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Air Traffic Controller Acceptability of Unmanned Aircraft System Detect-and-Avoid Thresholds

Eric R. Mueller
Ames Research Center, Moffett Field, CA

Douglas R. Isaacson
Ames Research Center, Moffett Field, CA

Derek Stevens
Stanford University, Stanford, CA

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Eric R. Mueller
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Derek Stevens
Stanford University, Stanford, CA

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, CA 94035-1000

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Abstract

A human-in-the-loop experiment was conducted with 15 retired air traffic controllers to investigate two research questions: (a) what procedures are appropriate for the use of unmanned aircraft system (UAS) detect-and-avoid systems, and (b) how long in advance of a predicted close encounter should pilots request or execute a separation maneuver. The controller participants managed a busy Oakland air route traffic control sector with mixed commercial/general aviation and manned/UAS traffic, providing separation services, miles-in-trail restrictions and issuing traffic advisories. Controllers filled out post-scenario and post-simulation questionnaires, and metrics were collected on the acceptability of procedural options and temporal thresholds. The states of aircraft were also recorded when controllers issued traffic advisories. Subjective feedback indicated a strong preference for pilots to request maneuvers to remain well clear from intruder aircraft rather than deviate from their IFR clearance. Controllers also reported that maneuvering at 120 seconds until closest point of approach (CPA) was too early; maneuvers executed with less than 90 seconds until CPA were more acceptable. The magnitudes of the requested maneuvers were frequently judged to be too large, indicating a possible discrepancy between the quantitative UAS well clear standard and the one employed subjectively by manned pilots. The ranges between pairs of aircraft and the times to CPA at which traffic advisories were issued were used to construct empirical probability distributions of those metrics. Given these distributions, we propose that UAS pilots wait until an intruder aircraft is approximately 80 seconds to CPA or 6 nmi away before requesting a maneuver, and maneuver immediately if the intruder is within 60 seconds and 4 nmi. These thresholds should make the use of UAS detect and avoid systems compatible with current airspace procedures and controller expectations.

I. Introduction

Unmanned aircraft systems (UAS) will equip with detect-and-avoid (DAA) systems that meet the regulatory requirement for pilots to "see and avoid" other aircraft. These systems must alert pilots of impending encounters early enough to allow them to determine and execute the appropriate action, but not so early that they cause disruption to air traffic control (ATC) plans and priorities. While a significant amount of recent research has investigated the minimum time required by the pilot to execute the DAA function,[i,ii,iii,iv,v] little objective data is available that indicates the earliest time pilots should contact ATC to avoid intruder aircraft. The DAA system may alert a pilot to a potential close encounter whenever such an encounter is predicted, and pilots prefer as much warning time as can be reliably provided, so the pilot's needs will not provide a reasonable upper limit to the alerting horizon threshold. The ATC-acceptable alerting time therefore drives the maximum time at which to alert pilots, which in turn dictates minimum surveillance sensor requirements. The maximum alerting horizon is therefore a critical and fundamental parameter in the design of a DAA system.

Several prototype DAA systems are under development or undergoing flight tests, but none have used ATC acceptability to establish an upper limit to the alert time provided to the pilot. The only parameters established for the separation standard between UAS and other aircraft include the range to proximate aircraft such that pilots of those aircraft do not feel unsafe, interoperability with the traffic alert and collision avoidance system (TCAS), and interoperability with established ATC procedures.[vi] Only the last of these establishes an upper bound to the alerting time; the others provide a lower bound. Quantifying "interoperability" with ATC is a challenge because that concept incorporates many competing goals in many different contexts,[1] but the notion of traffic advisories and safety alerts is useful in bounding the alerting thresholds. Controllers issue traffic advisories (TA) to IFR and VFR[2] aircraft when, in their judgment, "proximity may diminish to less than the applicable separation minima." Typically these advisories are issued well before safety has been compromised and are intended to cue the pilot to visually acquire the other aircraft and determine whether evasive action will be required. A safety alert (SA) is issued when "an aircraft is in a

[1] For example, pilots must provide a separation assurance function that augments air traffic controllers' provision of separation, but they must not employ it so frequently that they distract controllers or create secondary close encounters with proximate aircraft.

[2] Instrument flight rules (IFR) and visual flight rules (VFR)

position that … places it in unsafe proximity to … other aircraft."[vii] An SA represents an imminent threat to safety that requires immediate action by the pilot and is typically issued by a controller only a few times over an entire career. The normal process by which a manned aircraft pilot would employ their see-and-avoid capability, and therefore what a controller would expect a UAS pilot to do when using their DAA system, is to receive a TA, decide appropriate action based on their own visual or sensory inputs, coordinate those actions with ATC and then maneuver before an SA is required. The first alert time for a DAA system, therefore, should be somewhat later than the time at which a typical TA is issued but well enough in advance of an SA that appropriate maneuvers make such an alert unnecessary. No prior work is known that establishes the factors and thresholds used by controllers to determine whether and when to issue an alert or advisory.

The contribution of the research presented in this paper is quantification of the conditions under which air traffic controllers issue TAs along with subjective feedback on how long before a close encounter it is appropriate for a pilot to request a maneuver. A human-in-the-loop experiment involving 15 retired air traffic controllers supplied the required data. The distribution of times and distances at which the controllers issued TAs may be used in combination with other airspace and encounter parameters to determine the earliest time at which pilots should request avoidance maneuvers from air traffic controllers. They may be alerted to potential encounters before this threshold, but they should refrain from contacting ATC until the threshold because intervention and resolution of the encounter by ATC is still likely enough that immediate action is not required. The data presented in this paper should be used to determine an appropriate self-separation threshold (defined in more detail in the following section) that does not disrupt ATC operations and provides sufficient time for pilots to remain well clear of proximate aircraft.

This paper describes the experimental setup of the study of air traffic controller behavior in the following section. It then presents the subjective feedback received from controller participants about the appropriateness of three different candidate self-separation thresholds. A second section on results presents the distribution of temporal and geometric parameters that characterize when TAs are issued. Finally, the paper provides recommendations for the factors that should be used to determine a self-separation threshold and suggests threshold times and distances that should be validated by future studies.

II. Experiment Setup

This section outlines key details of the experiment design and infrastructure used to collect the controller acceptability and traffic advisory data. It also describes the qualifications of the experiment participants, the traffic scenarios they were presented with and the training they received to ensure the simulation closely represented real-world conditions.

A. Independent Variables

The experiment included two independent variables: the UAS self-separation procedure and the threshold time at which pilots requested or executed a self-separation maneuver. This threshold is referred to as the "request/maneuver threshold" because it reflects the time at which the pilot would either request an intruder-avoidance maneuver from ATC or execute a maneuver and notify ATC afterwards. In essence, this is the first time at which ATC becomes aware that the UAS pilot intends to use the DAA system. This threshold is a new one defined for this experiment and is distinct from the UAS community's accepted definition of the self-separation threshold (SST), which is the point at which the pilot determines a maneuver is necessary, or the self-separation execution threshold (SET), which is the last point at which the UAS can maneuver to remain well clear. The request/maneuver threshold would lie in between these two thresholds. The specification of this new threshold is important because it provides a way to link the ATC acceptability metric to the time required by the pilot to determine an appropriate maneuver (after the SST) and before a loss of well clear is guaranteed (before the SET).

The UAS self-separation procedures designed for this experiment require either coordination with ATC prior to a maneuver (Option A), or allow maneuvering without an amended clearance after crossing the request/maneuver threshold, assuming a prior traffic advisory from ATC has not been received (Option B). Lacking a controller-issued traffic advisory, the request/maneuver threshold defines the point in time the UAS pilot would either request

Figure 1. Air traffic control lab at NASA's Crew-Vehicle Systems Research Facility.

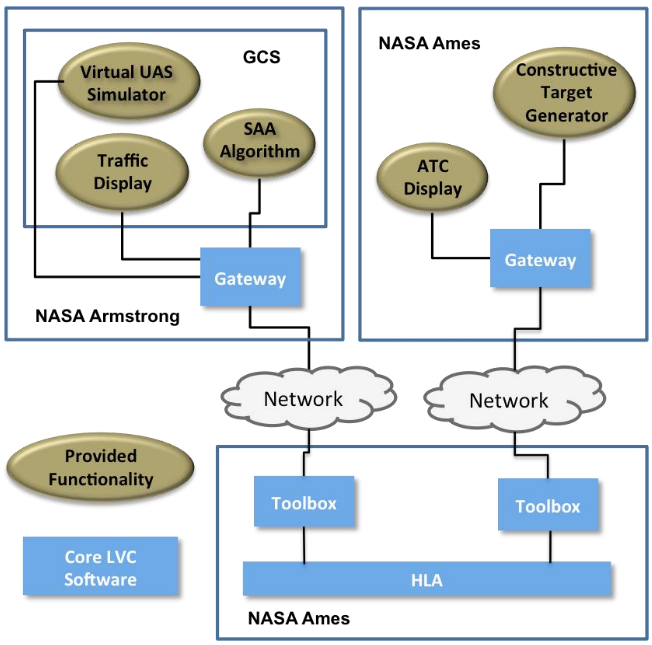

Figure 2. Network functional architecture of the LVC-DE.

an amended clearance from ATC (Option A), or initiate an avoidance maneuver and subsequently notify ATC (Option B). In either case, if the controller did issue a traffic advisory prior to the SST, the pilot was instructed to immediately request an amended clearance using either a prototype DAA system or a scripted maneuver. These procedures are presented in detail in Appendix I. Three threshold values were included in the experiment: 60, 90 and 120 sec. This range was selected based on the results of prior pilot-in-the-loop studies[ii,iii] that indicated the lowest value would not be enough time to reliably avoid a loss of well clear, while the largest value was deemed to be plenty of time by all pilots. The larger value was also expected to impact controller workload because it would overlap and interfere with the controller's separation actions.

B. Apparatus

The experiment employed human air traffic controller subjects and pseudo-pilot participants in a simulated air traffic environment. The air traffic controller subjects ("controllers") of the experiment were located in the NASA Crew-Vehicle Systems Research Facility's (CVSRF) ATC Laboratory (ATC Lab) as shown in Figure 1. The controllers provided standard ATC services using controller stations similar to the Display System Replacement (DSR) consoles used in Air Route Traffic Control Center (ARTCCs) in the domestic U.S. air traffic system.[xi] Controllers communicated with pilot confederates via voice communications using an interface similar to that used in ARTCCs. The live, virtual, constructive, distributed simulation environment (LVC-DE) architecture[viii] employed by the simulation was distributed across two NASA facilities as depicted in Figure 2. A more detailed system architecture diagram is shown in Appendix G.

Pseudo-pilot confederates in the experiment were located at NASA ARC; each controlled multiple aircraft through an interface optimized for ATC simulations called the multi-aircraft control system (MACS). These pseudo-pilots control the movement of both conventional (manned) aircraft and unmanned aircraft in the simulation. Aircraft movement is simulated by MACS using 4 degree of freedom (position/velocity and roll) performance models for all aircraft types.[ix,x] The MACS pilot interface allows the pseudo-pilot to control multiple aircraft simultaneously and to respond to air traffic instructions for each aircraft in a timely manner.

A single UAS Ground Control Station, called Vigilant Spirit Control Station[ix] (VSCS), was located at NASA's Armstrong Flight Research Center (NASA-AFRC) and used to simulate the flight of one UAS in the simulated environment to a higher degree of fidelity than the MACS pseudo-pilot interface provided. The VSCS simulates an aircraft with performance characteristics similar to that of the General Atomics Predator B. Voice communications between the VSCS pilot and controllers, as well as computed VSCS states, are distributed to the other simulation agents via the LVC-DE gateway.

As depicted in Figure 2, the LVC-DE consolidates information from the simulated agents (controller stations, MACS pseudo-pilot stations, and VSCS) and routes relevant information and communications to the appropriate receiving agents. For example, if the VSCS pilot commands a right turn for his aircraft and notifies ATC via voice that he has turned right for traffic, the turn would be reflected in the aircraft position as computed by VSCS, and that position, along with the preceding voice communication, would be sent to the LVC-DE. The LVC-DE would route the voice communications between the VSCS pilot and ATC to all aircraft on the simulated ATC frequency, and the computed position of the VSCS would be appropriately updated on both ATC and pseudo-pilot displays.

C. Simulation Participants

The controller subjects employed in the experiment were recently retired air traffic controllers from U.S. ATC facilities. Demographic information was collected from the controller subjects via a questionnaire (Appendix D). Controller subjects had on average 26 years of experience controlling traffic, primarily at ARTCC facilities and with some limited experience at TRACON facilities. Eleven of the fifteen controller subjects had experience controlling UAS at some point during their careers.

The pilots of the VSCS ground control station were active UAS pilots with at least 100 hours experience flying in domestic controlled airspace (i.e. not in military operations areas or other restricted airspace). They and the pseudo pilots controlling all other traffic were also current IFR-rated pilots and therefore were experienced in the procedures and phraseology used to communicate with the controller subjects.

D. Airspace

Controller subjects provided standard air traffic services to pilots of simulated aircraft operating in Oakland ARTCC Sectors 40 and 41 (ZOA40/41), which are shown bounded by a red polygon in Figure 13. ZOA 40/41 is an ARTCC sector just north of the San Francisco Bay, comprised of Classes A and E airspace, and includes moderate to high levels of IFR and VFR air traffic. Commercial air transport operations in the sector follow mostly North-South routes into and out of the SFO-OAK-SJC metroplex: northbound traffic climbing or level, and southbound traffic level or descending. ZOA 40/41 serves two Class D airports: Sonoma County Airport (KSTS) and Napa County Airport (KAPC). Crossing (east-west) IFR traffic is common with aircraft going to/from Reno/Tahoe. VFR traffic is common in ZOA 40/41 due to its proximity to San Francisco, the Northern California coastline and the Napa and Sonoma valleys (all popular sightseeing destinations). Travis Air Force Base RAPCON borders ZOA 40/41 to the east and introduces a significant number of UAS operations into the experiment airspace.

E. Traffic Scenarios

Four scenarios were generated from air traffic recordings and modified to represent a range of typical conditions encountered by controllers managing air traffic operating in ZOA 40/41. Air traffic consisted of both conventional (manned) and unmanned IFR traffic, as well as VFR traffic that would typically be present in ZOA 40/41. VFR traffic in each scenario exhibited three levels of "participation" consistent with current air traffic operations: 1) equipped with an operating transponder and receiving air traffic services, 2) equipped with an operating transponder, but not receiving air traffic services, and 3) without an operating transponder and not receiving ATC services (also called a "primary target"). Each scenario was augmented with UAS flights to model future operations with frequent and sustained UAS activity. Flight tracks were adjusted (temporally and/or spatially) to result in ten scripted encounters between IFR and VFR aircraft in each scenario. Of these ten encounters, five were between conventional (manned) aircraft and VFR aircraft, and five were between unmanned aircraft and VFR aircraft.

Controller workload (subjectively) varied within and between scenarios from light/moderate to heavy, but was always designed to be high enough to reduce the controllers' ability to provide additional ATC services (e.g. traffic advisory service). Traffic loading alone was typically sufficient to achieve this purpose in each scenario, but increased traffic or airspace complexity was sometimes necessary to meet the intended level of controller workload. Some controller subjects exhibited greater proficiency in managing air traffic, primarily due to *a priori* knowledge of ZOA 40/41 procedures. These controllers were identified in training (prior to data collection), and increased complexity was introduced as necessary in the form of miles-in-trail restrictions for SFO arrivals.

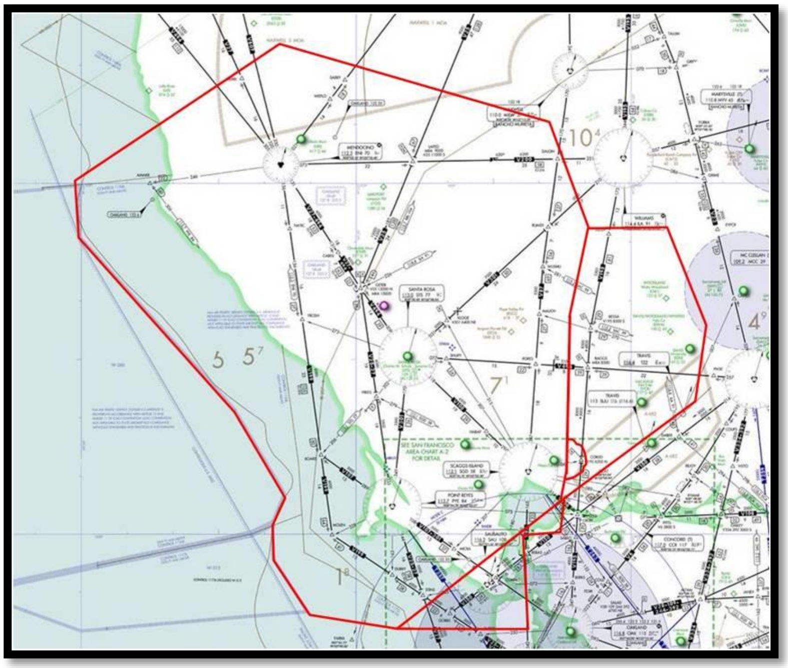

Figure 3. Experiment airspace, Oakland ARTCC sectors 40 and 41.

