Table

	ATC Subjective Questions			
	Difficulty to interact with UAS operator	Acceptability of traffic reroutes	Difficulty meeting flow and separation requirements with UAS	Overall Workload
CSD	p = .634	p = .732	p = .105	p = .242
Delegation	p = .105	p = .009	p = .630	p = .264
CSD* Delegation	p = .830	p = .883	p = .559	p = .500

While the post-trial air traffic controllers' subjective ratings were overall not significant, the ratings themselves are worth note. In the difficulty to interact with UAS operator, the scores were overall acceptable (*M* = 1.42, *SE* = .006). The ratings for difficulty in maintaining flow and separation with a UAS present in sector were low to manageable (*M* = 3.49, *SE* = 2.10). The overall workload scores were high, but manageable (*M* = 5.81, *SE* = .399). The higher overall workload scores when compared to the UAS operators' ratings (*M* = 3.98, *SE* = .29) are not surprising as the controllers maintained positive control over their sector while working with the UAS in either extended or full delegation.

Air traffic controller post-simulation subjective questions. Air traffic controller questionnaire responses are discussed by question type: sector management queries, the controllers' perceived capabilities of the UAS operators, and the perceived airspace safety and level of delegation preference.

The tables show the responses given by the air traffic controllers, and the percentages of trials (13, one per UAS operator) that were given the responses.

Multiple questions were asked to investigate the air traffic controllers' experiences performing sector management (Table 11). Workload levels involved with managing a sector with an unmanned aircraft were found to be on par with or higher than normal current day operations. Meeting flow and separation requirements when the UAS operator was in extended delegation was seen to be between somewhat difficult and very difficult, on average. Full delegation was seen to be easier for the controllers to maintain flow and separation, with over half of the responses being rated as not at all difficult. In both extended and full delegation, controllers believed the UAS operator was able to maintain separation 92.3% of the time.

The responses for whether or not the UAS created problems for the controllers' managing their sectors were split, with just over half of the responses saying the UAS did not create problems. When asked if the UAS required special handling, 100% of the responses said yes, with just under 70% of the responses saying that special handling was used between 0 - 25% of the time. Open ended questions were asked on strategies used for special handling, with the average response being to use altitude restrictions for aircraft descending into the UAS's flight level. See Table 11 for air traffic controller sector management question ratings and response percentages (rounded to the tenth).

Table 11

ATC Sector Management Questions

Subjective Question	Response
WL managing a sector with a UAS in it compared to normal operations with only manned aircraft	30.8% Neither higher or lower 46.2% Somewhat higher 23.1% Much Higher
Difficulty maintaining flow and separation with the UAS in extended delegated separation compared to normal operations	7.7% Not at all difficult 38.5% Somewhat difficult 53.9% Very difficult
Difficulty maintaining flow and separation with the UAS in full delegated separation compared to normal operations	53.9% Not at all difficult 46.2% Somewhat difficult
The UAS operator was able to maintain separation in extended delegation	92.3% Yes 7.7% No
The UAS operator was able to maintain separation in full delegation	92.3% Yes 7.7% No
Did the UAS aircraft performance create problems for managing your sector?	46.2% Yes 53.9% No
Did the UAS require special handling? If yes, what percentage of the scenario time?	100% Yes 69.2% 0-25% of time 30.8% 25-50% of time

The controllers' overall perception of UAS operator capabilities were on par with their perception of manned aircraft pilot capabilities. All UAS operator participants were found to have enough knowledge of the airspace and procedures to communicate and respond to the air traffic controllers' instructions. This is not surprising as all UAS operator participants were required to have at minimum a private pilot certificate. See Table 12 for air traffic controller perception of UAS operators' capabilities ratings and response percentages.

Table 12

ATC Perception of UAS Operators' Capabilities

Subjective Question	Response
How immediately did UAS operators respond to instructions compared to manned pilots	7.7% Much Less Immediately 38.5% Somewhat Less Immediately 53.9% Same As Manned
How appropriately did UAS operators respond to instructions compared to manned pilots	7.7% Much Less Appropriate 15.4% Somewhat Less Appropriate 76.9% Same As Manned
Did UAS operators use correct terminology when communicating, compared to manned pilots	7.7% Much Less Use 61.5% Somewhat Less Use 30.8% Same As Manned
The UAS operators have enough knowledge of the airspace and procedures to communicate	100% Yes
The UAS operators have enough knowledge of the airspace and procedures to respond to instructions	100% Yes

Across all participants, the air traffic controllers preferred full delegation. The controllers rated the perceived level of safety in the air transportation system with a UAS present as having on average the same level of safety as compared to normal operations. Matching the workload ratings of the air traffic controllers, full delegation was perceived as being safer than extended delegation, with 92.3% of the trials being considered the same level of safety as normal operations in the current airspace. See Table 13 for air traffic controller perceived safety and preference ratings and response percentages (rounded to the tenth).

Table 13

ATC Perceived Safety and Preference Ratings

Subjective Question	Response
Preferred level of delegation of separation	100% Full delegation
Perceived level of safety of air transportation system with UAS in extended delegated separation compared to normal operations	53.9% Same level of safety 46.2% Somewhat less safe
Perceived level of safety of air transportation system with UAS in full delegated separation compared to normal operations	92.3% Same level of safety 7.7% Somewhat less safe

The 100% preference across participants by the air traffic controllers for full delegation correlates with the 92.3% rating of UAS flying under full delegation having the same perceived level of safety compared to the controllers' perceptions of normal current day operations, as well as the better controller acceptability ratings of UAS operator reroutes when in full delegation.

Discussion

The purpose of this thesis was to determine the feasibility of UAS performing delegated separation in the NAS. The study was a 2 x 2 within-subjects design, with level of delegation (extended delegation vs. full delegation) and traffic display information level (basic, traffic only vs. conflict detection present) as independent manipulations. The effects of delegated separation and traffic display information level were collected through objective and subjective measures of performance, workload, and situation awareness.

Loss of Separation

Loss of separation data were analyzed by looking at the closest horizontal and vertical distances intruding aircraft reached in regards to the UAS per trial. A loss of separation was determined to have occurred when the minimum distances reached between the UAS and the intruder were within a distance of 5 nm horizontal and 1,000 ft vertical. In this experiment, there were no significant effects on loss of separation; on average there was less than one loss of separation per trial (M = .44, SE = .124).

