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UAS in the NAS Air Traffic Controller Acceptability Study-1: The Effects of Horizontal Miss Distances on Simulated UAS and Manned Aircraft Encounters

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UAS IN THE NAS AIR TRAFFIC CONTROLLER ACCEPTABILITY STUDY-1: THE EFFECTS OF HORIZONTAL MISS DISTANCES ON SIMULATED UAS AND MANNED AIRCRAFT ENCOUNTERS

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This study examined air traffic controller acceptability ratings based on the effects of differing horizontal miss distances (HMDs) for encounters between UAS and manned aircraft. In a simulation of the Dallas/Fort Worth (DFW) East-side airspace, the CAS-1 experiment at NASA Langley Research Center enlisted fourteen recently retired DFW air traffic controllers to rate well-clear volumes based on differing HMDs that ranged from 0.5 NM to 3.0 NM. The controllers were tasked with rating these HMDs from “too small” to “too excessive” on a defined, 1-5, scale and whether these distances caused any disruptions to the controller and/or to the surrounding traffic flow. Results of the study indicated a clear favoring towards a particular HMD range. Controller workload was also measured. Data from this experiment and subsequent experiments will play a crucial role in the FAA’s establishment of rules, regulations, and procedures to safely and efficiently integrate UAS into the NAS.

Unmanned Aircraft Systems (UAS) are no longer technological systems of the unforeseeable distant future, but rather of the present and near future. They are systems that are evolving quickly and will soon become commonplace in the National Airspace System (NAS). According to the Federal Aviation Administration (FAA) Modernization and Reform Act of 2012 (2012), the United States Congress mandated the FAA to open the NAS to civil UAS “as soon as practicable, but not later than September 30, 2015.” However, opening the NAS to civil UAS is a challenging task, a task that encompasses multiple safety issues of which include detect and avoid (DAA) implementations, self-separation (SS) procedures, and collision avoidance (CA) technologies to remain well-clear of other aircraft. Routine access to the NAS will require UAS to have new equipage, standards, rules and regulations, and procedures, among others, in addition to a slew of supporting research efforts. As a result, the National Aeronautics and Space Administration (NASA) has established a multi-center “UAS in the NAS” project, in collaboration with the FAA and industry, to examine essential safety concerns regarding the integration of UAS in the NAS. Among NASA’s guiding research efforts is NASA Langley Research Center’s (LaRC) air traffic Controller Acceptability Study (CAS) human-in-the-loop (HITL) experiment series. The first CAS experiment (CAS-1) researched a subset of safety features to examine well-clear volumes by simulating differing horizontal miss distances (HMDs) at the Dallas/Fort Worth (DFW) East-side airspace.

The concepts of remaining well-clear and DAA come from current standards under which pilots currently operate within the NAS. According to Title 14, Part 91, Section 91.111 (a), of the Code of Federal Regulations (14CFR 91.111 (a)), “no person may operate an aircraft so close to another aircraft as to create a collision hazard,” and 14CFR 91.113 (b), under right-of-way rules, states “*General*. When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.” In essence, these standards, among others, require pilots to follow right-of-way rules and remain well-clear, by seeing and avoiding, other aircraft. In an Air Traffic Services (ATS) environment, pilots are expected to comply with those requirements while also complying with Air Traffic Control (ATC) instructions and clearances, or to negotiate changes, as necessary, to those instructions and clearances. Pilots capable of seeing and avoiding other aircraft are mostly expected to maneuver and communicate in predictable ways; ways that preserve the safety, orderliness, and efficiency of the ATS environment. Inherently, UAS pilots will be expected to operate in a similar manner. As such, in October of 2009, the term sense and avoid (SAA), used interchangeably with DAA and comparable to manned aircraft see-and-avoid requirements, was defined as “the combination of UAS Self-Separation (SS) plus Collision Avoidance (CA) as a means of compliance with 14CFR Part 91, §91.111 and §91.113” and published by the FAA-sponsored SAA for UAS Workshop Final Report. The SAA for UAS Workshop Final

Report goes on to define SS and CA as a means to remain well-clear and as a means to avoid Near Mid-Air Collisions (NMACs), respectively. Under Section 6, 7-6-3 (b), of the Aeronautical Information Manual (AIM), the FAA defines NMACs as “an incident associated with the operation of an aircraft in which a possibility of collision occurs as a result of proximity of less than 500 feet to another aircraft...” Figure 1 shows the different volumes and boundaries associated with remaining well-clear. In order to remain well-clear, the Self-Separation Volume (SSV) size should be large enough to avoid corrective Resolution Advisories (RAs) for Traffic Collision Avoidance System (TCAS)-equipped intruders; safety concerns for controllers; and, undue concern for proximate see-and-avoid pilots. Determination of minimum and maximum operationally acceptable SSV sizes will inform the design space for required DAA surveillance accuracy. Current standard NAS operations are the building blocks for which future UAS NAS operations will advance.

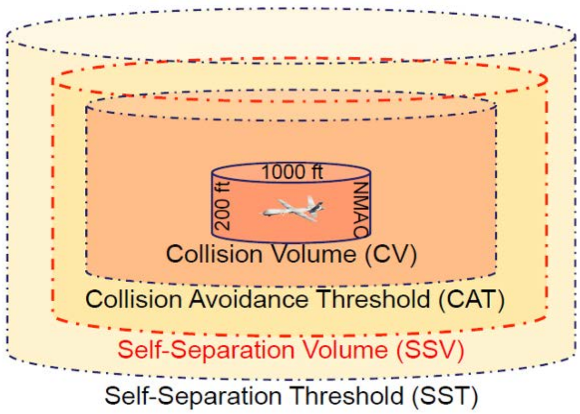

Figure 1. NASA’s Separation Assurance/Sense-and-Avoid Interoperability (SSI) SSV represents a concept volume of remaining well-clear. *Note*. CAT, SSV and SST boundaries are notional and generally not cylindrical.