F. Subject/Participant Instructions and Training

The controller subjects received a briefing (Appendix E) each morning that included a concise background and summary of NASA's UAS Integration into the NAS Project, an overview of study objectives, and instructions for provision of ATC services during the simulation as well as methods of data collection for the study and a daily schedule of activities. Only two of the study objectives were briefed prior to data collection: 1) improving NASA air traffic simulation fidelity, and 2) gathering data to develop controller models for subsequent batch simulations. Controller subjects were not informed in advance of the objective to evaluate different UAS self-separation procedures as knowledge of this objective was deemed to potentially affect controller performance and influence responses to post-run questionnaires. Instructions for controllers in this briefing were limited to those relating to the briefed objectives, including treating the simulation as actual operations to maximize the fidelity of the study and improve data quality, and noting any inconsistencies or issues with the simulation to dedicated experiment observers.

At the conclusion of the summary briefing controller subjects received training to become familiar with the study airspace, air traffic flows, traffic management initiatives, and phraseology for provision of ATC services to UAS operating in the airspace. This training included an airspace/procedures briefing as well as a series of practice sessions to familiarize controller subjects with aspects of the simulation facility and to ensure proficiency in the provision of ATC services. Practice sessions were conducted until the experiment director subjectively assessed proficiency in the airspace as adequate for the purposes of the study. During these training sessions, the experiment director also assessed the need for additional, workload-increasing measures in each scenario. This additional step was done to roughly equalize workload across controller subjects with varying levels of proficiency and to ensure that controller workload was sufficient to impact additional ATC services (i.e., traffic advisories). For example, subjects who showed higher proficiency were tasked with sequencing aircraft into the TRACON airspace at a minimum "miles in trail" distance from preceding aircraft.

G. Experiment Design

The simulation used to collect data on the acceptability of UAS detect-and-avoid alerting thresholds was also designed to gather data related to other experimental objectives on UAS operations. The overall simulation setup and design has been documented in a companion paper.[xi] The design documented in this section only addresses those aspects of the experiment design related to the stated objectives of this study. In particular, it presents the independent and dependent variables and their associated metrics that address the primary objective of evaluating ATC acceptability of UAS self-separation procedures and maneuver thresholds.

A self-separation procedure (Option A or B) was assigned for each of the aforementioned ten scripted encounters in a scenario. These scripted encounters and their associated self-separation procedure were included in a scenario script provided to each pseudo-pilot for reference during the course of each simulation run (see Appendix I). The pseudo-pilots followed scenario-specific scripts according to the instructions provided on how to execute the procedures during the course of the experiment (Appendices I and K).

A range of parameters was recorded during each simulation run to objectively measure aspects of the UAS DAA system's performance, the traffic controller's performance and their interactions. Subjective assessment from controller subjects is also sought because air traffic controller acceptability is difficult to quantify for new concepts or types of operation, as is the case with UAS self separation. Metrics collected during each simulation run are classified into three categories: encounter data, traffic advisory data, and simulation artifact data.

Traffic advisory data is collected to improve controller performance modeling in batch simulations and help determine when controllers expect pilots to begin monitoring and avoiding intruders. The ability of the controller to identify developing encounters between IFR and VFR aircraft under moderate to high workload will determine whether or not a UAS crosses the SST and begins to use its DAA system, and even potentially crosses the request/maneuver threshold or SET. The following three traffic advisory metrics were collected during each simulation run: 1) time to CPA (T_{cpa}) and relative geometry (range, bearing, relative altitude) at which a traffic advisory is issued, 2) the predicted CPA that necessitated a TA, and 3) whether a TA was issued prior to the aircraft crossing the SST.

All the aforementioned metrics were collected during the course of a scenario. Following each scenario, subject controllers completed a questionnaire intended to evaluate controller acceptability of the tested self-separation procedures and the request/maneuver thresholds for the scenario just completed, and to provide context and clarification for the objective measures. The post-run and end-of-day controller questionnaires (Appendices B and C, respectively) provided subjective assessment of the UAS self-separation procedure acceptability, traffic complexity and controller workload, and revealed to the controller subjects the third objective of the study relating to controller acceptability and recognition of objectionable pilot behavior.

A balanced experimental design (Table 1) ensured that the independent variables were presented to subjects in an order that balanced learning and scenario workload effects across procedure types, pilots and alerting thresholds. The actual number of encounter samples collected in each condition varied between subjects because controllers did not systematically issue the same traffic advisories in each condition, though in the aggregate the number of encounters across the experimental conditions were quite similar. The codes in Table 1 are defined in Table 2.

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Table 1. Independent variables by controller and trial.

Controller #	Trial 1	Trial 2	Trial 3	Trial 4
1	LO, UNC, C1	HI, CRD, C3	LO, CRD, C2	HI, UNC, C4
2	HI, CRD, C3	LO, UNC, C1	HI, UNC, C4	LO, CRD, C2
3	LO, UNC, C2	LO, UNC, C1	HI, CRD, C3	HI, UNC, C4
4	HI, UNC, C3	LO, CRD, C1	HI, CRD, C4	LO, UNC, C2
5	LO, CRD, C1	HI, UNC, C3	LO, UNC, C2	HI, CRD, C4
6	HI, UNC, C3	HI, CRD, C4	LO, UNC, C2	LO, CRD, C1
7	LO, UNC, C2	LO, CRD, C1	HI, CRD, C4	HI, UNC, C3
8	LO, UNC, C1	LO, CRD, C2	HI, UNC, C4	HI, CRD, C3
9	HI, CRD, C4	LO, UNC, C2	LO, CRD, C1	HI, UNC, C3
10	HI, UNC, C4	HI, CRD, C3	LO, CRD, C2	LO, UNC, C1
11	LO, UNC, C2	HI, CRD, C4	HI, UNC, C3	LO, CRD, C1
12	LO, CRD, C2	HI, UNC, C4	HI, CRD, C3	LO, UNC, C1
13	HI, CRD, C3	HI, UNC, C4	LO, UNC, C1	LO, CRD, C2
14	HI, UNC, C4	LO, CRD, C2	LO, UNC, C1	HI, CRD, C3
15	LO, CRD, C1	LO, UNC, C2	HI, UNC, C3	HI, CRD, C4

Table 2. Independent variable condition codes.

Experiment Condition	Code
high scenario complexity	HI
low scenario complexity	LO
75% of scenario's encounters use procedure A, 25% B	CRD
75% of scenario's encounters use procedure B, 25% A	UNC
Traffic scenario	C#

III. Results

The following two sections present subjective data on the primary independent variables: the two self-separation procedural options and the three request/maneuver temporal thresholds. The last two sections present objective metrics on the relative aircraft states at which controllers issued traffic advisories, first in relation to the independent variables and then as part of an analysis that could be used to predict when a traffic advisory would be issued. Knowledge of when traffic advisories are normally issued is useful because when a controller issues an advisory it is then appropriate for the pilot to determine whether the intruder poses a potential safety threat and request a maneuver if it does. Controllers were unanimous on this point.

A. Subjective Evaluation of Self-Separation Procedures

One of the principal objectives of this study was to determine the acceptability to controllers of procedures in which the pilot did or did not obtain an amended clearance for a self-separation maneuver before executing that maneuver. Although measuring this level of acceptability was difficult and statistically significant differences between the two procedural options were not found in any of the relevant metrics, it was clear from observations during the scenarios and interviews after the simulation that strong preferences do exist. In particular, two common themes were observed consistently during the experiment: controllers universally reported preferring that pilots of IFR aircraft first obtain an amended clearance before executing any self-separation maneuver regardless of the magnitude of that maneuver; and secondly, only when an encounter is imminent (i.e. with a time to CPA under about a minute) and the controller has failed to issue a traffic advisory is it relatively acceptable for pilots to indicate that they are maneuvering immediately. A representative piece of written feedback from one controller was

> *"Real-world IFR pilots should not & almost never will turn without a clearance. [It is] almost emergency status to enact such a maneuver... I would have read the pilot the riot act & possibly written him up..."*

The clear message from the controllers is that if there is any time available to request an amended clearance, then one should be requested.

Although the notion that IFR pilots should coordinate with ATC before executing self-separation maneuvers is well understood and by far the most common procedure, experienced pilots report that deviations from a clearance are sometimes necessary, whether due to high controller workload, inability to make a request on a heavily used voice frequency, or the imminence of a problem requiring a deviation.[3] Perhaps even more surprising is that despite controllers' strong preference for pilots to coordinate maneuvers, their desire to accommodate pilot preferences and adapt to any unforeseen airspace circumstances meant that they rarely objected directly to pilot deviations or ordered pilots to immediately return to the original clearance. This desire manifested itself in no measurable or significant differences in self-reported workload, ability to provide additional services or detection of airspace or pilot anomalies between the two procedural conditions. When a numerical value between 1 and 5 is assigned to each of the possible answers to questions in the post-run and post-simulation surveys (see the questionnaires in Appendices B and C and the individual responses in Appendix L) the workload and impact on additional services are not statistically different between the two procedural conditions: mean self-reported workload for procedures A and B (Appendix B question 5 and Figure L1) were 3.50 and 3.52, respectively ($p=0.91$), and mean impact on ability to provide additional services

[3] See title 14 of the code of federal regulations part 91 sections 123 and 181.

B (Appendix B question 6 and Figure L2) was 3.00 and 2.90 (p=0.99). Airspace and pilot anomalies were actually more likely to be noticed in the request procedure A (52%, 14 yes responses out of 27 total responses) than the execute/notify procedure B (39%, 11 yes responses out of 28 total responses), though post-simulation review shows these anomalies were not related to pilot deviations from clearances (see Appendix B question 7 and Figure L3). The difference in the response rate between the two conditions is not statistically significant (p=0.36). The take away from this finding is that controllers are quite resilient to failures to follow established procedures, but this resilience does not imply that such failures should become precedents.

The self-reported workload and degree of objectionable behavior between the procedural conditions were not significantly different when controllers were asked about these metrics after each scenario, principally because other factors like providing separation services or miles-in-trail restrictions were observed to overwhelm any such effect, if it existed. However, 29% of controllers did report that pilot deviations from a clearance created an adverse situation at some point in the experiment (see Appendix C question 6 and Figure L4). So although the study was unable to objectively measure a safety impact from those particular pilot actions—a metric that is often fraught with difficulty because of the many overlapping safety procedures and technologies in place to avoid a safety impact on the airspace—there was clearly a degree of concern about such operations reported by the controller participants.

A question that arises regularly in the area of UAS-NAS integration is whether airspace stakeholders will consider UAS to be any different from manned aircraft once they have the technologies and procedures in place to meet all the airspace integration requirements. While the goal of many research programs is to make UAS functionally identical to manned aircraft, the question has lingered as to whether air traffic controllers would treat them differently knowing a pilot was not on board. When controllers were asked whether UAS maneuver requests were more or less acceptable than manned aircraft requests they reported most often that deviations by UAS are similarly acceptable to those of manned aircraft (see Appendix C question 9 and Figure L5). Those responses suggest that controllers do not differentiate between the two aircraft types. In fact, the UAS requests were more likely to be rated as more acceptable than manned aircraft requests because some controllers believed the superior-range sensors available to the UAS would provide better information to those pilots than visual acquisition alone would for manned pilots. Other feedback suggested that UAS *would* be treated differently from manned aircraft if they operated in ways that led controllers to distrust their behavior or capabilities, for example by turning and changing altitude without warning when a communication link is lost. However, this differentiation would be based on observed behaviors and leads to the same differential treatment that low-time general aviation pilots receive as compared to commercial pilots. No significant bias towards or against UAS operations was measured in this simulation.

B. Subjective Acceptability of Alert Thresholds

There were two primary goals in examining the acceptability to controllers of different request/maneuver thresholds: (1) to determine how far ahead of an encounter a pilot should maneuver or request a maneuver; and (2) to understand whether any of the thresholds would increase controller workload or reduce their ability to provide additional services because they were busy responding to pilot requests. The experiment setup relied only on post-scenario and post-simulation questionnaires to determine workload and controller impact in order to avoid introducing distractions.

At the end of each scenario controllers were asked to rate their overall workload, whether the workload impacted their ability to provide additional services (i.e. issuance of traffic advisories) and whether they noticed any pilot behavior or simulation artifacts that did not conform to their expectations for behavior in the real world. The differences in the numbers of responses for each alert threshold, shown in Appendix L in Figures L6, L7 and L8, are not statistically significant, indicating either that the threshold differences did not affect the metrics or that other airspace factors contributed so much to these metrics that differences between the thresholds were not measurable.

Debriefings with the controllers indicated that the largest threshold was objectionable, and that at 120 seconds to CPA aircraft were often too far away for pilots to be concerned enough about an intruder to be requesting a maneuver. It was judged too early to maneuver at that point without coordinating first with the controller. Representative feedback from one controller illustrated the difference between typical behavior of pilots of manned aircraft and that of a UAS with a 120-sec request/maneuver threshold, even if the maneuver is coordinated with the controller:

> *"My experience was pilots rarely spotted traffic very early & almost never asked for turns around the traffic. They usually spot the traffic and just separate themselves with altitude or laterally. If the UAS detects traffic I would think they would trust their equipment re: altitude or heading -OR- they would ask ATC about the traffic, then respond appropriately."*

In addition to indicating that the 120-sec threshold is too large, this quote and similar feedback from other controllers suggests that the separation standard being used for UAS (approximately 0.8 nmi laterally and 400 ft vertically) is larger than what pilots find acceptable when performing visual see and avoid. It also implies that, contrary to the feedback from the preceding section, pilots do execute small maneuvers for separation with the implicit consent of the controller. These findings are difficult to confirm in simulation alone, however, so a nominal set of procedures and separation standard should be established and real-world performance of the pilot-DAA system monitored to ensure any necessary revisions are implemented.

In contrast to the 120-sec threshold, controllers expressed far fewer objections to the distance at which pilots were requesting or executing maneuvers in the 60- and 90-sec conditions. When an encounter progressed down to the lower threshold of 60 sec without a traffic advisory and pilots requested a maneuver, the controllers frequently reported that they had not observed the developing close encounter and nearly always approved the requested maneuver. This finding suggests that proactive pilot maneuvering when the controller is too busy to issue traffic advisories could increase safety. The 90-sec threshold was also generally acceptable unless the encounter geometry resulted in an aircraft-to-aircraft range of more than about 10 nmi. This situation was reported as unrealistic by controllers because pilots of manned aircraft rarely detect intruders at such distances and almost never are able to decide they are enough of a threat to request an evasive maneuver. It appears that both the time to CPA and the horizontal distance are necessary to determine whether a maneuver will be compatible with controller expectations.

C. Objective Data on Traffic Advisories

The difficulty of measuring subjective differences in controllers' perceptions of the procedural options and request/maneuver thresholds drove the need to examine objective data to address these research issues. Rather than relying on the controllers' objections to specific maneuver requests that were too early, we measured the times and relative geometries at which controllers issued traffic advisories. It was expected that pilot action to coordinate and execute a maneuver to avoid an intruder would be acceptable after a traffic advisory is issued, an expectation confirmed during observations of the simulation and feedback from controllers during the debriefing sessions. Note, however, that the pilot action times reported here are dependent not only on the controllers' decisions to issue traffic advisories, but also the scripted times at which the confederate pilots were instructed to request or execute maneuvers. Even the metrics related to times and distances at which the controllers issued traffic advisories are influenced to an extent by the fact that pilots would take action at a scripted point, precluding an advisory from being issued after that point. The net effect of this interaction is that the mean traffic advisory times and distances are somewhat larger than would be expected if the pilots had never taken any action, though the relative consistency of the metrics across request/maneuver threshold conditions suggests that the actual values are within about 10 sec or 0.5 nmi of the values reported here.