The low occurrence of losses of separation across the conditions implies that the addition of more information on the CSD, and the addition of more responsibility for separation assurance given to the UAS operator does not increase the chance of a loss of separation occurring. This finding is important for safety issues associated with UAS flying in the NAS as the potential increase of loss of separations associated with UAS flying in a manned sector is a main safety concern. Although losses of separation did occur, these data should be interpreted cautiously as this study contained experimental flight paths specifically designed to create conflicts. Further research should be performed to gain a more in depth understanding of how a UAS impacts the overall safety, flow, and management of flight operations in the NAS.

UAS Operator Workload

Workload was collected from the UAS operator by using online workload probes and through use of the NASA TLX. Pilot workload probes were analyzed by their ratings and by the response times of the pilots. No significant differences were found between the levels of delegation or the levels of information shown on the CSD, though ratings did trend towards significance with the conflict detection present condition having higher workload ratings than the basic condition. No significant differences were found on response times.

This trend towards higher workload probe scores on the UAS operator in the conflict detection present mode is not surprising as the operators were presented with a higher amount of information that they were required to pay attention to, process, make a decision on whether or not to avoid the conflict presented, and perform an action based upon that decision. Overall, workload probe scores did not surpass the “average” score of four. This result implies that even with the added workload of conflict detection and higher separation responsibility, pilots were able to perform their tasks without high workload pressure and with comparable response times across all conditions.

Overall workload scores on the NASA TLX were also not significant, though the level of delegation was seen to have a significant effect on the temporal dimension of workload, and the effect of frustration approached significance. The data from all other subscales did not differ significantly across the four experimental conditions. In both the temporal and frustration dimensions of workload, full delegation had lower scores than extended delegation. These findings are supported by previous research done on delegated separation that shows a reduction in workload when pilots are given full separation responsibilities (Krozel & Mogford, 2001; Lee, et al., 2003.; Johnson & Battiste, 2000).

UAS Operator Situation Awareness

Situation awareness measures were collected from the UAS operator by using online situation awareness probes analyzed by accuracy and response times and through the use of subjective questionnaires given post-CSD condition block.

Probe results showed highly significant differences in accuracy between the basic and conflict detection present CSD conditions, with the conflict detection present condition facilitating the UAS operator situation awareness with significantly higher accuracy ratings than the basic condition. The increase in

UAS operator situation awareness with the introduction of the conflict detection mode of the CSD is important to note. The lack of an out the window view associated with unmanned vehicles has been listed as a safety concern due to the potential for decreased UAS operator situation awareness. The presence of the conflict detection present mode not only increased UAS operator situation awareness without significantly increasing UAS operator workload, but was found to induce higher UAS operator created reroute acceptability ratings from the air traffic controllers. These results show a shared benefit created by the conflict detection present mode of the CSD for both the UAS operator and the air traffic controller.

Subjective questionnaire data collected post experimental block shows significant differences in pilot perceived situation awareness between the orders of CSD presentation, with the first experimental block presented having significantly lower perceived situation awareness ratings than the second experimental block presented. This finding is not surprising as the UAS operators had already completed two full trials and multiple training scenarios before they began the second experimental block, and had become accustomed to the apparatus and procedures associated with the study.

Probe results show an increase in situation awareness correlating to the increase of information being presented on the CSD, with no significant effects on response times or workload. Subjective questionnaire results do not show the same significant effect of CSD on ratings, though the data trend of higher conflict detection present ratings supports the probe findings. The finding that the second experimental block increases the feeling of subjective situation awareness regardless of condition is not surprising as the operator has gained better knowledge of how the display works and what to look out for by way of conflicts.

What is interesting is the trend of the conflict detection present CSD mode having a greater increase in situation awareness after being presented second, compared to the basic mode being presented second (Figure 22).

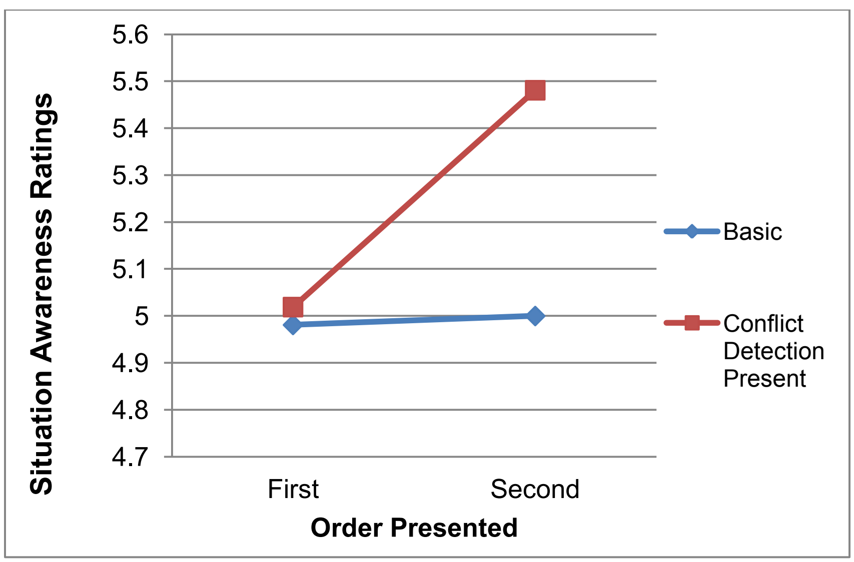

Figure 22. UAS Operator Perceived Situation Awareness. The conflict detection present CSD mode has a trend towards a greater increase in situation awareness after being presented second, compared to the basic mode being presented second.

This increase in situation awareness indicates the potential for an effect of training. Pilots may become more adept at their task when initially trained on a basic system, and then trained on a more advanced system. This finding is supported by Billinghurst et. al (2011), who found a similar effect when training participants on basic systems before introducing them to more complex NextGen systems.

These findings suggest that the addition of a conflict detection tool to the CSD has the potential to increase situation awareness without negatively affecting workload or pilot response times. Moreover, when training pilots on advanced displays concepts, the addition of learning a basic version of the display first may foster a more effective and efficient use of the advanced system. Further research is required to more accurately determine the effects of flight deck display training and content.

Air Traffic Controller Workload Probes

ATC workload probes were analyzed by their ratings and by the response times of the ATC per trial. No significant differences were found in workload probe scores, though both ATC had manageable workload ratings throughout the scenarios. No significant differences were found in probe response times.