The mean times to CPA at which pilots maneuvered, requested a maneuver or received a traffic advisory as a function of the request/maneuver threshold condition is shown in Figure 4. The figure shows that, when an advisory is not received, the pilots tend to request/maneuver at the appropriate times, albeit about 10 sec late 90-sec condition and 20 sec late in the 120-sec condition. In contrast, the mean times at which advisories are issued are much more consistent, varying between 114 and 130 sec. The variation is largely due to differences between controllers' preferences in issuing advisories (shown in Appendix A), but is sufficiently consistent to allow plotting of the entire set of advisories as a cumulative distribution with which to fit a probabilistic model of the time to CPA and ranges at which controllers issue advisories. This analysis is presented in the following section. These values are consistent with the subjective feedback from the controllers that pilots should not request maneuvers to avoid intruders until they are less than 110 sec from CPA, since this would preempt the controller's natural procedure to advise the pilot of a potential problem and only later negotiate whether and what to do about it. The value of 110 sec should be considered an upper limit, not a preferred threshold time. (The ATC-preferred time is likely much lower.)

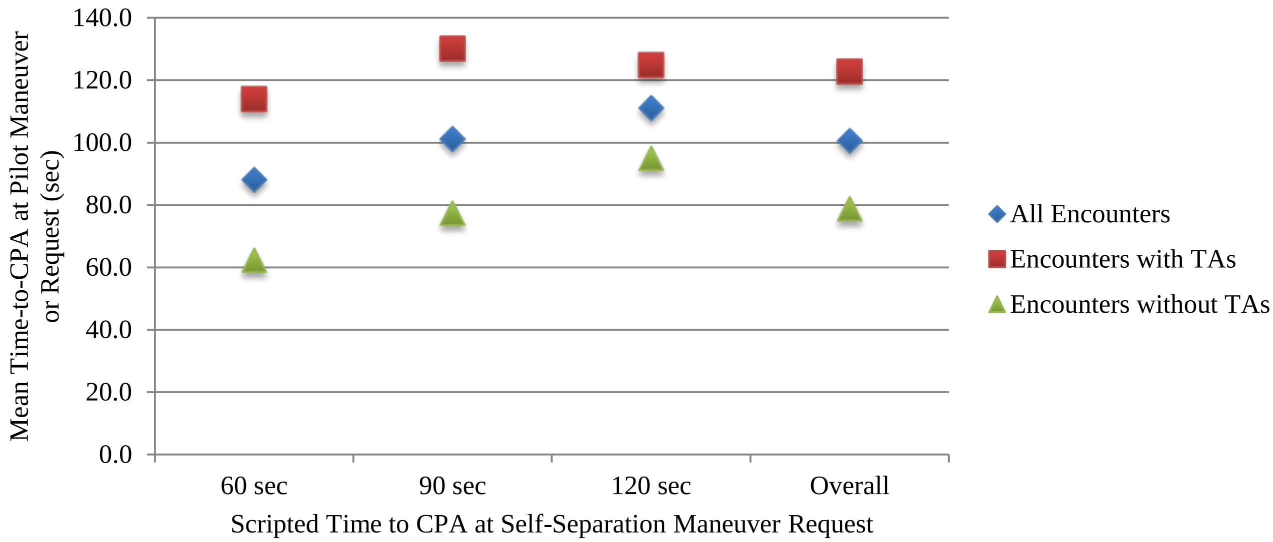

Figure 4. Mean times to CPA between aircraft at the point a traffic advisory (TA) was issued or pilots took action (when no TA had been received by the scripted threshold).

The horizontal distance between aircraft at which pilots maneuvered, requested a maneuver or received a traffic advisory as a function of the request/maneuver threshold condition is shown in Figure 5. The overall trends are similar to the time-to-CPA chart shown previously: the distances are dependent on the alert thresholds when pilots requested/maneuvered when no TA was received, but were independent of alert threshold when advisories were issued. The consistency of values around 8-9 nmi supports controllers' feedback that they are unlikely to issue an advisory if they do not think that a pilot will be able to see an intruder aircraft. The fact that these values are not significantly affected by the pilots' different request/maneuver thresholds indicates that the true distance at which they would typically issue the advisories is close to these values. Further, the data suggest that, in order to be consistent with controller expectations and manned aircraft behavior, UAS pilots should not request a maneuver to avoid an intruder until that intruder is less than 8 nmi away. This value of 8 nmi should be considered an upper limit, not a preferred threshold distance. (The ATC-preferred distance is likely much closer.)

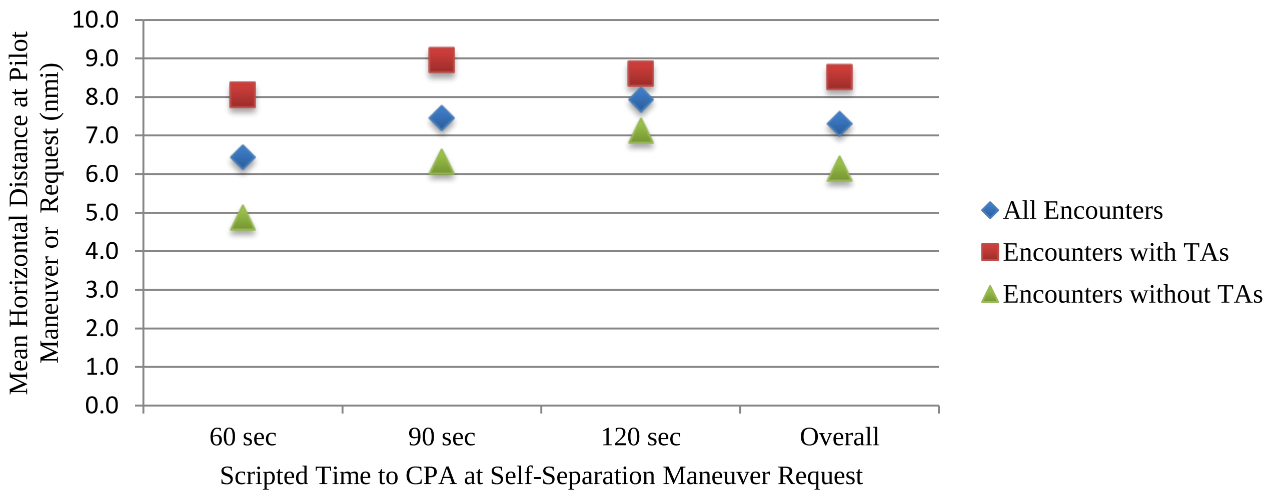

Figure 5. Mean horizontal distance between aircraft at the point a traffic advisory was issued or pilots took action (when no TA had been received by the scripted threshold).

The vertical separation between aircraft at which advisories were issued is not shown here because of the strong interplay between the horizontal and vertical dimensions and because the vertical separation was not systematically varied across the encounters in a way that would allow cross-condition comparisons. The horizontal distance at which the advisory was issued can be plotted because controllers will only issue advisories when the vertical distance will be small at CPA. Thus, the horizontal distance and not the vertical separation is the main factor driving the advisory decision. However, future analysis should examine the horizontal and vertical distances at CPA that must be satisfied in order for a controller to decide that an advisory is warranted.

A plot of the horizontal distance versus time to CPA at which each advisory was issued over the whole simulation is shown in Figure 14. Two aspects of that chart are notable: a diagonal limit that follows a line from the origin to the upper right indicates a maximum closure velocity of approximately 450 kts, a limit that will depend on the fastest expected intruder and the ownship velocity; secondly, except for a few encounters that controllers did not detect until the aircraft were already at CPA, advisories are always issued when aircraft are at least 1.65 nmi apart. This latter point is particularly relevant because it determines the distance at which an advisory would be issued for a slowly evolving encounter (e.g. an overtake).

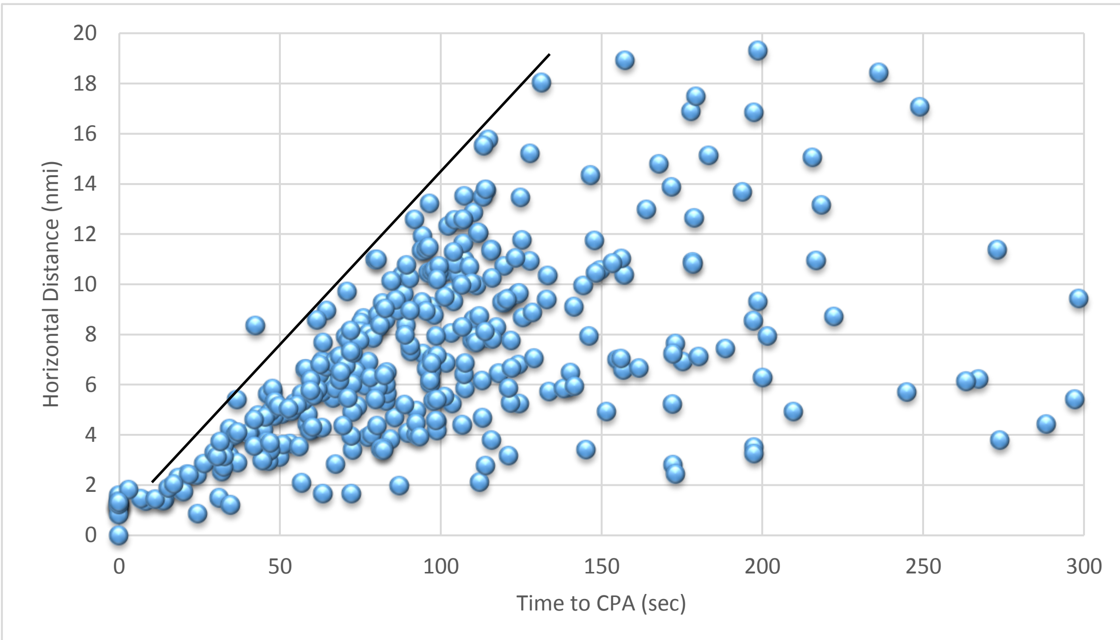

Figure 6. Horizontal distance and time to CPA at which each traffic advisory in the experiment was issued.

The encounter geometries at which traffic advisories were issued by the controllers is a key predictor of the point at which pilots may be expected to begin requesting maneuvers to remain well clear of intruder aircraft. Plots of the time to CPA and the horizontal distance as a function of relative heading at which the advisories were issued are shown in Figure 7. The contours of the distances and times at which these were issued, grouped into bins 30 degrees wide, are also plotted to help indicate the trend with relative heading. Note that 0 degree relative heading means the two aircraft were traveling in the same direction, while 180 degrees indicates a head-on encounter. These charts help indicate how heading, range and time to CPA for a particular encounter translate into the likelihood that a traffic advisory will be issued.

The data from Figure 7 is replotted in Figure 8 to more clearly show the trend of the horizontal range and time to CPA as a function of relative heading at which traffic advisories were issued. It is expected that head-on encounters, because of their relatively high closure rate in comparison with other encounter angles, would be alerted at larger ranges and shorter times to CPA, while those encounters in which the aircraft are traveling in roughly the same direction and therefore have relatively more similar speeds would be alerted at shorter ranges and with longer times to CPA. Figure 8 largely supports this expectation, though because of a limited number of data points in some relative heading angle bins this trend is not monotonic: encounters near 120 degrees interrupt the overall trend. However, the data do support the notion that controllers use the same basic alerting criteria designed for self separation and collision avoidance systems that combines a temporal criterion with a geometric one to safely incorporate high and low range-rate encounters without an excessive number of false alerts.

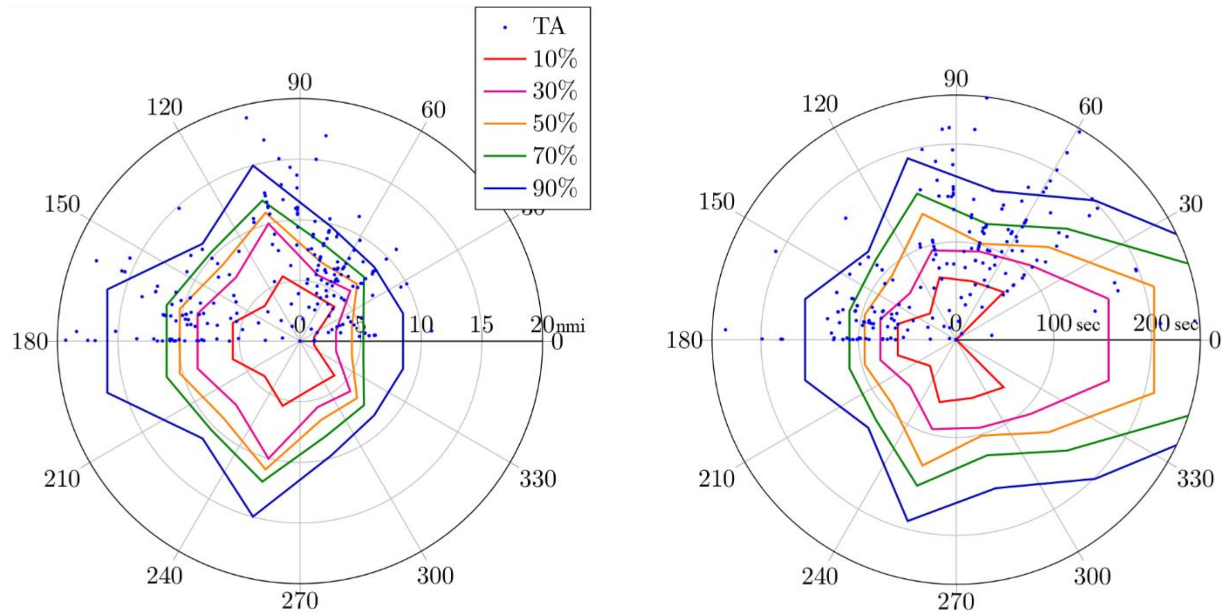

Figure 7. Contours of horizontal distance and time to CPA at which controllers issued TAs as a function of relative heading. Outer rings are at 20 nmi and 250 seconds, respectively. Headings are measured in a range of 0 to 180 degrees, but the contours are drawn symmetrically up to 360 degrees for clarity.

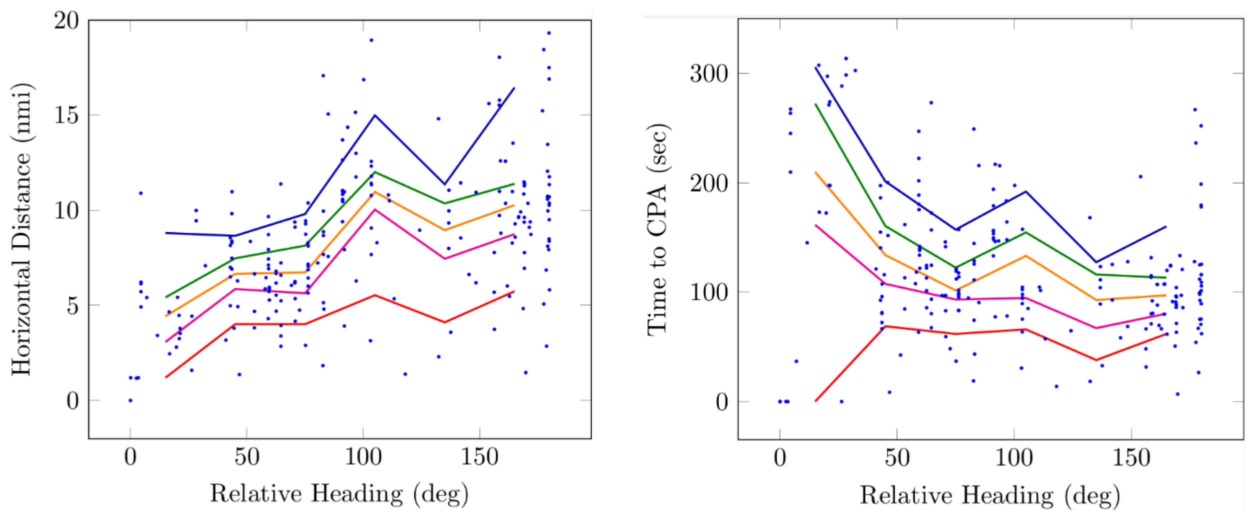

Figure 8. Relative heading vs horizontal range (left) and time to CPA (right) for each traffic advisory issued. Contours are identical to those shown in Figure 7.

D. Distributions of Traffic Advisories by Range and Time to CPA

This section presents empirically fitted models of the ranges and times to CPA at which controllers issued traffic advisories. It does not try to predict when an advisory will be issued, examine all the potential metrics controllers might use to decide whether and when to issue an advisory, nor investigate the interplay between different metrics' contributions to the probability that an advisory will be issued. The value of this analysis is its quantification of objective temporal and geometric metrics against the behavior of controllers, which is the first step towards completing the additional analyses listed above. Until those analyses are completed and a traffic advisory model has been produced, this data should be used to ensure pilots do not request resolution maneuvers when controllers would not normally consider a given encounter to yet warrant action.