The NASA TLX results showed no significant differences in the overall workload ratings between the basic and conflict detection present CSD condition, no significant differences between extended delegation and full delegation, and no significant interaction between CSD and delegation conditions. While no significant differences were found between the extended and full levels of delegation, results showed higher workload ratings in the extended delegation condition than the full delegation condition.

The effect of CSD condition approached significance for temporal workload, with scores being lower in the basic condition. No significant differences or interactions were found for mental, frustration, effort, physical or performance degradation. While the subscale results were not significant, this might have been due to overall manageable ratings that did not change significantly throughout the conditions and trended towards lower scores in full delegation. This air traffic controller workload trend correlates to the same finding in UAS operator workload; extended delegation created a higher overall workload for participants. It is important to note that for both the air traffic controller and the UAS operator, extended delegation created an increase on temporal workload, significantly for the UAS operator, and an overall trend for higher ratings in this delegation condition. These results imply an advantage of full delegation to extended delegation that is shared between the air traffic controller and UAS operator.

Post-Trial Subjective Questions

The level of delegation was seen to have a significant effect on the UAS operator’s perceived difficulty to interact with air traffic control, as well as to have a correlating trend on the air traffic controllers' perceived difficulty to interact with the UAS operators. For both types of participants, extended delegation created higher difficulty scores than full delegation. This is in support of the findings that show an increase in workload on both the air traffic controllers and the UAS operators when extended delegation was in use. The correlated workload and difficulty ratings show a shared advantage between the controllers and the pilots when full delegation is in use.

The level of delegation was also seen to significantly affect the level of acceptability air traffic controllers had towards the UAS operators' reroutes. When full delegation was in use, the air traffic controllers found the UAS operators' reroutes to be significantly more acceptable. Higher air traffic controller acceptability of flight path reroutes is an additional benefit to reduced workload created by the use of full delegation.

While multiple subjective questions were not found to have significant differences, the results are of note. For the UAS operators, the ratings for both the acceptability of their final flight path, and the acceptability of their reroutes to avoid traffic conflicts were not found to be significant. This was due to overall ratings of acceptability on a scale of zero (acceptable) to seven (unacceptable); $M = 2.59$, $SE = .30$ and $M = 2.63$, $SE = .28$ respectively. These ratings show an overall feeling of acceptability in flight path modifications from both the air traffic controllers and the UAS operators.

Interestingly, while the CSD condition did not have a significant effect on how acceptable the UAS operators perceived their final flight path to be, the CSD condition was found to have a trend on how difficult it was for the air traffic controllers to maintain flow and separation requirements with the UAS present. Air traffic controllers found the basic CSD condition to increase the difficulty in maintaining flow and separation requirements in their sector than when the conflict detection present CSD condition was in use by the UAS operator. This trend was not significant however, and overall difficulty ratings for maintaining flow and separation were low to manageable, $M = 3.49$, $SE = 2.10$.

This finding is of note as the conflict detection present condition made it easier for air traffic controllers to maintain flow and separation requirements while increasing the UAS operator situation awareness, and without significantly increasing UAS operator workload.

Post-Simulation Subjective Questions

While the UAS operators were mixed on their opinions of flying in a shared environment with UAS in the current NAS, over 60% of the participants were willing to share the airspace with properly trained unmanned vehicle operators. The importance of training is further emphasized with all participants rating that they gained more confidence operating the UAS and working in delegated separation conditions as they gained more practice. This finding correlates with the increase in UAS operator situation awareness found in the second experimental block of scenarios.

The post-simulation workload ratings for both UAS operators and air traffic controllers were found to correlate with probe and NASA TLX ratings with overall scores found to be manageable. A trend in level of delegation can be seen in the post-simulation ratings, and correlate with other workload measures; full delegation was found to create lower workload than extended delegation. Air traffic controller workload levels involved with managing a sector with an unmanned aircraft were rated to be on par with or somewhat higher than normal current day operations. Meeting flow and separation requirements when the UAS operator was in extended delegation was seen to be between somewhat difficult and very difficult, on average. Full delegation was seen to be easier for the controllers to maintain flow and separation, with over half of the responses being rated as not at all difficult. The workload ratings show a benefit to the use of full delegation that is shared between UAS operators and air traffic controllers.

The responses for whether or not the UAS created problems for the air traffic controllers managing their sectors were split, with just over half of the responses saying the UAS did not create any problems. When asked if the UAS required special handling, 100% of the responses said yes, with just fewer than 70% saying that special handling was used between 0 - 25% of the time. While special handling was used a minor amount of the time, it is important to note that air traffic controller workload and losses of separation were not found to be significantly affected by the conditions. Air traffic controllers mentioned that the special handling they performed, primarily altitude restrictions, was the same type of handling they would do for other special use aircraft, such as those used in police patrols, and was not out of the ordinary.

The UAS operators' willingness to use the CSD ratings shows that they are more willing to fly a UAS in the NAS when using the CSD, with about 76% of the pilots being unwilling to fly a UAS without one. UAS operators are also more willing to fly a UAS in the NAS when conflict detection is present on the CSD, and all participants felt that the addition of a CSD in a UAS ground control station would increase the safety of UAS flight in the NAS. These findings are not surprising as the conflict detection present mode was found to significantly increase the accuracy ratings for situation awareness probes. Situation awareness is a vital aspect in conflict detection and avoidance, arguably increasing in importance for UAS operators as they do not have an out the window view and rely more heavily upon their traffic display.

The UAS operator CSD usability ratings show an overall favorable view towards the use of the CSD. Across all operators, the CSD was used to determine reroutes, and the information displayed on the CSD in both the basic and conflict detection modes was found to be useful. Overall, UAS operators found the conflict detection mode to be more useful when compared to the basic mode, which correlates with the increase in situation awareness and an increased willingness to fly a UAS ratings, as well as an increase in the air traffic controllers' acceptability ratings for the UAS operators' reroutes. Additionally, over 50% of the UAS operators found their workload to be easier in the conflict detection mode than in the basic mode, a finding that is correlated across workload measures collected.

UAS operators felt that more necessary information was available on the CSD when in conflict detection mode. When asked what information they would like to see that was not available in the simulation, UAS operators most commonly responded with being able to see the entire flight path of the surrounding aircraft and an overlay of instrument and approach airways. While not used in this experiment, it is worth noting that both of these capabilities are available on the Ames 3D CSD and have been found to assist in separation assurance and increased situation awareness. Further research should be performed to investigate if the display of aircraft trajectories and overlays of airways on the UAS operators' CSD has a positive effect on the air traffic controllers' reroute acceptability and difficulty in maintaining flow and separation ratings.