The time to CPA and the relative range between aircraft at which traffic advisories were issued are shown in Table 3. That table shows that the median time to CPA at which an advisory is issued is 109 sec and the range is 8.29 nmi; these values are consistent with controllers' feedback in post-simulation interviews and questionnaires that they are unlikely to issue an advisory if they do not believe the pilot is likely to see the intruder and suggested that would occur around about 8 nmi. The table also indicates that only 25% of advisories are issued when the time to CPA is less than 83.5 sec or range is less than 5.86 nmi; in other words 75% of all advisories were issued with larger times or distances. This may be roughly interpreted by a pilot observing an intruder at this temporal or geometric threshold as evidence that the controller may have been too busy or distracted to notice this encounter because in 75% of similar encounters an advisory would already have been issued. In such circumstances the pilot should be confident that coordinating a maneuver with the controller will not be a nuisance and may increase safety.

Only 10% of advisories were issued with a time to CPA below 62 seconds and a range under 3.8 nmi. At this point the overwhelming majority of TAs would already have been issued and therefore may constitute evidence that the controller is so busy that a TA is unlikely to be issued and the immediacy of the encounter requires action before coordination may take place. It should be emphasized that pilots should not wait until this 60-sec threshold and then take uncoordinated action; rather if an encounter with an intruder is first alerted near this threshold, then uncoordinated action is likely necessary. These proposed 60- and 80-sec thresholds are consistent with the intruder-alerting logic recently tested in piloted simulations.[xi] The thresholds received positive subjective feedback, indicating they are likely to satisfy both pilots and air traffic controllers when used for DAA systems on UAS.

Table 3. Empirical values of the proportion of TAs issued at given metrics or below.

Percentage of Data	Time to CPA (sec)	Range between Aircraft (nmi)
10%	61.7	3.82
25%	83.5	5.86
50%	109.0	8.29
75%	153.5	10.80
90%	215.6	13.52

The data used to generate Table 3 is plotted as a set of contours in Figure 9 to show the relationship between the temporal and geometric factors. The figure indicates the proportion of traffic advisories that were issued with greater temporal *and* geometric encounter characteristics than the given point in the space of these metrics. A three-dimensional representation of the probabilities that the contours represent is shown in Figure 10. While the contours are flat (horizontal or vertical) where they intersect the axes, indicating that only one of the two metrics is an important predictor of the probability of a traffic advisory in these conditions, the curved nature of the contours between these extremes shows that both metrics do contribute to the advisory probability.

To illustrate the use of these plots, if the current horizontal distance between aircraft is about 8 nmi and the time to CPA is less than 75 seconds, then the probability of an advisory is 50%. However, if the time to CPA is 100 sec the probability is 40%, dropping to 20% at 130 sec and being nearly zero for any time greater than 180 sec. Such a contour plot could be used to indicate the probability that an advisory would normally have been issued at this point in a given encounter, with a particular level of probability (e.g. 75%) being selected as the point at which a pilot should begin discussing potential maneuvers with the controller if they have not already received a traffic advisory. This does not imply that the DAA system should avoid alerting a pilot until this point; instead the alert should have come at least 20 seconds earlier to allow the pilot time to obtain situation awareness about the intruder, determine an appropriate course of action and prepare to input the maneuver into the flight control system. If a traffic advisory is received before the threshold probability is reached then the pilot will be ready to respond appropriately, and if one is not received by the threshold the pilot will be ready to request a well-considered resolution maneuver.

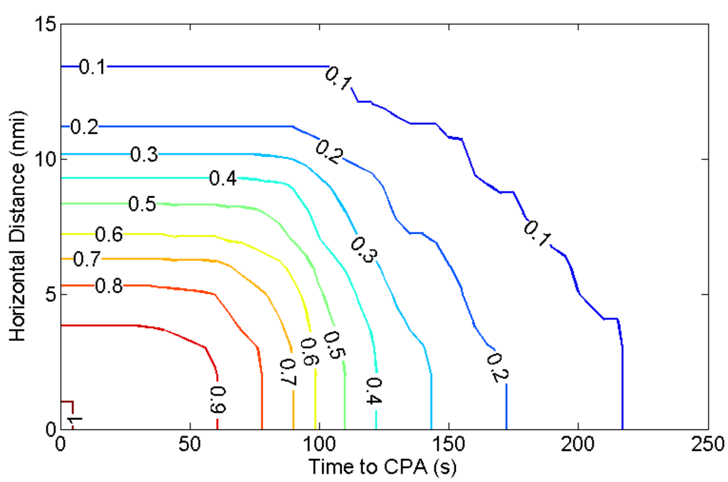

Figure 9. Contours of the proportion of traffic advisories issued given the distance and time criteria were greater than or equal to the metrics on each axis.

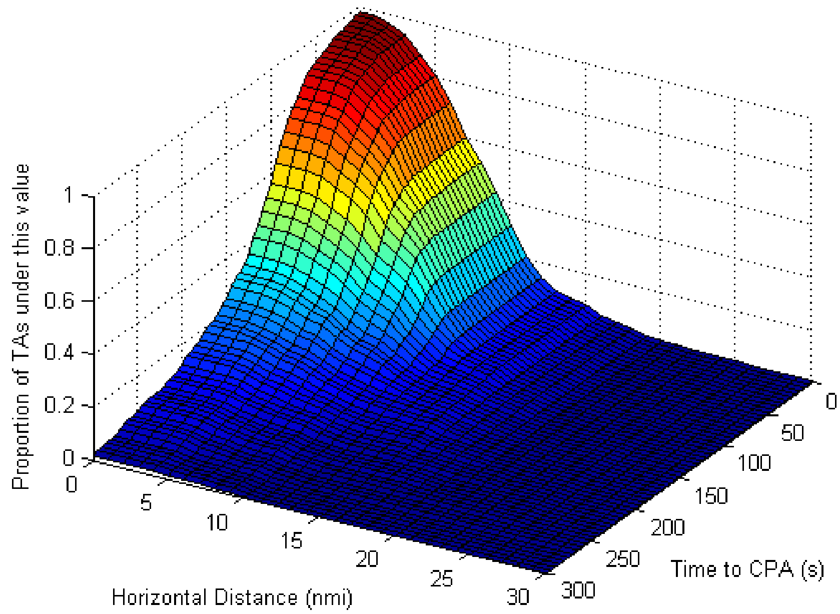

Figure 10. Three-dimensional representation of the empirical data on the probability a traffic advisory is issued as a function of horizontal distance and time to CPA.

The threshold at which a pilot should begin coordinating with a controller about a potential maneuver cannot be directly selected from the data gathered in this study, but future studies could examine an appropriate threshold using the empirical data collected here. For that purpose several different distributions were fit to the empirical data, with the best two among a wide range of distribution reported in Table 4. That table also reports the parameters of a best-fit Normal distribution for reference purposes, not because it is a particularly good representation of the data.

Table 4. Maximum likelihood estimates of the best parameter fits for two traffic advisory metrics.

Distribution Type	Time to CPA (sec)			Distance to CPA (nmi)		
	Parameters	Log-Likelihood	Max Error	Parameters	Log-Likelihood	Max Error
Generalized extreme value	k=0.0239, σ=50.16, μ=95.59	-1145.0	7.28%	k=-0.0060, σ=3.29, μ=6.84	-573.9	6.18%
Gamma	a=3.49, b=35.98	-1149.2	7.31%	a=4.38, b=1.99	-574.8	6.17%
Normal	μ=125.7, σ=67.5	-1170.8	13.6%	μ=8.70, σ=4.23	-594.4	9.21%

The best fit of the tested distributions was the generalized extreme value (GEV) distribution, which is normally used to model the value of the largest (most extreme) member of each of a set of samples drawn from the same distribution. The log-likelihood of each fit, which is the probability that the empirical data set was generated from the given distribution, was higher for the GEV distribution than any other for both the time and distance metrics. The maximum error in the fitted cumulative distribution function (CDF) from the empirical CDF also compared favorably with other distributions, though it was not always the best in this respect. The maximum error is defined as the maximum difference between the probability of a traffic advisory being issued at a given threshold as estimated by the distribution and the actual observed frequency with which advisories had been issued. For example, a maximum error of 7.28% could mean that if the predicted number of advisories issued with a time to CPA under 125 sec is 60% the actual observed number is 67.28% The best fit parameters for this distribution are given in Table 4, and the probability distribution function (PDF) is given by,

$$y = f(x \mid k, \mu, \sigma) = \left(\frac{1}{\sigma}\right)\exp\left(-\left(1 + k\frac{(x-\mu)}{\sigma}\right)^{-\frac{1}{k}}\right)\left(1 + k\frac{(x-\mu)}{\sigma}\right)^{-1-\frac{1}{k}} \tag{1}$$

Although the GEV distribution was the best fit overall of the empirical data, its theoretical basis does not appear to match the processes at work in a controller's decision to issue a traffic advisory, and its success may be due to chance given the large number of distributions tested. A function that has been used to model human response times in this domain[xii] is the gamma distribution: its log-likelihood is nearly as good as the GEV distribution and its maximum error is slightly lower for the range metric. The simpler form of the distribution and its prior use in this domain may make it a more attractive candidate to model the probability a controller will issue a traffic advisory at a given temporal or geometric threshold. The PDF of the gamma distribution is

$$y = f(x \mid a, b) = \frac{1}{b^{a}\Gamma(a)} x^{a-1} e^{\frac{x}{b}} \tag{2}$$

To help visualize the performance of the three distributions whose parameters are reported in Table 4, each fit is plotted against the empirical data as either a PDF (Figure 11) or CDF (Figure 12). These charts illustrate the closeness of the GEV and gamma distributions, along with the relative inaccuracy of the normal distribution. Future work should explore multivariate distributions that can fit both the temporal and geometric variables into a single probability distribution, along with more sophisticated models that incorporate additional metrics in an attempt to predict when an advisory will be issued for a specific encounter.

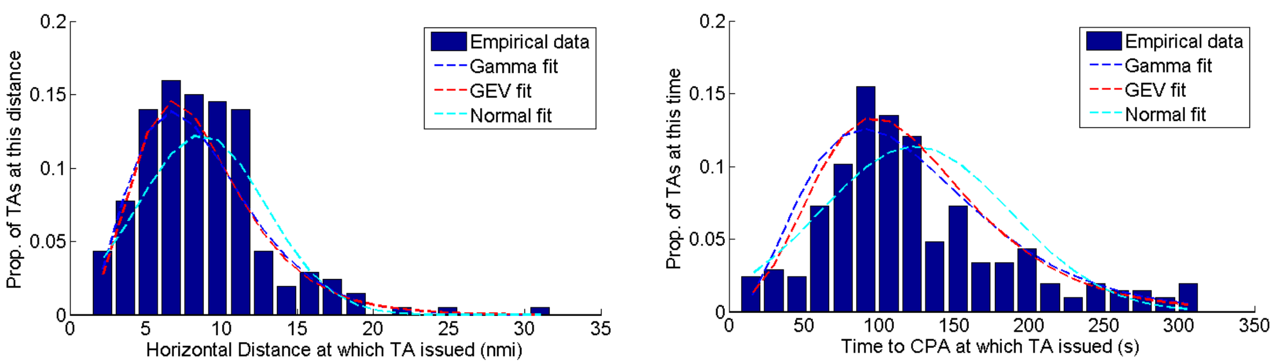

Figure 11. PDF of the empirical data on range (left) or time to CPA (right) at which controllers issued traffic advisories. Best fits for three distributions are overlaid on the empirical data.

IV. Conclusions

A human-in-the-loop experiment was conducted with 15 retired air traffic controllers to investigate the appropriateness of procedures for the use of DAA systems and the maximum temporal and geometric thresholds at which pilots should request a maneuver to remain well clear. Each controller managed aircraft in four different scenarios with mixed IFR and VFR traffic. Controllers provided separation services, miles-in-trail restrictions and additional services, workload permitting. Of particular interest in this study was the issuance of traffic advisories, which are used to notify pilots that evasive action may be necessary to avoid intruder aircraft. Two procedural options were tested in the pilots' use of the DAA system within each scenario, and three different request/maneuver thresholds were tested in a between-subjects comparison. Controller participants filled out post-scenario and post-simulation questionnaires on workload and realism of pilot behaviors, and pointed out to observers during the simulation any "objectionable" pilot maneuvers. Metrics were collected on the rate of objectionable behaviors as a function of the independent variables and the relative states of aircraft when controllers issued traffic advisories.

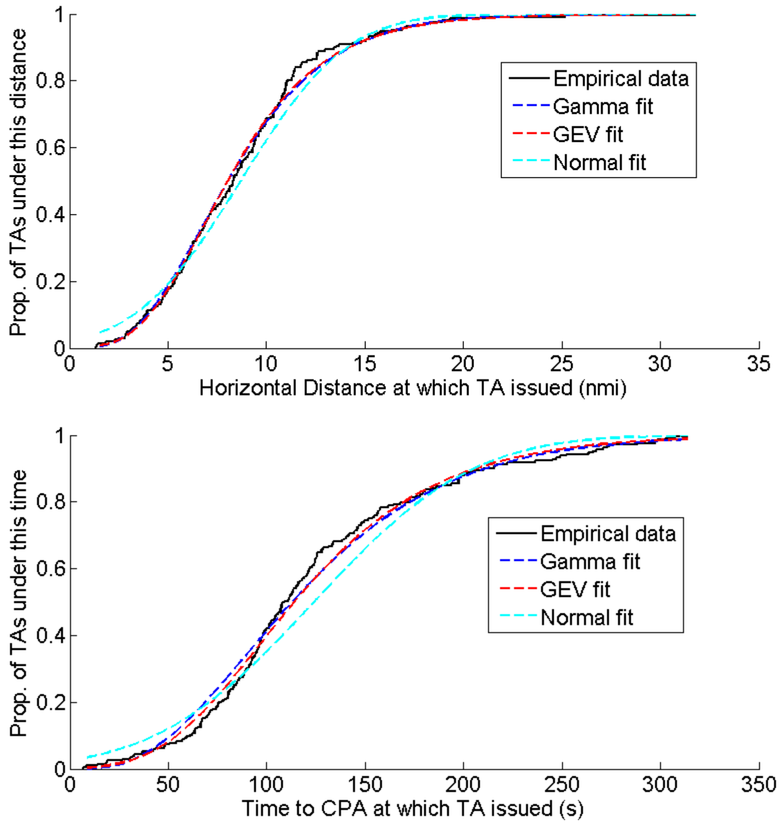

Figure 12. CDFs of the empirical data on range (top) or time to CPA (bottom) at which controllers issued traffic advisories (TA). Best fits for three distributions are overlaid on the empirical data.

The subjective feedback from the controller participants indicated a strong preference for pilots to request maneuvers to remain well clear from intruder aircraft rather than deviate proactively from their IFR clearance and notify the controller afterwards. However, many controllers indicated that under certain circumstances it might be necessary for pilots to take action before consulting with a controller. Controllers also indicated that a maneuver threshold of 120 seconds until CPA frequently led to pilot requests that were unnecessary and deviations that were too large. When the procedural condition required pilots to only notify the controller after they had maneuvered, controllers reported those actions could lead to unsafe situations. In contrast, when the maneuver threshold was set to 60 or 90 seconds, the pilots' requests were more consistent with controller expectations. However, although controllers believed the timing of the requests was appropriate, the magnitudes of requested maneuvers were frequently judged as too large. Because these maneuvers were sized to avoid the quantitative UAS well clear definition, this feedback may indicate that the UAS well clear standard is larger than the one employed by pilots of manned aircraft. This inconsistency could differentiate UAS from manned aircraft in terms of their effect on the airspace.

Controllers issued traffic advisories (TAs) to aircraft pairs that, in their judgment, could evolve into a violation of the applicable separation standard. Under current operations, controllers expect pilots may then request a maneuver to ensure they do not violate the standard, which in the case of UAS is the quantitative well-clear definition. The point at which controllers issue these traffic advisories may be used as an upper limit to the time or distance from a close encounter at which the pilot should request a maneuver. The relative states of aircraft were recorded at the points controllers issued traffic advisories in the simulation, with the minimum separation for a “routine” TA of 1.65 nmi (a non-routine TA would be one the controller would have issued earlier had they noticed the encounter earlier). The time to CPA and relative range metrics, which are used to predict encounters in other separation algorithms, were then fit against a series of distributions, and it was found that the generalized extreme value and gamma distributions are good matches to the empirical data.

We propose that pilots wait to request a maneuver until after controllers would usually have issued an advisory in similar encounter conditions, potentially using a threshold of 75% probability that an advisory would have been issued. This threshold would mean that pilots should wait until CPA is approximately 80 seconds away or the intruder is within about 6 nmi to request a maneuver, using the prior 20-30 seconds to begin preparing an appropriate maneuver. Controllers will normally have issued 90% of advisories before an encounter progresses to 60 seconds and 4 nmi, which corresponds to a very short alert time. If the controller has not issued a TA prior to this point, data and subjective feedback from this simulation indicates they are likely too busy to provide the additional TA service. Controllers indicated that proactive maneuvering by the UAS to remain well clear under these circumstances should increase safety. Implementation of these criteria in the procedural use of DAA systems and alerting logic should lead to pilot requests that are compatible with controller expectations and preserve the typical pilot-controller interaction process, leading to more seamless UAS operations in the domestic U.S air transportation system.