The air traffic controllers' overall perception of UAS operator capabilities were on par with their perception of manned aircraft pilot capabilities. All UAS operator participants were found to have enough knowledge of the airspace and procedures to communicate and respond to the air traffic controllers' instructions. As the UAS operator participants were required to have at minimum a private pilot certificate, this was not a surprising finding. Further research should be done to investigate the effects of different levels of flight experience, certifications, and video game use on UAS operation to better define what the requirements will be for UAS operators in the NAS.

Across all participants, the air traffic controllers preferred full delegation 100% of the time. The controllers rated the perceived level of safety in the air transportation system with a UAS present as having on average the same level of safety as compared to normal operations. Full delegation was perceived as being safer than extended delegation by the air traffic controllers, a finding that is correlated with both the controllers' preference, and the workload ratings of both the controllers and the UAS operators. This again suggests that the use of full delegation creates benefits experienced by both the UAS operator and the air traffic controller.

Comparison of the Current Unmanned Systems Results to Manned Flight

An important objective measure collected in this experiment was the number of losses of separation that occurred per condition within 5 nm horizontal and 1000 ft vertical. While this study found no significant differences between conditions, the number of LOS are comparable to other studies. A study done by Fern, Kenny, Shively and Johnson (2012) measured baseline compliance rates for UAS operating in the current airspace system with the same sector and traffic patterns of this experiment, though air traffic control was responsible for maintaining separation. Results showed comparable rates of overall LOS (*M* = 0.292, *SD* = 0.464) to those collected in this study (*M* = 0.442, *SD* = 0.725). Vu et al. (2012) studied delegated separation for manned aircraft using the same separation standards. Results from Vu et al. interestingly showed a higher rate of overall LOS than this study (*M* = 0.625), also with no significant differences in the rate of LOS between the different levels of delegation. While a comparable rate of LOS did occur in these studies, these data points should be interpreted cautiously as all flight paths were specifically designed to create conflicts.

Previous studies focusing on manned aircraft performing delegated separation showed a decrease in the number of message exchanges and instructions between ATC and pilots (Grimaud, Hoffman, & Zeghal, 2001; Vu et al., 2012; Zeghal, Grimaud, Hoffman. & Rognin, 2001). The same result was found in the current study; there were fewer interactions between the UAS operator and ATC under delegated separation. The ATC preference for full delegation in this study is also consistent with previous findings of controllers rating delegated separation to be an effective and useful tool in maintaining flow and separation (Grimaud, et al., 2001).

The ATC ratings collected in this study further indicated that controllers had an easier time of meeting flow and separation requirements. They also reported that UAS operator created reroutes were significantly more acceptable under full delegation. These ratings are consistent with previous findings in manned flight that report increases in efficiency based on time, distance, fuel consumption, straightness of trajectories, and closest point of approach (Grimaud, et al., 2001; Lee et al., 2003). Additionally, faster response times from flight crews in full delegation to off nominal scenarios have also been found; flight crews were less likely to be passive and wait for the air traffic controller to intervene in the event of a loss of separation when ATC is not responsible (Prinzel et al., 2011; Johnson, Battiste, Delzell, Holland, Belcher & Jordan, 1997; Vu et al., 2012).

Full delegation was associated with lower UAS operator workload ratings in this experiment. In the temporal and frustration dimensions of the NASA TLX, and post-simulation likert scales, full delegation resulted in lower workload ratings than extended delegation. These findings are consistent with previous research done on delegated separation when manned pilots are given full separation responsibilities (Johnson & Battiste, 2000; Krozel & Mogford, 2001; Lee et al., 2003; Prinzel et al., 2011). While ATC workload ratings were not found to be significantly different, the overall workload ratings were manageable (M = 5.913, SE= .220). They were also similar to typical workload probe ratings from previous studies performed in the FDDRL using the same workload probe scale with air traffic controller participants (Battiste et al., 2012; Johnson el al., 2012; Vu et al., 2012).

When using the cockpit situation display, UAS operators reported that the conflict detection mode was more useful and comprehensive than the basic mode. This correlated with an increase in operator SA, higher ATC reroute acceptability ratings, and lower UAS operator post-sim WL ratings. These findings are consistent with previous findings of manned pilots having a high confidence in using cockpit displays of traffic information (CDTIs) for delegated separation (Domino, Tuomey, Mundra & Smith, 2010; Johnson, Battiste, Delzell, Holland, Belcher & Jordan, 1997).

Future Research Considerations

Future research should be done to determine UAS operator requirements and training requirements, in addition to determining the optimal way to present conflict detection alerts. In this experiment, alerts were given to the UAS operator as far as 20 minutes out, which caused many UAS operator participants to voice frustrations at such early alerts. It is unknown what the proper timing for alerts should be for a UAS to successfully avoid a conflict as their flight characteristics (such as speed and maneuverability) are different than manned aircraft. Further research should be done, perhaps through the use of parametric studies, to investigate the effects of differing flight characteristics on alert usage and UAS operator responses.

A more in-depth look at the conflict data in this experiment may help to shed light on this by an additional analysis determining how far out the intruders were before the alerts were given. It would also be useful to examine how long it took the UAS operator to respond to the alert, maneuver and avoid the conflict. Finally, it would be important to determine the threshold for distance/time that allowed the UAS operator to successfully avoiding the conflict and how many conflicts were actively vs. passively avoided (active move or passive change in leg of flight path). These data sets could provide useful information for future studies to focus on determining what the proper time and distance thresholds are for providing UAS operators with alert notifications. The use of trajectory based vs. ballistic based conflict information should also be considered. Trajectory based conflict information should help to reduce the amount of false alarms, or unnecessary alerts, such as in the cases of passive conflict avoidance.

Conclusion

The purpose of this thesis was to determine the feasibility of UAS performing delegated separation in the NAS. The results of this study support the feasibility of UAS performing delegated separation in the NAS while providing areas in need of further research. Overall, adjusting the level of separation responsibility and amount of information available to the UAS operators on the CSD was not found to have an adverse effect on performance as shown by the low amounts of losses of separation. The results of the study show benefits related to the use of a more advanced CSD with conflict detection capabilities, and to the use of full delegation.