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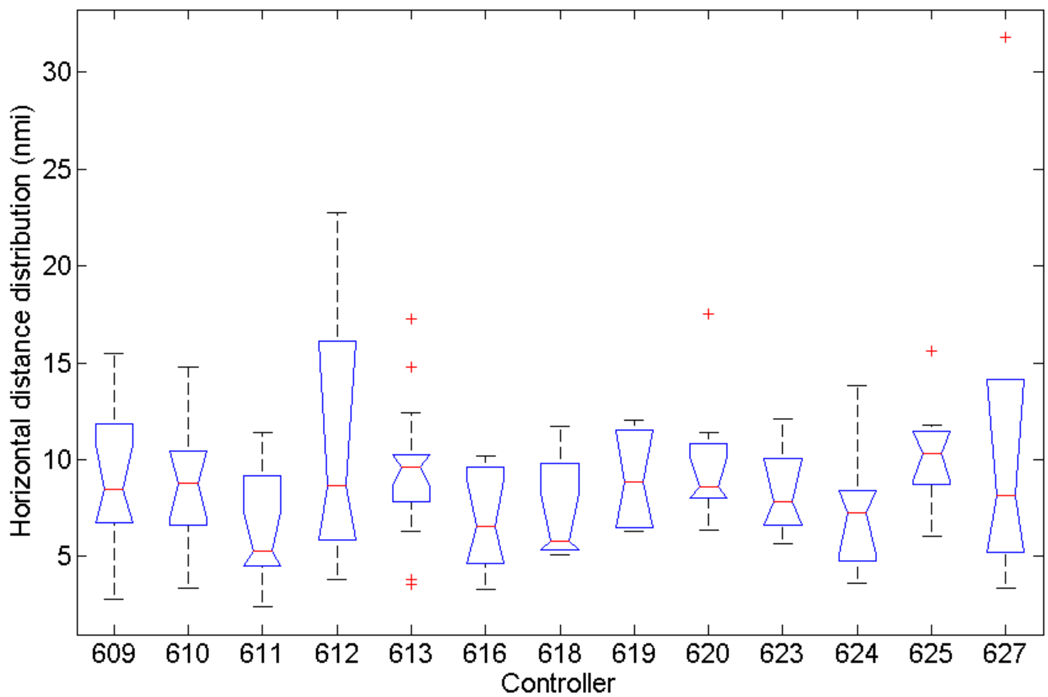
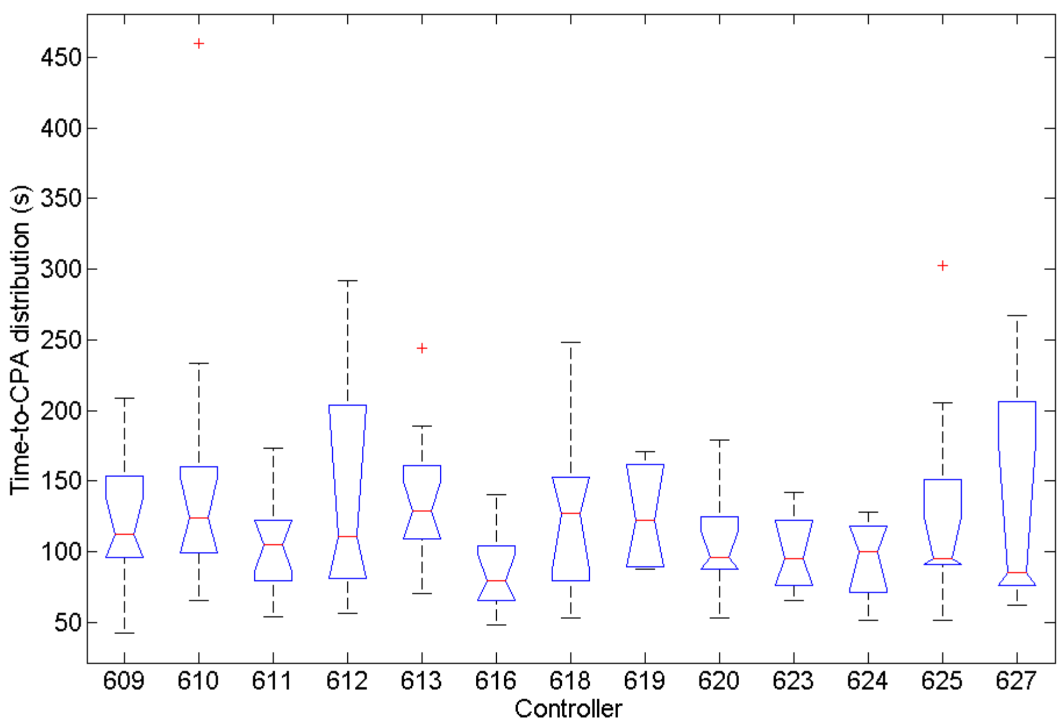
VII. Appendicies

A. Traffic Advisory Metrics by Controller Participant





B. Post-Run Controller Questionnaire

Date: ______________ First Scenario

1. The flow of traffic in my sector was representative of a low altitude en route sector. (Check one line below)

__ Yes
__ No
__ Uncertain

Comments:

____

2. The traffic density in my sector was realistic relative to current-day operations (check one box below)

Much less busy than normal	Somewhat less busy than normal	Typical	Somewhat busier than normal	Much busier than normal

Comments:

____

3. As compared with normal real-world operations, the number of the encounters in this trial was:

Much less frequent	Somewhat less frequent	Typical	Somewhat more frequent	Much more frequent

Comments:

____

4. As compared with normal real-world operations, the complexity of the encounters in this trial was:

Much easier to detect and resolve	Somewhat easier to detect and resolve	Neither easier nor more difficult to detect and resolve	Somewhat more difficult to detect and resolve	Much more difficult to detect and resolve

Comments:

____

5. As compared with normal real-world operations, how would you rate your workload during this scenario?

Much lower than normal	Somewhat lower than normal	Typical	Somewhat higher than normal	Much higher than normal

Comments:

____

6. Did the workload and complexity of the scenario impact your ability to provide additional services (direct routings, traffic advisories, etc.)?

Zero impact on additional services	A small impact on additional services	Could provide a typical degree of additional services	Large impact on additional services	Unable to provide additional services

Comments:

____

7. Did you notice any ghost controller, aircraft, pilot, or software behavior in the simulation that did not conform to your expectations or that was unlike behavior in the real world?
   __ Yes
   __ No
   __ Uncertain

If yes, please list all such examples:

____

Did such behavior reduce your situational awareness, increase your workload, or have any other detrimental impacts on your performance?

____

C. Post-Simulation Controller Questionnaire

Date: _______________

1. As compared with air traffic control displays used operationally, the ATC display environment used during the simulation:

Had major display issues that prevented me from performing routine tasks	Had minor display issues that detracted from my ability to control traffic	Was adequate for controlling air traffic	Was a good emulation of a controller workstation, with only minor differences	Was a realistic emulation of a controller workstation

Comments:
____

2. Did any pilots *request* deviations due to traffic?
__ Yes
__ No
__ Uncertain

If yes, were any requests inappropriate?
____

3. Did any pilots deviate for traffic *without requesting* an amended clearance?
__ Yes
__ No
__ Uncertain

- Were any deviations (without amended clearances) unacceptable or inappropriate?

Comments: ____

4. Did the pilots deviate for traffic in a way similar to pilots in the real world?

Very similar to pilots in the real world	Similar to pilots in the real world	Not similar or different to pilots in the real world	Different than pilots in the real world	Very different from pilots in the real world

Comments: ____

5. Do you feel you noticed all pilot deviations?
   __ Yes
   __ No
   __ Uncertain

   Comments: ____

6. Did any deviations (without an amended clearance) create an adverse situation, for example a conflict with a third aircraft?
   __ Yes
   __ No
   __ Uncertain
   Comments: ____

7. How would you have preferred the pilot conduct the deviation, particularly with respect to prior coordination with you?

   Comments: ____

8. What circumstances contributed to whether a deviation was acceptable?

   Comments: ____

9. Were deviations requested or made by unmanned aircraft more or less acceptable to you than those made by pilots of manned aircraft?

UAS deviations much less acceptable	UAS deviations less acceptable	UAS deviations same acceptability	UAS deviations more acceptable	UAS deviations much more acceptable

   Comments: ____

10. Discuss the procedural alternatives presented in this simulation with the researcher, then answer the following questions:
    - Did you notice a difference in the procedures from encounter to encounter?

      __ Yes

      __ No

      __ Uncertain

      Comments: ____

    - Which procedure version did you prefer? Under what circumstances would each version be appropriate?

      Comments: ____

D. Air Traffic Controller Demographics Questionnaire

*Please fill in the blanks or circle your response to **each question** below*

1a. What types of facilities have you worked in? (Circle all that apply):

FAA ATCT   Military ATCT   FAA TRACON

Military RAPCON   ARTCC

1b. How many years at each?

FAA ATCT ____________________

Military ATCT ____________________

FAA TRACON ____________________

Military RAPCON ____________________

ARTCC ____________________

1c. If applicable, did you achieve Full Performance Level (FPL) at: (Circle all that apply)

FAA ATCT	YES	NO	N/A
Military ATCT	YES	NO	N/A
FAA TRACON	YES	NO	N/A
Military RAPCON	YES	NO	N/A
ARTCC	YES	NO	N/A

1d. Briefly describe your experience at each facility (e.g., location, duration, responsibilities):

____

2. Briefly describe any other experience you might have in air traffic management, such as Flight Services, Supervision, Training, or TMA (e.g., location, duration, responsibilities):

____

3a. Have you ever worked within ZOA airspace?

YES NO

3b. If yes, how many years of experience do you have with ZOA airspace?

____

____

4a. Do you have any experience working with unmanned aircraft systems (UAS)?

YES NO

4b. If yes, please rate your level of experience working with UAS:

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

4c. What type/model of UAS do you have experience working with?

____

____

5a. Do you have any experience serving as a participant in simulation research?

YES NO

5b. If yes, how many years of experience do you have as a simulation participant?

____

____

6a. Do you have any experience participating in simulation research involving UAS?

YES NO

6b. If so, how many years of experience do you have with UAS simulation research?

____

____

7a. Do you have any experience with ERAM?

YES NO

7b. If yes, could you describe your experience briefly?

8a. Do you have normal or corrected to normal visual acuity?

YES NO

8b. Do you have normal color vision?

YES NO

E. Experiment Briefing to Air Traffic Control Participants

National Aeronautics and Space Administration

Air Traffic Controller Briefing

"Integrated" Human in the Loop Simulation

Eric Mueller
Doug Isaacson
Seung Man Lee
Chester Gong
Confesor Santiago

6/9/14

1

Simulation Background

- UAS integration in the national airspace system (NAS) project
  - Developing the requirements for UAS to safely integrate with existing air traffic in the next several years
  - Principle objective is for UAS to behave just like manned aircraft from an ATC perspective
- Past simulations have investigated requirements for pilot interaction with the UAS systems, including response times
- Future simulations and flight tests will demonstrate the safety of the overall concept and technologies for UAS-NAS integration
- This simulation is the first of the "integrated" simulation studies and will provide a baseline for later safety demonstrations

2

Overall Objectives

- Evaluate the fidelity of the air traffic simulation environment for future simulations and flight tests
- Collect data that improves modeling of controller performance in batch simulations

3

Instructions

- To help us improve simulation fidelity, please point out any simulation or scenario inconsistencies, problems, concerns, bugs, etc. during the run.
  - The observer will note these and follow up with any additional details you wish to provide at the end of the run.
  - The pseudo-pilot adherence to real operations is important, please point out any time they don't conform to your expectations or it raises your workload/increases complexity.

4

Data Collection

- Written surveys distributed after each scenario and at the end of the day
  - Simulations inconsistencies, bugs, un-realistic situations, etc.
  - Evaluation of controller interface
  - Comparison of traffic densities, complexity workload, flow characteristics with the real world
  - Whether simulation inconsistencies affected your performance

5

Daily Schedule

Time	Task	Duration
830	Introduction / Controller Briefing	20
850	MACS Training	30
920	MACS Practice	80
1040	Break	10
1050	First Scenario	40
1130	Post Trial Forms	10
1140	Lunch	60
1240	Second Scenario	40
1320	Post Trial Forms	10
1330	Break	10
1340	Third Scenario	40
1420	Post Trial Forms	10
1430	Break	10
1440	Fourth Scenario	40
1520	Post Trial Forms	10
1530	Debrief	60
1630	End	

6

F. Experiment Debrief to Air Traffic Control Participants

National Aeronautics and Space Administration

Air Traffic Controller Debrief

"Integrated" Human in the Loop Simulation

1

Background

- Federal aviation regulations (FARs) related to responsibility for aircraft-to-aircraft separation are contradictory under common interpretations
  - 91.111: Pilot may not operate in a way that creates a collision hazard
  - 91.113: Pilot must remain well clear of other aircraft
  - 91.123: Pilot may not deviate from an ATC clearance except in an emergency
  - 91.181: Allows pilot to "maneuver the aircraft to pass well clear of other air traffic"
- Application of FARs is based on historical, legal interpretation
  - Traditional pilots and ATC have established a generally complementary division of separation responsibility
  - Several factors suggest this division of separation responsibility may not apply to UAS
    - Longer range detection of intruder aircraft (e.g. airborne radar)
    - Better algorithms to determine separation maneuvers at long ranges
    - Unknown performance of self-separation function when using a 2D display rather than out-the-window view

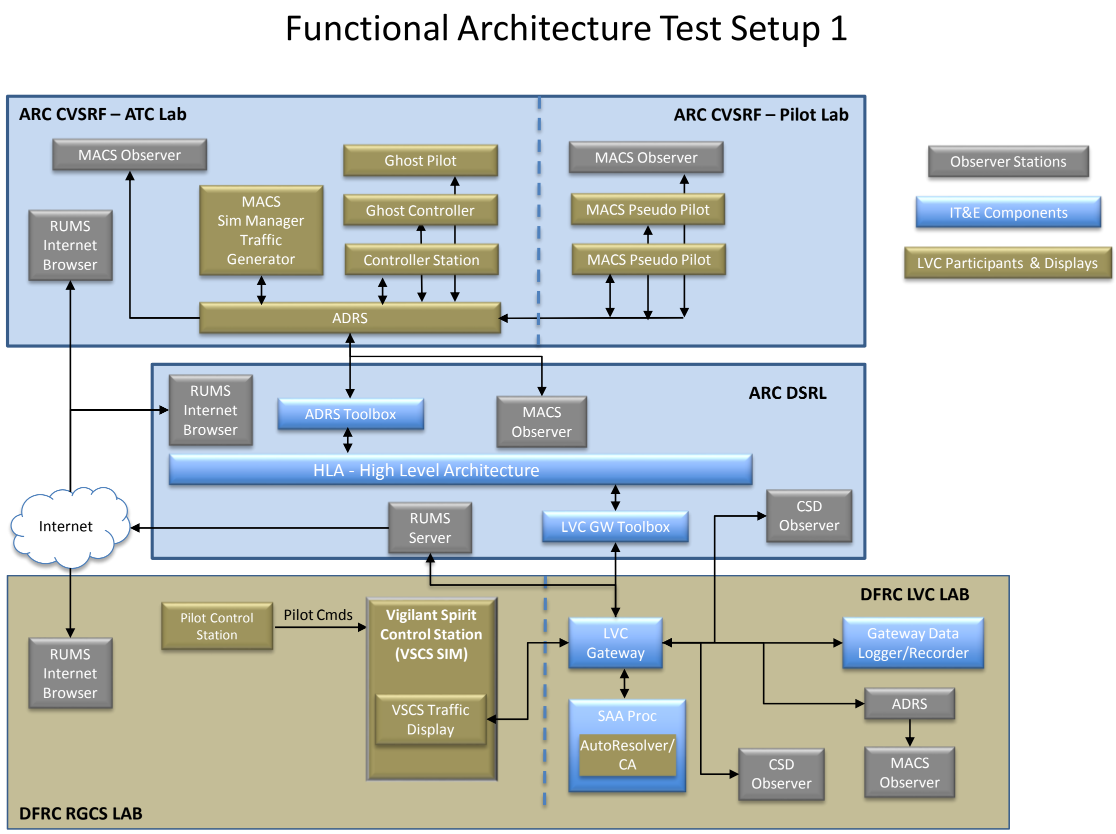
2

Specific Objectives

- Evaluate the acceptability to the controller of maneuvers performed for "self separation"
  - Compare procedures in which SS maneuvers are or are not coordinated with ATC before execution
  - Measure the deviation magnitude the controllers (1) detect and (2) object to
  - Provide data to support DAA use conops for SC-228 Ops sub-group
- Collect data that improves batch simulations
  - Time required for controllers to approve or disapprove self separation maneuvers
  - Use controller-approved maneuvers to improve self-separation algorithm recommendations
  - Time and distance thresholds at which traffic advisories are issued, and airspace/scenario characteristics that suppress these advisories