In the more advanced conflict detection present mode of the CSD, pilots had significantly higher situation awareness without a significant negative effect on their reaction times or workload levels. While there was a trend toward higher workload ratings associated with the conflict detection present mode, it is possible that this slight increase could be ameliorated by training the pilot in a basic traffic display first. Post simulation workload ratings showed that over 50% of the UAS operators found their workload to be lower in the conflict detection mode as well. In addition to the increased UAS operator situation awareness and low workload ratings, air traffic controllers were more likely to rate the reroutes performed by the UAS operator as being acceptable. Air traffic controllers also reported having an easier time performing flow and separation requirements in their sector when the conflict detection present mode of the CSD was in use.

In the full level of delegation, both UAS operators and air traffic controllers benefited from the transition of separation responsibility. A decrease in temporal workload, and a trend towards reduced frustration was found for both air traffic controllers and UAS operators in full delegation. Subjectively, both air traffic controllers and UAS operators reported that the interaction between them was easier in full delegation, and air traffic controllers preferred the UAS operator to have full delegation responsibilities 100% of the time across all of the trials.

The use of a more advanced CSD and full delegation responsibilities given to the UAS operator were found to create significantly reduced workload, significantly increased situation awareness and significantly easier communications between the UAS operator and air traffic controller without significantly increasing the amount of losses of separation.

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Appendix A: San José State University IRB Approval

SAN JOSÉ STATE UNIVERSITY

Division of Academic Affairs

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From: Pamela Stacks, Ph.D.
Associate Vice President
Graduate Studies and Research

Date: July 13, 2012

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"UAS in the NAS: Unmanned Aircraft Systems (UAS) Performing Delegated Separation in the National Airspace (NAS)"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the confidentiality of the subjects' identity when they participate in your research project, and with regard to all data that may be collected from the subjects. The approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Dr. Pamela Stacks, Ph.D. immediately. Injury includes but is not limited to bodily harm, psychological trauma, and release of potentially damaging personal information. This approval for the human subject's portion of your project is in effect for one year, and data collection beyond July 13, 2013 requires an extension request.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services that the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2427.

Protocol #S1204001

cc. Kevin Jordan 0120

Appendix B: San José State University Informed Consent

San José State
UNIVERSITY

Department of Industrial & Systems Engineering
Engr 485
One Washington Square
San Jose, CA 95192-1020
Voice: 408-924-3301
Fax: 408-924-4040
www.engr.sjsu.edu

AGREEMENT TO PARTICIPATE IN RESEARCH AT
SAN JOSE STATE UNIVERSITY

Responsible Investigator(s): Caitlin Kenny

Title of Protocol: UAS in the NAS: Unmanned Aircraft Systems (UAS) Performing Delegated Separation in the National Airspace (NAS)

1. You have been asked to participate in a research study investigating the feasibility of Unmanned Aircraft System (UAS) performing delegated separation in the National Airspace (NAS).

2. You will be asked to operate a simulated UAS in the NAS, manage multiple aircraft as a pseudo pilot, or manage simulated air traffic at an air traffic control workstation. This study will be conducted at the NASA Ames Research Center's Flight Deck Display Research Laboratory between the dates of July 22-September 30, 2012. Your participation will involve 30 minute sessions, run across 1 day, with frequent breaks for refreshment and stretching.

3. There will not be any risks present in this study outside of what are present in daily life.

4. Direct benefits from participation in this study may include skill maintenance and the gaining of greater insight into the possible advances in the air transportation system involving UAS. An indirect benefit may be the feeling of reward gained from the knowledge that your participation may be contributing to these advances.

5. Although the results of this study may be published, no information that could identify you will be included. The data collected from your participation will also be stored on password protected computers, with access granted only to those with the password.

6. Compensation for your participation will be provided for by San Jose State University Research Foundation based on your qualifications and task.

7. Questions about this research may be addressed to Caitlin Kenny at Caitlin.A.Kenny@nasa.gov. Complaints about the research may be presented to Dr. Kevin Jordan, Ph.D., Professor of Psychology, SJSU, (408) 924-5626. Questions about a research subjects' rights, or research-related injury may be presented to Pamela Stacks, Ph.D., Associate Vice President, Graduate Studies and Research, at (408) 924-2427.

8. No service of any kind, to which you are otherwise entitled, will be lost or jeopardized if you choose to not participate in the study.

9. By signing this document, you acknowledge that your consent is being given voluntarily. You may refuse to participate in the entire study or in any part of the study. If you decide to participate in the study, you are free to withdraw at any time without any negative effect on your relations with San Jose State University or with any other participating institutions or agencies.

10. At the time that you sign this consent form, you will receive a copy of it for your records, signed and dated by the investigator.

Your signature on this document indicates agreement to participate in the study and your consent to the anonymous video and audio recording of yourself for data analysis or illustrative purposes. The signature of a researcher on this document indicates agreement to include the below signed subject in the research and attestation that the subject has been fully informed of his/her rights.

______________________________ ____________
Signature Date

______________________________ ____________
Investigator's Signature Date

Appendix C: NASA Ames Informed Consent

Ames Research Center

CATEGORY II – HUMAN RESEARCH MINIMAL RISK CONSENT

To the Research Participant: Please read this consent form and the attached protocol and/or subject instructions carefully. Make sure all your questions have been answered to your satisfaction before signing.

A. **I agree to participate** in the ______________________ research experiment as described in the attached protocol or subject instructions. I understand that I am employed by ______________________ who can be contacted at ______________________.

B. **I understand that my participation could cause me minimal risk*, inconvenience, or discomfort.** The purpose and procedures have been explained to me and I understand the risks and discomforts as described in the attached research protocol.

C. **To my knowledge,** I have no medical conditions, including pregnancy, that will prevent my participation in this study. I understand that if my medical status should change while I am a participant in the research experiment there may be unforeseeable risks to me (or the embryo or fetus if applicable). I agree to notify the Principal Investigator (PI) or medical monitor of any known changes in my condition for safety purposes.

D. **My consent to participate has been freely given.** I may withdraw my consent, and thereby withdraw from the study at any time without penalty or loss of benefits to which I am entitled. I understand that the PI may request my withdrawal or the study may be terminated for any reason. I agree to follow procedures for orderly and safe termination.

E. **I am not releasing NASA or any other organization or person from liability for any injury** arising as a result of my participation in this study.