3

G. LVC-DE Detailed System Architecture[xi]



H. Detect-and-avoid Procedures for Pilots as an Experiment Variable

Operational Concept

- Self-separation from VFR aircraft is the responsibility of all pilots, even those receiving ATC separation services
- Procedural options for use of self-separation (SS) system: pilot responsibility
  - Request an amended clearance (option A)
  - Notification at the time of deviation from clearance (option B)
- Traffic advisories (TAs) are issued between all aircraft talking to ATC as an "additional service, workload permitting"
  - Before a TA is provided to an IFR aircraft, either procedural option is reasonable
  - After a TA is provided, only a request for amended clearance is reasonable (option A)

Candidate SS Procedures (final)

Option	Description	Discussion	Reference Regulations/Guidance
A	Amended Clearance (preferred)	Time permitting, pilot is required to request an amended clearance when a Self Separation maneuver would cause a deviation	14 CFR 91.123a, AIM 4-4-1a, AIM 4-4-1b
B	ATC Notification ASAP following initiation of Self Separation Maneuver	Time constraints, workload, and/or frequency congestion preclude prior deviation notification. While not constituting an emergency, the pilot must deviate to remain well clear, and is required to request an amended clearance upon (post-maneuver) notification of deviation to ATC.	14 CFR 91.123c, AIM 4-4-1a, 4-4-10f

Independent Variables - Primary

- Pilot requires clearance (scenarios C*A)
  - If a TA is received before the “self-separation threshold” pilot follows option A: request an amended clearance
  - If a TA has not been received by the time the “self-separation threshold” is met, pilot follows option A: request an amended clearance
- Pilot does not require clearance (scenarios C*B)
  - `If a TA is received before the “self-separation threshold” pilot follows option A: request an amended clearance
  - If a TA has not been received by the time the “self-separation threshold” is met, pilot follows option B: notification after deviation initiation
- Each scenario will have pilots follow one or the other of these options.
- The “self separation threshold” will be set to one of three values: 60, 90 and 120 seconds

	60 sec. SST	90 sec. SST	120 sec. SST
Pilot requires clearance			
Pilot does not require clearance			

Scripted Encounters

- In each encounter, either procedure A or B will be followed
  - Pseudo pilots will have a complete script of the procedural actions to take and the appropriate phraseology
- If a TA is received prior to the “self-separation threshold”
  - Pilot requests an amended clearance (A)
  - This is the “typical” case, expected under normal traffic circumstances
- If a TA is not received by the threshold
  - Pilot requests a maneuver (A) or notifies controller just after execution (B)
  - This is the “atypical” case, expected when controller is too busy to provide additional services or cannot detect the intruder (e.g. primary target)
- If an amended clearance is received before the encounter the pseudo pilots follow the controller’s instructions
  - This data point is essentially lost
  - Clearance issued may be compared with scripted maneuvers and autoresolver recommendations as an additional research finding

I. Aircraft Maneuver and Action Scripts by Scenario

Scenario C-1a					
Event Time	Action Aircraft	Intruder Aircraft	Location	VFR Advisory	Action
04:30	HAWK21	PCM6328	46NM from PYE	YES	Request right 10 degree turn
				NO	Request right 10 degree turn for traffic
10:20	N439AP	N1360L	23NM from BESSA	YES	Request left 10 degree turn (wait 60s after aircraft rcv'd on MACS to request)
				NO	Request left 10 degree turn for traffic (wait 60s after aircraft rcv'd on MACS to request)
10:45	OPT468	N17621	98NM from RBL	YES	Request left 20 degree turn
				NO	Request left 20 degree turn for traffic
11:30	PCM6328		15nm from PYE		Descend to 5'500 feet
12:30	N36JJ		When acquired		Check in VFR climbing to 5'500 feet. Request IFR clearance via direct ILA direct SMF @ 7'000 feet
18:00	N818X		45NM from STS		Request VFR advisories
18:30	N439AP		48NM from UKI		Cancel IFR. Begin descent @ 500 fpm.
19:00	N36JJ	N727PA	36NM from ILA	YES	Execute right 10 degree turn, notify ATC following maneuver initiation
				NO	Execute right 10 degree turn without advising ATC
23:28	N139R		When acquired		Check in climbing VFR to 7'500 feet
24:00	HAWK21	N727PA	5NM NW POPES	YES	Request right 20 degree turn
				NO	Request right 20 degree turn for traffic
27:00	AMF230	N818X	36NM from ENI	YES	Request right 20 degree turn
				NO	Request right 20 degree turn for traffic
27:30	HAWK21	N139R	5NM E SNUPY	YES	Climb to 8000 ft, notify ATC following maneuver initiation
				NO	Climb to 8000 ft without advising ATC
28:30	N7701F		When acquired		Check in VFR climbing to 15'500 feet
30:30	N739DS		124NM from TRK		Request IFR clearance direct TRK @ 11'000 feet
32:00	N818X		25NM from APC		Descend to APC
33:30	N71HE		35NM from STS		Descend to STS @ 1'000 fpm
34:00	N7701F		40NM from MXW		Climb @ 1'000 fpm
36:00	N739DS	N71HE	2NM N MAUCH	YES	Execute right 20 degree turn, notify ATC following maneuver initiation
				NO	Execute right 20 degree turn without advising ATC
37:00	SKW5448	N7701F	10NM NE WUSHU	YES	Request right 20 degree turn
				NO	Request right 20 degree turn for traffic
40:30	N685QS	N700BS	13NM from SNUPY	YES	Request right 10 degree turn
				NO	Request right 10 degree turn for traffic
44:30	N685QS		13NM from O69		Cancel IFR. Begin descent @ 500 fpm.

HITL Encounters - Final

Scenario C-1b					
Event Time	**Action Aircraft**	**Intruder Aircraft**	**Location**	**VFR Advisory**	**Action**
04:30	HAWK21	PCM6328	46NM from PYE	YES	Execute right 10 degree turn, notify ATC following maneuver initiation
				NO	Execute right 10 degree turn without advising ATC
10:20	N439AP	N1360L	23NM from BESSA	YES	Execute left 10 degree turn, notify ATC following maneuver (wait 60s after aircraft rcv'd)
				NO	Execute left 10 degree turn without advising ATC (wait 60s after aircraft rcv'd)
10:45	OPT468	N17621	98NM from RBL	YES	Execute left 20 degree turn, notify ATC following maneuver initiation
				NO	Execute left 20 degree turn without advising ATC
11:30	PCM6328		15nm from PYE		Descend to 5'500 feet
12:30	N36JJ		When acquired		Check in VFR climbing to 5'500 feet. Request IFR clearance via direct ILA direct SMF @ 7'000 feet
18:00	N818X		45NM from STS		Request VFR advisories
18:30	N439AP		48NM from UKI		Cancel IFR. Begin descent @ 500 fpm.
19:00	N36JJ	N727PA	36NM from ILA	YES	Request right 10 degree turn
				NO	Request right 10 degree turn for traffic
23:28	N139R		When acquired		Check in climbing VFR to 7'500 feet
24:00	HAWK21	N727PA	5NM NW POPES	YES	Execute right 20 degree turn, notify ATC following maneuver initiation
				NO	Execute right 20 degree turn without advising ATC
27:00	AMF230	N818X	36NM from ENI	YES	Execute right 20 degree turn, notify ATC following maneuver initiation
				NO	Execute right 20 degree turn without advising ATC
27:30	HAWK21	N139R	5NM E SNUPY	YES	Request climb to 8000 ft
				NO	Request climb to 8000 ft for traffic
28:30	N7701F		When acquired		Check in VFR climbing to 15'500 feet
30:30	N739DS		124NM from TRK		Request IFR clearance direct TRK @ 11'000 feet
32:00	N818X		25NM from APC		Descend to APC
33:30	N71HE		35NM from STS		Descend to STS @ 1'000 fpm
34:00	N7701F		40NM from MXW		Climb @ 1'000 fpm
36:00	N739DS	N71HE	2NM N MAUCH	YES	Request right 20 degree turn
				NO	Request right 20 degree turn for traffic
37:00	SKW5448	N7701F	10NM NE WUSHU	YES	Execute right 20 degree turn, notify ATC following maneuver initiation
				NO	Execute right 20 degree turn without advising ATC
40:30	N685QS	N700BS	13NM from SNUPY	YES	Execute right 10 degree turn, notify ATC following maneuver initiation
				NO	Execute right 10 degree turn without advising ATC
44:30	N685QS		13NM from O69		Cancel IFR. Begin descent @ 500 fpm.

Scenario C-2a					
Event Time	Action Aircraft	Intruder Aircraft	Location	VFR Advisory	Action
05:00	HAWK21	N784PA	4NM W LAPED	YES	Request right 20 degree turn
				NO	Request right 20 degree turn for traffic
07:00	N226ER		@ check in		Request VFR advisories
12:15	N784PA		55NM from SMF		Descend to 1'000 feet @ 500 fpm
13:00	QXE784	N226ER	@ MAUCH	YES	Execute left 15 degree turn, notify ATC following maneuver initiation
				NO	Execute left 15 degree turn without advising ATC
15:00	CPZ813	N4319M	10NM SE LAPED	YES	Request right 10 degree turn
				NO	Request right 10 degree turn for traffic
15:00	N628RE		When acquired		Check in VFR, climbing to 12'500 feet
18:00	N226ER		@WUSHU		Request IFR Clearance direct UKI @ 7'000 feet.
18:15	HAWK21	N6321M	2NM N WUSHU	YES	Request right 10 degree turn
				NO	Request right 10 degree turn for traffic
20:30	N226ER	N4319M	10NM N KLOGE	YES	Reduce ROC to 250 fpm, notify ATC following maneuver initiation
				NO	Reduce ROC to 250 fpm without advising ATC
21:00	N372LE		When acquired		Check in VFR, climbing to 12'500 feet
22:15	N628RE		85NM from RBL		Request IFR clearance to RDD via direct RBL @12'000 feet.
23:15	N372LE		222NM FROM MFR		Request IFR clearance direct MFR @ 12'000 feet
24:15	N1402S		50NM from UKI		Request VFR advisories
25:00	N807BD	N3AF	@ MAUCH	YES	Execute left 10 degree turn, notify ATC following maneuver initiation
				NO	Execute left 10 degree turn without advising ATC
25:30	N47878		48NM from SMF		Descend to 1'000 feet @ 1'000 fpm
26:30	N226ER		20NM from UKI		Cancel IFR. Begin descent.
28:00	OPT1837	N1402S	8NM NE LAPED	YES	Request to climb 500 feet
				NO	Request to climb 500 feet for traffic
29:15	N429EG		38NM from STS		Descend to 100 feet @ 1'000 fpm
30:00	N628RE	N429EG	5NM E LAPED	YES	Request right 10 degree turn
				NO	Request right 10 degree turn for traffic
30:15	N1402S		25NM from UKI		Descend to 600 feet @2'000 fpm
31:15	N372LE	N1402S	10NM NW LAPED	YES	Request 20 degree right turn
				NO	Request 20 degree right turn for traffic
34:00	AMF556	N229TS	10NM N STS	YES	Request right 10 degree turn
				NO	Request right 10 degree turn for traffic

Scenario C-2b					
Event Time	**Action Aircraft**	**Intruder Aircraft**	**Location**	**VFR Advisory**	**Action**
05:00	HAWK21	N784PA	4NM W LAPED	YES	Execute right 20 degree turn, notify ATC following maneuver initiation
				NO	Execute right 20 degree turn without advising ATC
07:00	N226ER		@ check in		Request VFR advisories
12:15	N784PA		55NM from SMF		Descend to 1'000 feet @ 500 fpm
13:00	QXE784	N226ER	@ MAUCH	YES	Request 15 degree left turn
				NO	Request 15 degree left turn for traffic
15:00	CPZ813	N4319M	10NM SE LAPED	YES	Execute a 10 degree right turn, notify ATC following maneuver initiation
				NO	Execute a 10 degree right turn without advising ATC
15:00	N628RE		When acquired		Check in VFR, climbing to 12'500 feet
18:00	N226ER		@WUSHU		Request IFR Clearance direct UKI @ 7'000 feet.
18:15	HAWK21	N6321M	2NM N WUSHU	YES	Execute a 10 degree right turn, notify ATC following maneuver initiation
				NO	Execute a 10 degree right turn without advising ATC
20:30	N226ER	N4319M	10NM N KLOGE	YES	Request slowed ROC, then reduce ROC to 250 fpm (controller doesn't need ROC)
				NO	Request slowed ROC for traffic, then reduce ROC to 250 fpm
21:00	N372LE		When acquired		Check in VFR, climbing to 12'500 feet
22:15	N628RE		85NM from RBL		Request IFR clearance to RDD via direct RBL @12'000 feet.
23:15	N372LE		222NM FROM MFR		Request IFR clearance direct MFR @ 12'000 feet
24:15	N1402S		50NM from UKI		Request VFR advisories
25:00	N807BD	N3AF	@ MAUCH	YES	Request left 10 degree turn
				NO	Request left 10 degree turn for traffic
25:30	N47878		48NM from SMF		Descend to 1'000 feet @ 1'000 fpm
26:30	N226ER		20NM from UKI		Cancel IFR. Begin descent.
28:00	OPT1837	N1402S	8NM NE LAPED	YES	Execute a climb of 500 feet, notify ATC following maneuver initiation
				NO	Execute a climb of 500 feet without advising ATC
29:15	N429EG		38NM from STS		Descend to 100 feet @ 1'000 fpm
30:00	N628RE	N429EG	5NM E LAPED	YES	Execute right 10 degree, notify ATC following maneuver initiation
				NO	Execute right 10 degree turn without advising ATC
30:15	N1402S		25NM from UKI		Descend to 600 feet @2'000 fpm
31:15	N372LE	N1402S	10NM NW LAPED	YES	Execute right 20 degree, notify ATC following maneuver initiation
				NO	Execute right 20 degree turn without advising ATC
34:00	AMF556	N229TS	10NM N STS	YES	Execute right 10 degree turn, notify ATC following maneuver initiation
				NO	Execute right 10 degree turn without advising ATC

Scenario C-3a					
Event Time	**Action Aircraft**	**Intruder Aircraft**	**Location**	**VFR Advisory**	**Action**
05:30	HAWK21	N2914Q	@ MOLEN	YES	Request 20 degree left turn
				NO	Request 20 degree left turn for traffic
06:15	N1227D		46NM from BOARS		Descend to 9'500 feet @1'000 fpm
09:00	APC1961	N274DC	3NM S RUMSY	YES	Request 10 degree right turn
				NO	Request 10 degree right turn for traffic
15:30	CHP18	N739DS	8NM W FROSH	YES	Execute 10 degree left turn, notify ATC following maneuver initiation
				NO	Execute 10 degree left turn without advising ATC
17:45	N777DF		32NM from UKI		Descend to 600' @ 1'000 fpm
19:00	N24665		When acquired		Check in VFR, climbing to 7'500 feet
21:00	N24665		2NM from KLOGE		Request IFR clearance direct TVL @ 7'000 feet
23:30	N3174T		20NM from FROSH		Request direct CEC and climb to 12'000 feet. *(GHOST-NOTE POSITION OF N90SE)*
24:00	N24665	N263RB	@ MAUCH	YES	Request left 15 degree turn
				NO	Request left 15 degree turn for traffic
24:30	N736QS	N401DL	6NM N KLOGE	YES	Execute 15 degree right turn, notify ATC following maneuver initiation
				NO	Execute 15 degree right turn without advising ATC
25:17	N747CA		When acquired		Check in VFR, climbing to 7'500 feet
25:30	N90SE		360NM from SMO		Climb to 15'500 feet
26:30	N3174T	N90SE	6NM E FROSH	YES	Request slowed ROC, then reduce ROC to 250 fpm (controller doesn't need ROC)
				NO	Request slowed ROC for traffic, then reduce ROC to 250 fpm
29:00	KIKIT13		@ AMAKR		Request IFR @ 15'000 feet
32:30	N248DA	N747CA	5NM SE MAUCH	YES	Execute 20 degree left turn, notify ATC following maneuver initiation
				NO	Execute 20 degree left turn without advising ATC
34:25	N89VC		4NM from AMAKR		Descend to 13'500 feet @ 1000 fpm
36:30	N87464		123NM from TRK		Request VFR advisories
37:00	HAWK21	N89VC	10NM SE AMAKR	YES	Request 10 degree right turn
				NO	Request 10 degree right turn for traffic
38:00	N85TB	N87464	5NM SW MAUCH	YES	Request 15 degree right turn
				NO	Request 15 degree right turn for traffic
40:00	REAPR44	N89VC	15NM NW MAUCH	YES	Request 30 degree left turn
				NO	Request 30 degree left turn for traffic