F. **I hereby agree that all records collected by NASA in the course of this study are available** to the research study investigators, support staff, and any duly authorized research review committee. I grant NASA permission to reproduce and publish all records, notes, or data collected from my participation, provided there will be no association of my name with the collected data and that confidentiality is maintained, unless specifically waived by me.

G. **I have had an opportunity to ask questions and have received satisfactory answers** to all my questions. I understand that the PI for the study is the person responsible for this activity and that any questions regarding the research will be addressed to him/her during the course of the study. I have read the above agreement, the attached protocol and/or subject instructions prior to signing this form and I understand the contents.

* ***Minimal Risk*** means that the probability and magnitude of harm or discomfort anticipated in the research are not greater, in and of themselves, than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests.

Signature of Research Participant Date	Signature of Principal Investigator Date
Printed/Typed Name of Research Participant	Printed/Typed Name of Principal Investigator
Address	Telephone Number of Principal Investigator
City, State, Zip Code	**Subject Signature:** Authorization for Videotaping
Telephone Number of Test Subject	**Subject Signature:** Authorization for Release of Information to Non-NASA Source(s)

ARC 475 (MAR 06) Previous editions are obsolete

Appendix D: UAS Operator Demographics Questionnaire

UAS in the NAS
MUSIM Operator Demographics

Subject Number: ________ *Age:* ________ *Date:* ______________

PART I - Game Playing and Other Media Exposure

	Time per day	**Days per week**	**N/A**
1. How often do you play on a video game console?			
2. How frequently do you play single user video games on a PC?			
3. How frequently do you play multi-player networked video games on a PC?			
4. How much time do you spend on a personal computer/laptop?			
5. How much time do you spend watching online video?			
6. How much time do you spend on the internet?			
7. How much time do you spend watching streamed or downloaded video from a mobile device (i.e. iPod, other mp3 player)?			
8. How much time do you spend on the internet from a mobile device (i.e. iPod, Google phone)?			
9. How much time do you spend in internet chat rooms or live interactive blogs?			

10. Approximately how many text messages do you send?

_________**#/hour** _________**#/day** _________**N/A**

11. At what age did you begin to use a personal computer? _________ years

12. At what age did you begin to use a mouse? _________ years

13. Have you ever played in an online, 3D virtual interactive world?

_________Yes _________No _________N/A

14. What input gaming device have you spent the most time/hours using? *Please circle.*
    a) Joystick
    b) Mouse
    c) Trackball
    d) Playstation Controller
    e) Xbox Controller
    f) Gameboy Controller
    g) Nintendo Wii Remote Controller
    h) Nintendo DS
    i) Steering Wheel
    j) Flight Yoke
    k) Other (please write in): ______________________________
    l) I've never played

15. What types of video games do you typically play? *Check all that apply.*
    - □ First Person Shooter (e.g. Call of Duty)
    - □ Third Person Shooter (e.g. Halo)
    - □ Role Playing (single player, e.g. Dungeons and Dragons)
    - □ MMO (multi-player, e.g. World of Warcraft)
    - □ Vehicle/Flight Simulation (e.g. MS Flight Sim)
    - □ Strategy (e.g. Civilization)
    - □ Sports (e.g. Madden)
    - □ Music (e.g. Guitar Hero)
    - □ Other (please write in)

PART II - Flight Simulation

1. Do you have any flight simulation experience on programs such as MS Flight Sim?

Yes No

If Yes, Please Specify:

a) Number of hours: __________

b) Type:

____

____

2. Do you have any flight simulation experience on rated flight training simulators?

Yes **No**

If Yes, Please Specify:

a) Number of hours: __________

b) Type:

____

____

PART III - Pilot Experience

1. Do you have any pilot flying experience: **Yes** **No**

If Yes, please complete the following:

a) Flight Hours: _______________

b) Military**:** **Yes** **No**

c) IFR rated**:** **Yes** **No**

c) Other Ratings:

____

____

d) Aircraft Types:

____

____

2. How would you rate your familiarity with flying using traffic displays (e.g. TCAS)?

Not Familiar	Somewhat Familiar	Familiar	Very Familiar	Expert

3. Do you have any UAS flying experience: Yes No

If Yes, please complete the following:

a) Flight Hours: _______________

b) Military: **Yes** **No**

c) Aircraft Types:

____

____

____

Appendix E: ATC Demographics Questionnaire

Operator Demographics Questions

1. Please indicate your experience as an air traffic controller by circling yes or no to the places in which you are either working or have worked in the past:

Civilian Tower(s) YES NO

If yes:

How many years? ___________________

Did you achieve Full Performance Level (FPL)? YES NO

Briefly describe your experience (e.g. locations worked, duties, years at each location):

____

____

____

Additionally, if you have experience in multiple facilities from any category please ask for additional paper.

Military Tower(s) YES NO

If yes:

How many years? ___________________

Did you achieve Full Performance Level (FPL)? YES NO

Briefly describe your experience (e.g. locations worked, duties, years at each location):

____

____

Civilian TRACON(s) YES NO

If yes:

How many years? ____________________

Did you achieve Full Performance Level (FPL)? YES NO

Briefly describe your experience (e.g. locations worked, duties, years at each location):

____

____

____

Military TRACON(s) (or equivalent) YES NO

If yes:

How many years? ____________________

Did you achieve Full Performance Level (FPL)? YES NO

Briefly describe your experience (e.g. locations worked, duties, years at each location):

____

____

____

Civilian Center(s) YES NO

If yes:

How many years? ____________________

Did you achieve Full Performance Level (FPL)? YES NO

Briefly describe your experience (e.g. locations worked, duties, years at each location):

____

____

____

Military Center(s) (or equivalent) YES NO

If yes:

How many years? ____________________

Did you achieve Full Performance Level (FPL)? YES NO

Briefly describe your experience (e.g. locations worked, duties, years at each location):

____

____

____

Civilian Airspace with UAS access YES NO

If yes:

Briefly describe your experience (e.g. locations worked, types of UAS managed, etc.):

____

____

____

Miliary Airspace with UAS access YES NO

If yes:

Briefly describe your experience (e.g. locations worked, types of UAS managed, etc.):

____

____

____

2. Please describe any other experience you might have in **air traffic management** such as Flight Services, Supervision, Training or TMA (e.g. locations worked, duties, years at each location).

____

____

____

3. Please Rate your experience with ZLA airspace.

1 No Experience	2	3	4 Somewhat Experienced	5	6	7 Very Experienced

4. Please Rate your experience with MACS software.

1 No Experience	2	3	4 Somewhat Experienced	5	6	7 Very Experienced

5. **Please Rate your experience with MUSIM software.**

1 No Experience	2	3	4 Somewhat Experienced	5	6	7 Very Experienced

6. **Please Rate your experience with simulation studies.**

1 No Experience	2	3	4 Somewhat Experienced	5	6	7 Very Experienced

7a. **If you are a retired controller,**

a. how many years have you been retired? ________

b. rate your radar experience

1 No Experience	2	3	4 Somewhat Experienced	5	6	7 Very Experienced

7b. **If you are a student controller,**

a. how many years of have you been studying to be a controller? ________

b. rate your radar experience

1 No Experience	2	3	4 Somewhat Experienced	5	6	7 Very Experienced

8. Are you a licensed pilot? YES NO

If yes, please indicate your FAA certificates/ratings by placing an "X" on all applicable lines

_______ Private _______ Commercial

_______ ATP ________Instrument

________ CFI ________ CFII

____

Other (describe):____

9.Please list any other qualifications you think are relevant as a participant in this study.

____

____

____

Appendix F: UAS Operator Post-Trial Questionnaire

UAS in the NAS
NASA TLX Workload Ratings

Please circle the number that best describes your opinion for each of the questions below.

Mental Demand: *How mentally demanding was the task?*	0 Low	1	2	3	4	5	6	7 High
Physical Demand: *How physically demanding was the task?*	0 Low	1	2	3	4	5	6	7 High
Temporal Demand: *How hurried or rushed was the pace of the task?*	0 Low	1	2	3	4	5	6	7 High
Effort: *How hard did you have to work to accomplish your level of performance?*	0 Low	1	2	3	4	5	6	7 High
Frustration: *How insecure, discouraged, irritated, stressed, and annoyed were you?*	0 Low	1	2	3	4	5	6	7 High
Performance Degradation: *How degraded was your ability to meet task goals?*	0 Low	1	2	3	4	5	6	7 High

Please circle the number that best describes your opinion for each of the questions below.

Overall Workload	0 Low	1	2	3	4	5	6	7 High
How difficult was it to interact with ATC?	0 Easy	1	2	3	4	5	6	7 Hard
How acceptable was your final flight path relative to the mission requirements?	0 Acceptable	1	2	3	4	5	6	7 Unacceptable
How acceptable were your reroutes to avoid traffic conflicts?	0 Acceptable	1	2	3	4	5	6	7 Unacceptable

Appendix G: ATC Post-Trial Questionnaire

UAS in the NAS
NASA TLX Workload Ratings

Please circle the number that best describes your opinion for each of the questions below.

Mental Demand: *How mentally demanding was the task?*	0 Low	1	2	3	4	5	6	7 High
Physical Demand: *How physically demanding was the task?*	0 Low	1	2	3	4	5	6	7 High
Temporal Demand: *How hurried or rushed was the pace of the task?*	0 Low	1	2	3	4	5	6	7 High
Effort: *How hard did you have to work to accomplish your level of performance?*	0 Low	1	2	3	4	5	6	7 High
Frustration: *How insecure, discouraged, irritated, stressed, and annoyed were you?*	0 Low	1	2	3	4	5	6	7 High
Performance Degradation: *How degraded was your ability to meet task goals?*	0 Low	1	2	3	4	5	6	7 High

Please circle the number that best describes your opinion for each of the questions below.

Overall Workload	0 Low	1	2	3	4	5	6	7 High
How difficult was it to interact with the UAS pilot?	0 Easy	1	2	3	4	5	6	7 Hard
How difficult was it to meet flow and separation requirements with a UAS in your sector compared to normal operations?	0 Easy	1	2	3	4	5	6	7 Hard
How acceptable were the UAS pilot's reroutes to avoid traffic conflicts?	0 Acceptable	1	2	3	4	5	6	7 Unacceptable

Appendix H: UAS Operator Post-Block SA Questionnaire

UAS in the NAS
Operator Post-Block Subjective SA ratings

Please answer these questions with regard to the traffic situations presented in the scenario.

My situation awareness was sufficient and effective	0 Low	1	2	3	4	5	6	7 High
I was aware of the locations of surrounding traffic	0 Low	1	2	3	4	5	6	7 High
I had the traffic information that I needed to complete mission reroutes	0 Low	1	2	3	4	5	6	7 High
I had the traffic information that I needed to successfully avoid conflicts with aircraft	0 Low	1	2	3	4	5	6	7 High
I was confident in my responses to mission and ATC requirements	0 Low	1	2	3	4	5	6	7 High
I was confident in my assessment of the traffic situation	0 Low	1	2	3	4	5	6	7 High
I was aware of traffic conflicts developing	0 Low	1	2	3	4	5	6	7 High
I was confident my choices of reroutes avoided conflicts with other aircraft	0 Low	1	2	3	4	5	6	7 High
There was enough time to respond to ATC and complete reroutes	0 Low	1	2	3	4	5	6	7 High

Appendix I: UAS Operator Post-Simulation Questionnaire

Participant: ______

UAS in the NAS
Operator Post-Simulation Questionnaire

INSTRUCTIONS: Place an "X" over the circle in the box that best describes your opinion. If you do not understand a question, please ask for clarification.

General Concept and Performance

		Strongly disagree	Somewhat disagree	Neither disagree nor agree	Somewhat agree	Strongly agree	Not applicable/ Did not use
1	I believe flying in a shared environment with UAS would be acceptable in the current environment:	O	O	O	O	O	O
2.	With appropriate training for UAS pilots, I would be willing to fly in an airspace that included UAS:	O	O	O	O	O	O
3.	I gained comfort with my ability to respond to the reroute orders as I gained more practice:	O	O	O	O	O	O
4.	I gained comfort with my ability to operate the UAS under EXTENDED delegated separation as I gained more practice:	O	O	O	O	O	O
5.	I gained comfort with my ability to operate the UAS under FULL delegated separation as I gained more practice:	O	O	O	O	O	O
6.	I believe my performance during the simulation reasonably reflects how I would fly in actual operations:	O	O	O	O	O	O
7.	I believe the overall workload associated with the concept of UAS in the NAS is manageable:	O	O	O	O	O	O
8.	Flying a UAS in EXTENDED delegated separation would not be possible due to high workload:	O	O	O	O	O	O
9.	Flying a UAS FULL delegated separation would not be possible due to high workload:	O	O	O	O	O	O
10.	ATC as experienced in this simulation was an acceptable representation of the real world:	O	O	O	O	O	O