Scenario C-3b					
Event Time	**Action Aircraft**	**Intruder Aircraft**	**Location**	**VFR Advisory**	**Action**
05:30	HAWK21	N2914Q	@ MOLEN	YES	Execute 20 degree left turn, notify ATC following maneuver initiation
				NO	Execute 20 degree left turn without advising ATC
06:15	N1227D		46NM from BOARS		Descend to 9'500 feet @1'000 fpm
09:00	APC1961	N274DC	3NM S RUMSY	YES	Execute 10 degree right turn, notify ATC following maneuver initiation
				NO	Execute 10 degree right turn without advising ATC
15:30	CHP18	N739DS	8NM W FROSH	YES	Request 10 degree left turn
				NO	Request 10 degree left turn for traffic
17:45	N777DF		32NM from UKI		Descend to 600' @ 1'000 fpm
19:00	N24665		When acquired		Check in VFR, climbing to 7'500 feet
21:00	N24665		2NM from KLOGE		Request IFR clearance direct TVL @ 7'000 feet
23:30	N3174T		20NM from FROSH		Request direct CEC and climb to 12'000 feet. *(GHOST-NOTE POSITION OF N90SE)*
24:00	N24665	N263RB	@ MAUCH	YES	Execute left 15 degree turn, notify ATC following maneuver initiation
				NO	Execute left 15 degree turn without advising ATC
24:30	N736QS	N401DL	6NM N KLOGE	YES	Request 15 degree right turn
				NO	Request 15 degree right turn for traffic
25:17	N747CA		When acquired		Check in VFR, climbing to 7'500 feet
25:30	N90SE		360NM from SMO		Climb to 15'500 feet
26:30	N3174T	N90SE	6NM E FROSH	YES	Reduce ROC to 250 fpm, notify ATC following maneuver initiation
				NO	Reduce ROC to 250 fpm without advising ATC
29:00	KIKIT13		@ AMAKR		Request IFR @ 15'000 feet
32:30	N248DA	N747CA	5NM SE MAUCH	YES	Request 20 degree left turn
				NO	Request 20 degree left turn for traffic
34:25	N89VC		4NM from AMAKR		Descend to 13'500 feet @ 1000 fpm
36:30	N87464		123NM from TRK		Request VFR advisories
37:00	HAWK21	N89VC	10NM SE AMAKR	YES	Execute 10 degree right turn, notify ATC following maneuver initiation
				NO	Execute 10 degree right turn without advising ATC
38:00	N85TB	N87464	5NM SW MAUCH	YES	Execute 15 degree right turn, notify ATC following maneuver initiation
				NO	Execute 15 degree right turn without advising ATC
40:00	REAPR44	N89VC	15NM NW MAUCH	YES	Execute 30 degree left turn, notify ATC following maneuver initiation
				NO	Execute 30 degree left turn without advising ATC

Scenario C-4a					
Event Time	Action Aircraft	Intruder Aircraft	Location	VFR Advisory	Action
03:00	CPZ833	N2914Q	8 NM W DALON	YES	Request 20 degree right turn
				NO	Request 20 degree right turn for traffic
06:00	N485ED		When acquired		Check in climbing to 8'000 feet
06:30	PCM7703	CGTKG	7NM N SGD	YES	Request 20 degree right turn
				NO	Request 20 degree right turn for traffic
08:30	CGTKG		13NM from O69		Descend to 100 feet
10:30	N828LP		13NM from RUMSY		Climb to 8'500 feet @ 250 fpm. Proceed direct RBL.
11:00	PCM7703		@ POPES		Request climb to 10'000 feet @ 250 fpm. (GHOST- Adjust ROC to merge with N248PH)
11:30	CGTKG		2.5NM from O69		Drop track
12:00	HAWK21		15NM from STIKM		CONTROLLER - Clear to hold @ STIKM/LT/10NM legs. X STIKM @ 5'000 feet
15:00	PCM7703	N248PH	2NM W RUMSY	YES	Reduce ROC to 250 fpm, notify ATC following maneuver initiation
				NO	Reduce ROC to 250 fpm without advising ATC
15:15	N323PA		When acquired		Check in VFR climbing to 7'500 feet
16:45	HAWK21	OPT402	2NM NE STIKM	YES	Request 10 degree right turn
				NO	Request 10 degree right turn for traffic
17:30	N485ED	N828LP	6NM SW DALON	YES	Request 30 degree right turn
				NO	Request 30 degree right turn for traffic
20:15	OPT402		157NM from ACV		Request IFR clearance direct ACV at 14'000 feet.
21:00	QXE2635	N323PA	2NM W MAUCH	YES	Execute 10 degree left turn, notify ATC following maneuver initiation
				NO	Execute 10 degree left turn without advising ATC
21:30	HAWK21	N3174T	4NM NE KLOGE	YES	Request 30 degree right turn
				NO	Request 30 degree right turn for traffic
25:45	N991KE	N14RJ	4NM N POPES	YES	Request 20 degree right turn
				NO	Request 20 degree right turn for traffic
27:15	N14RJ		112NM from TVL		Climb to 9'500 feet
27:15	N21679		When acquired		Check in VFR climbing to 7'500 feet
27:30	N21679		132NM from RDD		Request VFR advisories
30:50	N888LT		15NM from STS		Descend to 5'500 feet @ 500 fpm
32:00	N214Y	N888LT	4NM SW STS	YES	Request 10 degree right turn
				NO	Request 10 degree right turn for traffic
39:30	HAWK21	N200SN	10NM W SGS	YES	Execute 20 degree right turn, notify ATC following maneuver initiation
				NO	Execute 20 degree right turn without advising ATC

Scenario C-4b					
Event Time	Action Aircraft	Intruder Aircraft	Location	VFR Advisory	Action
03:00	CPZ833	N2914Q	8 NM W DALON	YES	Execute 20 degree right turn, notify ATC following maneuver initiation
				NO	Execute 20 degree right turn without advising ATC
06:00	N485ED		When acquired		Check in climbing to 8'000 feet
06:30	PCM7703	CGTKG	7NM N SGD	YES	Execute 20 degree right turn, notify ATC following maneuver initiation
				NO	Execute 20 degree right turn without advising ATC
08:30	CGTKG		13NM from O69		Descend to 100 feet
10:30	N828LP		13NM from RUMSY		Climb to 8'500 feet @ 250 fpm. Proceed direct RBL.
11:00	PCM7703		@ POPES		Request climb to 10'000 feet @ 250 fpm. (GHOST- Adjust ROC to merge with N248PH)
11:30	CGTKG		2.5NM from O69		Drop track
12:00	HAWK21		15NM from STIKM		CONTROLLER - Clear to hold @ STIKM/LT/10NM legs. X STIKM @ 5'000 feet
15:00	PCM7703	N248PH	2NM W RUMSY	YES	Request slowed ROC, then reduce ROC to 250 fpm (controller doesn't need ROC)
				NO	Request slowed ROC for traffic, then reduce ROC to 250 fpm
15:15	N323PA		When acquired		Check in VFR climbing to 7'500 feet
16:45	HAWK21	OPT402	2NM NE STIKM	YES	Execute 10 degree right turn, notify ATC following maneuver initiation
				NO	Execute 10 degree right turn without advising ATC
17:30	N485ED	N828LP	6NM SW DALON	YES	Execute 30 degree right turn, notify ATC following maneuver initiation
				NO	Execute 30 degree right turn without advising ATC
20:15	OPT402		157NM from ACV		Request IFR clearance direct ACV at 14'000 feet.
21:00	QXE2635	N323PA	2NM W MAUCH	YES	Request 10 degree left turn
				NO	Request 10 degree left turn for traffic
21:30	HAWK21	N3174T	4NM NE KLOGE	YES	Execute 30 degree right turn, notify ATC following maneuver initiation
				NO	Execute 30 degree right turn without advising ATC
25:45	N991KE	N14RJ	4NM N POPES	YES	Execute 20 degree right turn, notify ATC following maneuver initiation
				NO	Execute 20 degree right turn without advising ATC
27:15	N14RJ		112NM from TVL		Climb to 9'500 feet
27:15	N21679		When acquired		Check in VFR climbing to 7'500 feet
27:30	N21679		132NM from RDD		Request VFR advisories
30:50	N888LT		15NM from STS		Descend to 5'500 feet @ 500 fpm
32:00	N214Y	N888LT	4NM SW STS	YES	Execute 10 degree right turn, notify ATC following maneuver initiation
				NO	Execute 10 degree right turn without advising ATC
39:30	HAWK21	N200SN	10NM W SGS	YES	Request 20 degree right turn
				NO	Request 20 degree right turn for traffic

J. Pilot Observation Sheets for each Scenario

MACS Pilot & Observer Scenario: C1 A / B Date:

Event Time	Action Aircraft	Intruder Aircraft	Location	VFR Advisory	Time Executed	Maneuver Executed	Reason
04:30.0	HAWK21	PCM6328	46NM from PYE	YES / NO			
10:20.0	N439AP	N1360L	23NM from BESSA	YES / NO			
10:45.0	OPT468	N17621	98NM from RBL	YES / NO			
19:00.0	N36JJ	N727PA	36NM from ILA	YES / NO			
24:00.0	HAWK21	N727PA	5NM NW POPES	YES / NO			
27:00.0	AMF230	N818X	36NM from ENI	YES / NO			
27:30.0	HAWK21	N139R	5NM E SNUPY	YES / NO			
36:00.0	N739DS	N71HE	2NM N MAUCH	YES / NO			
37:00.0	SKW5448	N7701F	10NM NE WUSHU	YES / NO			
40:30.0	N685QS	N700BS	13NM from SNUPY	YES / NO			

MACS Pilot & Observer Scenario: C2 A / B Date:

Event Time	Action Aircraft	Intruder Aircraft	Location	VFR Advisory	Time Executed	Maneuver Executed	Reason
05:00.0	HAWK21	N784PA	4NM W LAPED	YES / NO			
13:00.0	QXE784	N226ER	@ MAUCH	YES / NO			
15:00.0	CPZ813	N4319M	10NM SE LAPED	YES / NO			
18:15.0	HAWK21	N6321M	2NM N WUSHU	YES / NO			
20:30.0	N226ER	N4319M	10NM N KLOGE	YES / NO			
25:00.0	N807BD	N3AF	@ MAUCH	YES / NO			
28:00.0	OPT1837	N1402S	8NM NE LAPED	YES / NO			
30:00.0	N628RE	N429EG	5NM E LAPED	YES / NO			
31:15.0	N372LE	N1402S	10NM NW LAPED	YES / NO			
34:00.0	AMF556	N229TS	10NM N STS	YES / NO			

MACS Pilot & Observer   Scenario: C3 A / B   Date:

Event Time	Action Aircraft	Intruder Aircraft	Location	VFR Advisory	Time Executed	Maneuver Executed	Reason
05:30.0	HAWK21	N2914Q	@ MOLEN	YES / NO			
09:00.0	APC1961	N274DC	3NM S RUMSY	YES / NO			
15:30.0	CHP18	N739DS	8NM W FROSH	YES / NO			
24:00.0	N24665	N263RB	@ MAUCH	YES / NO			
24:30.0	N736QS	N401DL	6NM N KLOGE	YES / NO			
26:30.0	N3174T	N90SE	6NM E FROSH	YES / NO			
32:30.0	N248DA	N747CA	5NM SE MAUCH	YES / NO			
37:00.0	HAWK21	N89VC	10NM SE AMAKR	YES / NO			
38:00.0	N85TB	N87464	5NM SW MAUCH	YES / NO			
40:00.0	REAPR44	N89VC	15NM NW MAUCH	YES / NO			

MACS Pilot & Observer   Scenario: C4 A / B   Date:

Event Time	Action Aircraft	Intruder Aircraft	Location	VFR Advisory	Time Executed	Maneuver Executed	Reason
03:00.0	CPZ833	N2914Q	8 NM W DALON	YES / NO			
06:30.0	PCM7703	CGTKG	7NM N SGD	YES / NO			
15:00.0	PCM7703	N248PH	2NM W RUMSY	YES / NO			
16:45.0	HAWK21	OPT402	2NM NE STIKM	YES / NO			
17:30.0	N485ED	N828LP	6NM SW DALON	YES / NO			
21:00.0	QXE2635	N323PA	2NM W MAUCH	YES / NO			
21:30.0	HAWK21	N3174T	4NM NE KLOGE	YES / NO			
25:45.0	N991KE	N14RJ	4NM N POPES	YES / NO			
32:00.0	N214Y	N888LT	4NM SW STS	YES / NO			
39:30.0	HAWK21	N200SN	10NM W SGS	YES / NO			

K. Pseudo-Pilot Instructions

Pseudo-Pilot (PP) and PP Observer Instructions

Who the instruction applies to:

PP = The two pseudo pilots
PPO = the pseudo-pilot observer
All = Both the PPs and PPO

High Priority for Final Training and Data Collection

1. (All) Note any maneuvers that you do not believe will resolve the conflict, and what maneuver would solve the conflict. Also note the scenario time.
2. (PPO) Write down the time at which each maneuver is executed, and what the maneuver was. Also circle the YES/NO to indicate whether a VFR advisory was received. If the maneuver was not executed write [NONE] and make a note of why (ATC already cleared conflict [ATC], noticed the scripted conflict too late [LATE], aircraft were just not in conflict [NC], etc.). If ATC changed the maneuver you were intending to execute, write down that new maneuver and [CHANGE]:
   Maneuver Time:___________ Maneuver Executed:________________ Reason:____________

Additional Instructions/Reminders

1. If a TA is received for a conflict not in the script, do the following:
   a. Acknowledge traffic in sight (manned) or detected (UAS)
   b. Follow directions from the controller, if any. If no instructions, do not request vectors around traffic, just let the encounter proceed.
2. If a scripted resolution is a rate of climb/descent, do not specifically request that rate. Only request a change (greater or less) than the current rate.
3. When to resume flight plan navigation after a resolution or deviation:
   a. If the controller was originally involved in negotiating or approving the resolution, or if they contacted you after you maneuvered, then request the return-to-flight-plan maneuver.
   b. If you have never talked to the controller about this deviation, the simply return to the flight plan.
4. If ATC intervenes to resolve a scripted conflict, or performs any other action that has the effect of resolving the scripted conflict, then skip that conflict. Make a note on the script that ATC was the reason no maneuver was executed.
5. Use vector lines (2 min) to decide when to initiate a maneuver or request, not the script time. This time occurs when the tips of the vectors (or any other part of them) overlap, the vector does not need to lie on the target itself. Every attempt will be made to make this condition consistent with the scripted time, but because of unforeseen controller actions early in the simulation the two will never be perfectly consistent.
6. If you have maneuvered without notification and the controller later contacts you, inform them that you already took XXX action to resolve the conflict (essentially the same as the post-notification procedure condition).
7. When you receive a TA and the procedure is to execute the maneuver and then inform the controller, you should first enter and execute the maneuver. Then immediately inform them that you have already taken XXX action.