Participant: ______

10.	I would be willing to fly Center airspace with a UAS WITHOUT using the trajectory cockpit situation display:	O	O	O	O	O	O
11.	I would be willing to fly Center airspace with a UAS using the BASIC mode of the cockpit situation display:	O	O	O	O	O	O
12.	I would be willing to fly Center airspace with a UAS using the TOOLS mode of the cockpit situation display:	O	O	O	O	O	O
13.	I was unable to successfully perform my mission due to the high workload associated with the rerouting events:	O	O	O	O	O	O
14.	I was unable to successfully perform my mission due to the high workload associated with avoiding conflicts:	O	O	O	O	O	O
15.	The scenarios were so unrealistic that I am unable to determine if the concept of flying a UAS in Center airspace is feasible:	O	O	O	O	O	O

Cockpit Situation Display Questions

1. How useful was this display for extracting the necessary airspace information in basic mode?

1 Not at all Useful	2	3	4	5 Very Useful

1. How useful was this display for extracting the necessary airspace information in tools mode?

1 Not at all Useful	2	3	4	5 Very Useful

2. How useful was this display in tools mode supporting interactions with ATC compared to the basic mode?

1 Not at all Useful	2	3 Equally Useful	4	5 Very Useful

3. How easy was this display to use in the basic mode given the mission requirements?

1 Very Difficult	2	3	4	5 Very Easy

2. How easy was this display to use in the tools mode given the mission requirements?

1 Very Difficult	2	3	4	5 Very Easy

3. What was your workload level difference when using the tools display mode compared to the basic display mode?

1 Much More Difficult	2 Somewhat More Difficult	3 The Same	4 Somewhat Easier	5 Much Easier

4. How valuable was the enhanced situation awareness provided by the tools display mode compared to the basic display mode?

1 Not at all Valuable	2	3	4	5 Very Valuable

5. Was all of the necessary information available from this display in the basic mode?

1 No Information Available	2	3	4	5 All Information Available

6. Was all of the necessary information available from this display in the tools mode?

1 No Information Available	2	3	4	5 All Information Available

7. Use of the CSD will enhance the safety of flying UAS in the NAS

1 No Safety Enhancement	2	3	4	5 Large Safety Enhancement

8. Did you use the CSD when determining your reroute requests? Yes / No

9. Was there any airspace information that was lacking that you would like to see?

10. Is there a different way that you would present traffic information?

11. Additional comments or suggestions:

Thank you for your participation in our research

Appendix J: ATC Post-Simulation Questionnaire

UAS in the NAS
ATC Post-Simulation Questionnaire

1. What was your workload level managing a sector with a UAS in it compared to normal operations with only manned aircraft?
   - ☐ Much Higher
   - ☐ Somewhat Higher
   - ☐ Neither Higher nor Lower
   - ☐ Somewhat Lower
   - ☐ Much Lower

2. How difficult was it to meet flow and separation management requirements with the UAS performing extended delegated separation in your sector compared to normal operations?
   - ☐ Very Difficult
   - ☐ Somewhat Difficult
   - ☐ Not at all Difficult
   - ☐ Somewhat Easier
   - ☐ Much Easier

3. How difficult was it to meet flow and separation management requirements with the UAS performing full delegated separation in your sector compared to normal operations?
   - ☐ Very Difficult
   - ☐ Somewhat Difficult
   - ☐ Not at all Difficult
   - ☐ Somewhat Easier
   - ☐ Much Easier

4. What was your perceived level of safety of the Air Transportation System with the presence of a UAS performing extended delegated separation in your sector compared to normal operations?
   - ☐ Much less safe
   - ☐ Somewhat less safe
   - ☐ Same level of safety
   - ☐ Somewhat safer
   - ☐ Much safer

5. What was your perceived level of safety of the Air Transportation System with the presence of a UAS performing full delegated separation in your sector compared to normal operations?
   - ☐ Much less safe
   - ☐ Somewhat less safe
   - ☐ Same level of safety
   - ☐ Somewhat safer
   - ☐ Much safer

6. Which level of delegation of separation responsibilities do you prefer?
   - ☐ ATC maintains all separation responsibilities (current day operations)
   - ☐ Extended delegation given to UAS operator
   - ☐ Full delegation given to UAS operator

7. Was the UAS pilot able to safely maintain separation responsibilities in the extended delegation scenarios?
   - ☐ Yes
   - ☐ No

8. Was the UAS pilot able to safely maintain separation responsibilities in the full delegation scenarios?
   - ☐ Yes
   - ☐ No

9. Compared to pilots of manned aircraft, how immediately did the UAS pilot respond to ATC instructions?
   - ☐ Much less immediately
   - ☐ Somewhat less immediately
   - ☐ Same as manned
   - ☐ Somewhat more immediately
   - ☐ Much more immediately

10. Compared to pilots of manned aircraft, how appropriately did the UAS pilots respond to ATC instructions?
    - ☐ Much less appropriately
    - ☐ Somewhat less appropriately
    - ☐ Same as manned
    - ☐ Somewhat more appropriately
    - ☐ Much more appropriately

11. Compared to pilots of manned aircraft, did the UAS pilots use the correct terminology when communicating with ATC?
    - ☐ Much less use of correct terminology
    - ☐ Somewhat less use of correct terminology
    - ☐ Same as manned
    - ☐ Somewhat more use of correct terminology
    - ☐ Much more use of correct terminology

12. Did the UAS pilots have enough knowledge of the airspace/procedures to communicate with ATC?
    - ☐ Yes
    - ☐ No

13. Did the UAS pilots have enough knowledge of the airspace/procedures to respond to ATC instructions?
    - ☐ Yes
    - ☐ No

14. Did the aircraft performance of the UAS create problems for managing your sector?
    - ☐ Yes
    - ☐ No

15. Did the UAS require special handling? If yes, what percentage of the scenario time?
    - ☐ Yes
        - ☐ 0-25%
        - ☐ 25-50%
        - ☐ 50-75%
        - ☐ 75-100%
    - ☐ No

16. What special handling procedures were used?

    ____

    ____

    ____

17. Did you have to have to prevent conflicts with the UAS because they were unable to maintain separation standards?
    - ☐ Yes
    - ☐ No

18. What strategies did you use for preventing conflicts with the UAS?