L. Subjective Responses to Post-Run and Post-Simulation Questionnaires

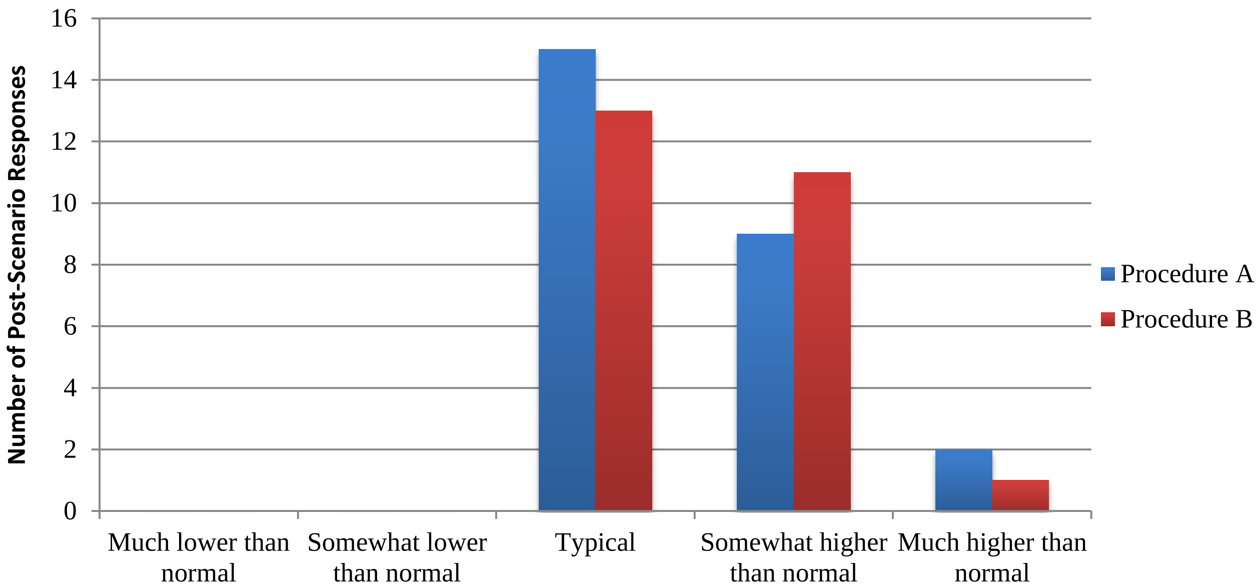


Figure L1. Responses by procedure to post-scenario question "As compared with normal real-world operations, how would you rate your workload during this scenario?" (Appendix B question 5).

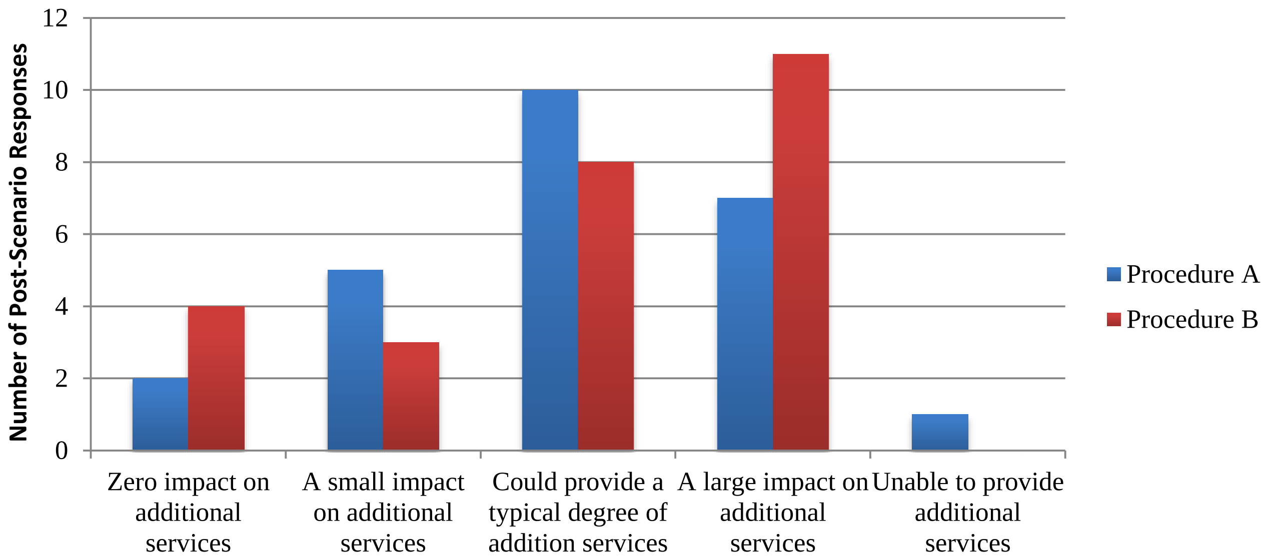


Figure L2. Responses by procedure to post-scenario question "Did the workload and complexity of the scenario impact your ability to provide additional services (direct routings, traffic advisories, etc.)?" (Appendix B question 6).

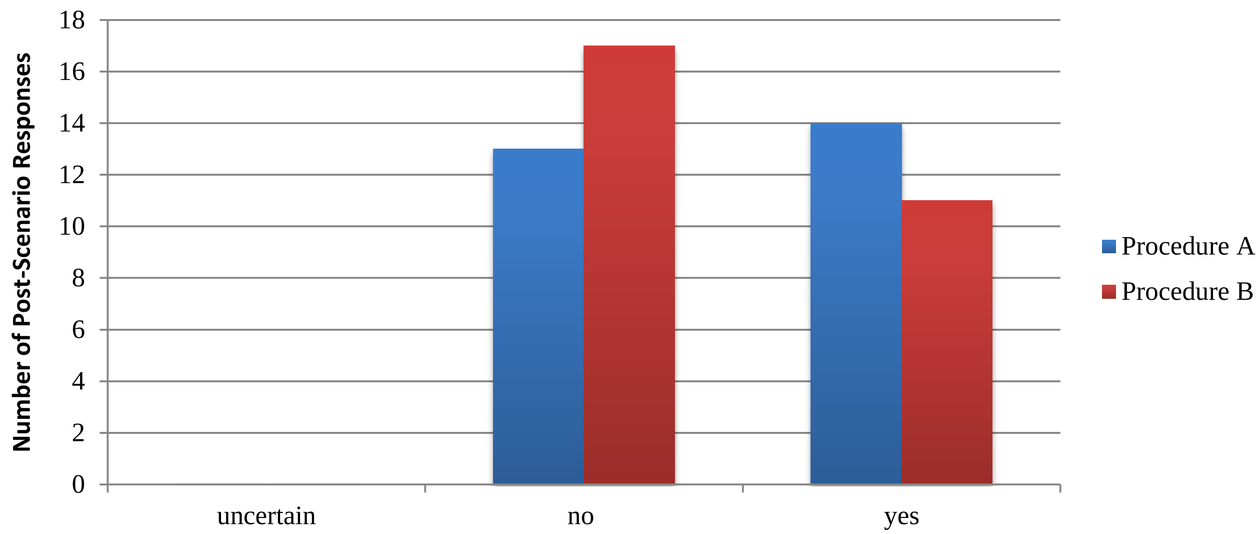


Figure L3. Response by procedure to post-scenario questionnaire "Did you notice any ghost controller, pilot, or software behavior in the simulation that did not conform to your expectations or that was unlike behavior in the real world?" (Appendix B question 7).

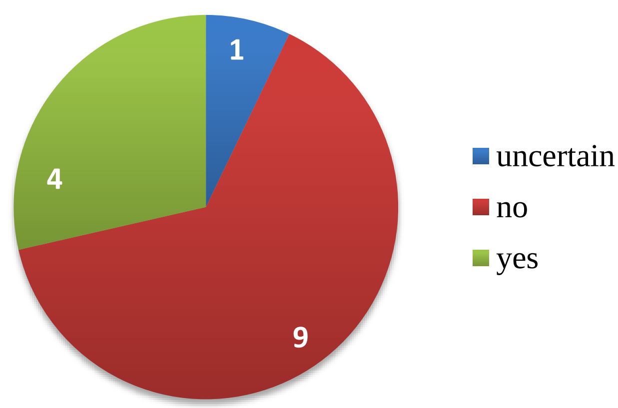


Figure L4. Response to post-simulation question "Did any deviations (without an amended clearance) create an adverse situation, for example a conflict with a third aircraft?" (Appendix C question 6). Percentage that responded "yes" was 29%.

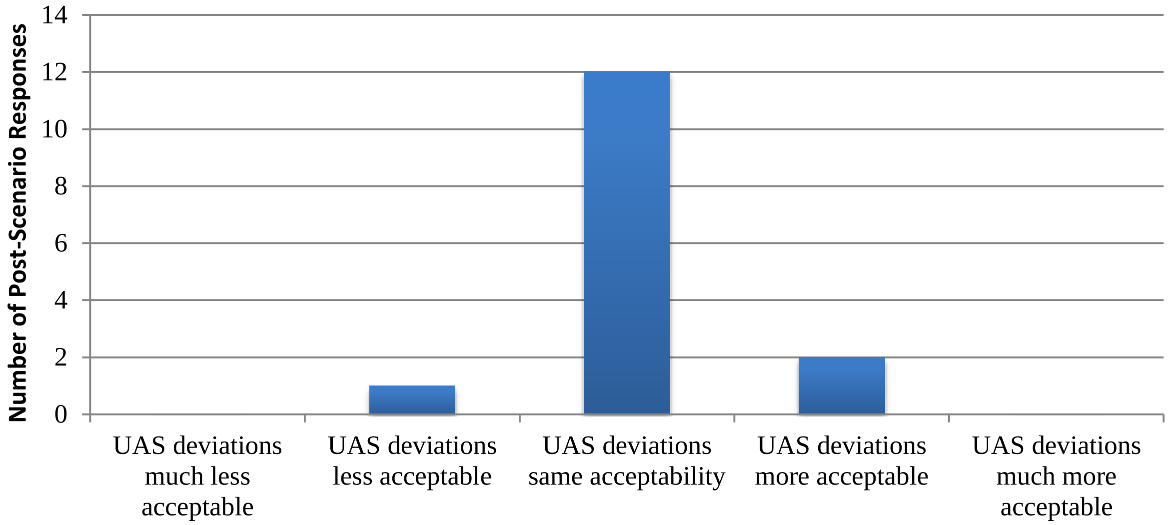


Figure L5. Response to post-simulation question "Were deviations requested or made by unmanned aircraft more or less acceptable to you than those made by pilots of manned aircraft?" (Appendix C, question 9).

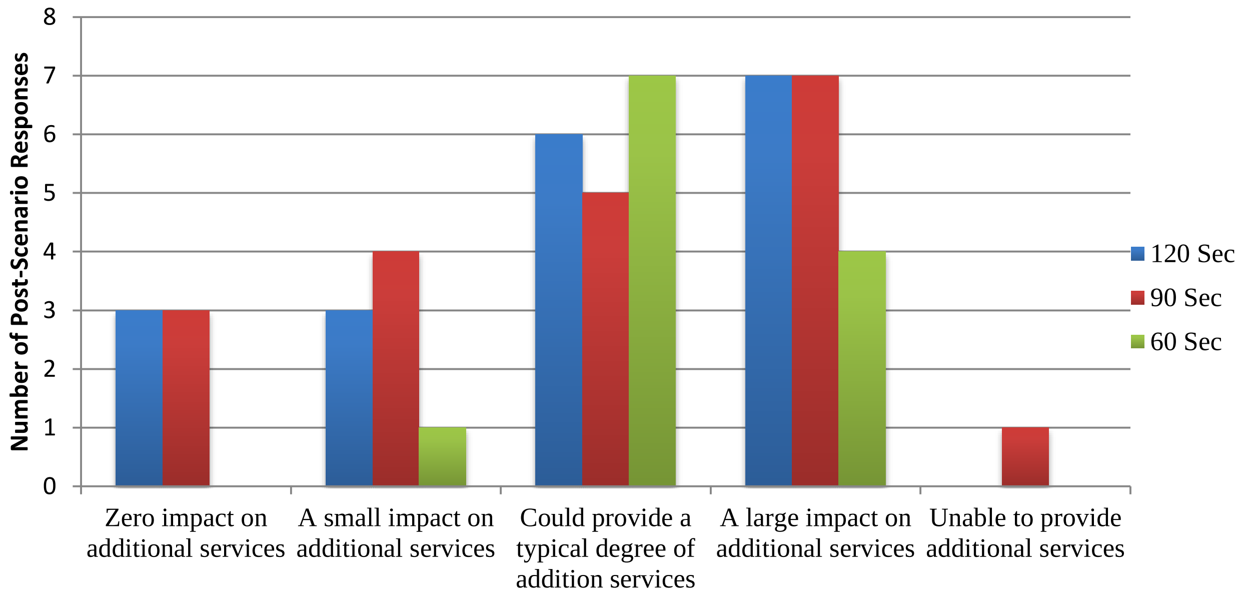


Figure L6. Responses by alert threshold to post-scenario question "As compared with normal real-world operations, how would you rate your workload during this scenario?" Mean of 120-second alert threshold condition was 3.53, of 90-sec condition was 3.55 and of 60-sec condition was 3.42 (Appendix B question 5).

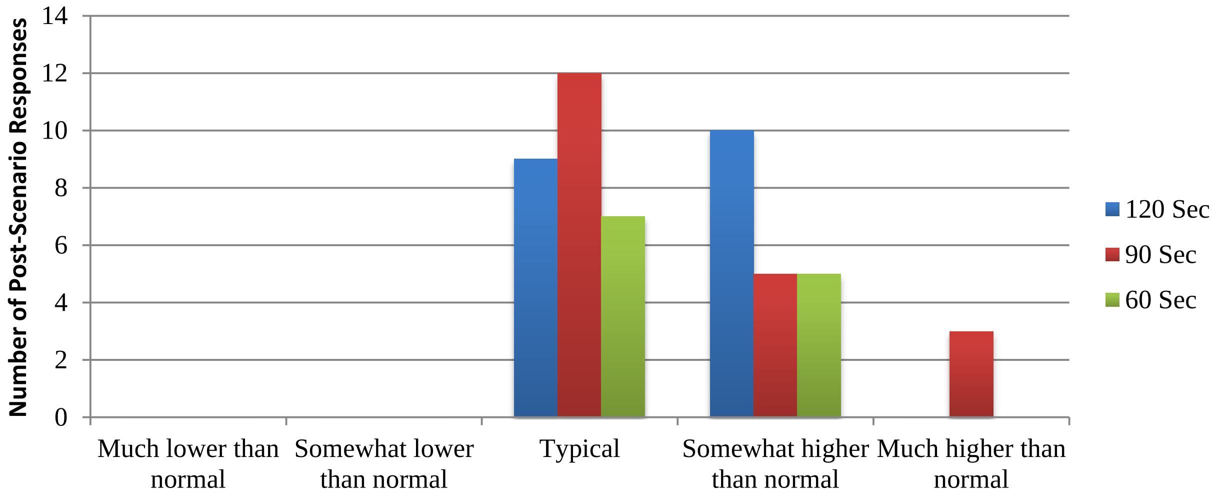


Figure L7. Response by alert threshold to post-scenario question "Did the workload and complexity of the scenario impact your ability to provide additional services (direct routings, traffic advisories, etc.)?" Mean of 120-second alert threshold condition was 2.89, 90-sec condition was 2.93 and 60-sec condition is 3.25. (Appendix B question 6).

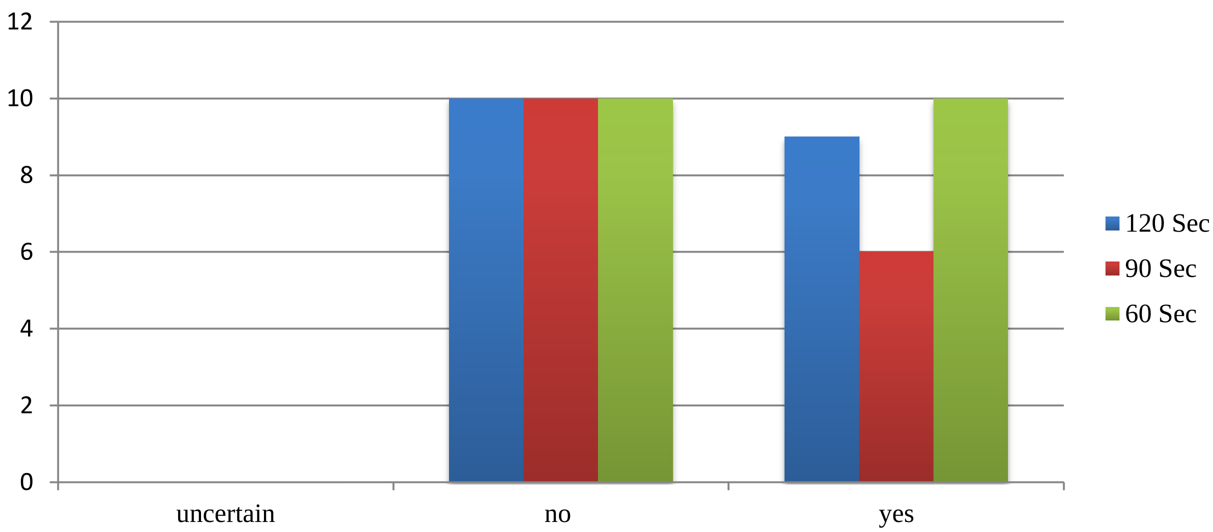


Figure L8. Responses by alert threshold to post-scenario question "Did you notice any ghost controller, pilot, or software behavior in the simulation that did not conform to your expectations or that was unlike behavior in the real world?" Percentage of yes responses was 47% in the 120-sec condition, 38% in the 90-sec condition and 50% in the 60-sec condition. Not statistically significant as evaluated with the Kruskal-Wallis test (p=0.744) (Appendix B question 7).