Controller Acceptability Study-1 Objectives

The primary focus of the CAS-1 experiment was on determining the effects of self-separation maneuvering tasks, as performed by pilots in a Ground Control Station (GCS) using simulated DAA-equipped UAS, on ATC workload and how the resulting maneuvers impacted ATC acceptability of the differing spacing parameters, also known as HMDs, which were implemented in the DAA algorithms.

The aim of CAS-1 was to address, through data collection and analysis, the following research questions: A) Are DAA SS maneuvers too small/too late, resulting in issuance of traffic safety alerts or air traffic controller perceptions of unsafe conditions?; B) Are DAA SS maneuvers too large (excessive “well clear” distances), resulting in behavior the air traffic controller would not expect and/or disruptions to traffic flow?; and, C) Are there acceptable, in terms of ATC ratings, workload, and closest point of approach data, DAA miss distances that can be applied to the development of DAA algorithms?

In order to address the above research questions, an appropriate experiment design was necessary to achieve the goal of the experiment’s primary focus and aim.

Method

Subjects

To keep in line with designing an appropriate experiment, ATC subjects who had real-world experience controlling the East-side area of DFW were sought after, and, as such, fourteen recently retired DFW controllers were utilized for this experiment. ATC experience among subjects ranged between 25.5 years to 33 years with an average of approximately 30.4 years. Subjects also had an average of approximately 20.4 years of DFW experience in a Terminal Radar Approach Control Facility (TRACON). Additionally, of that DFW experience, an average of 18.3 years’ worth of experience was in the East-side sector of the DFW TRACON (D10) region. Furthermore, out of the fourteen subjects, none had experience with UAS operations, which allowed for a fresh perspective to controlling UAS traffic encounters, and four of the fourteen controllers were active instructors at the DFW training center. Also, in order to maintain and simulate a close to real-world DFW environment and workload, two pseudo-pilots controlled each UAS GCS and two additional pseudo-pilots controlled background traffic. ATC positions, other than that of the subject controller, were ‘controlled’ via personnel acting as other DFW TRACON sector controllers. The subject controller was expected to communicate with these other sectors as he normally would in the field, with the exception of some Standard Terminal Automation Replacement System (STARS) functions;

STARS “provides controllers with critical operational information about aircraft positions, flight data, and weather” (FAA, 2012).

Independent Variables

With the aim of acquiring data on ATC acceptability ratings on differing spacing parameters, the primary Independent Variable (IV) of interest was determining the minimum acceptable HMD as a result of a given parameter in the DAA algorithm. The secondary IV of interest was the encounter geometry between the aircraft in the encounter situation.

Horizontal miss distances. CAS-1 researched six different HMD values that included the following spacing parameters measured in nautical miles (NM): 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0. These values were implemented in the DAA algorithm.

Encounter geometry. Three encounter geometries were utilized in CAS-1, which included opposite-direction, overtake, and crossing. Figure 2 visually portrays the different encounter geometries. The following parameters frame the secondary IV:

- Intruder opposite-direction at 180 degrees +/- 15 degrees (non-crossing)
- Intruder to right at 90 degrees +/- 15 degrees (crossing)
- Intruder ahead at 0 degrees +/- 15 degrees (overtaking, non-crossing)
- All geometries without vertical separation (but may include climbing/descending trajectories)
- UAS pilots were instructed to pass to the right of intruder for non-crossing geometries
- UAS pilots were instructed to pass in front of intruder for crossing geometries
- Intruder Speed Differential (5 speed values for crossing: 0, + 40, - 40, + 80, and - 80 knots)
- 42 test conditions: 6 opposite-direction, 6 overtake, 30 crossing
- 14 encounters per hour; 6 one-hour test sessions per subject enabled a replicate for each encounter

The parameters of the primary and secondary IVs are shown in Table 1.

Table 1.
Parameters of the primary and secondary independent variables.

Encounter Geometry	**Horizontal Miss Distances in Separation Algorithm**					
	0.5	*1.0*	*1.5*	*2.0*	*2.5*	*3.0*
Opposite-direction	1 speed	1 speed	1 speed	1 speed	1 speed	1 speed
Overtake	1 speed	1 speed	1 speed	1 speed	1 speed	1 speed
Crossing	5 speeds	5 speeds	5 speeds	5 speeds	5 speeds	5 speeds

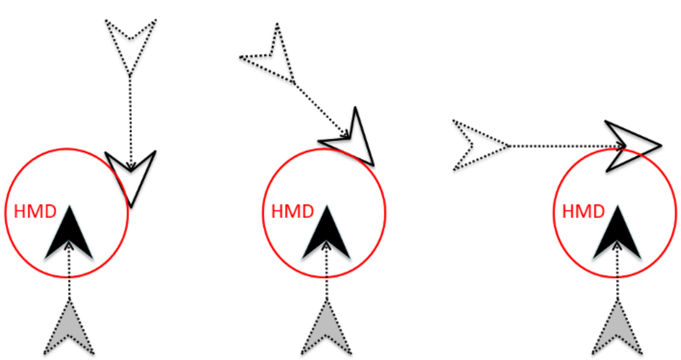

Figure 2. Encounter geometries used in CAS-1 included, from left to right, opposite-direction, overtake, and crossing encounters.

Scenarios

The scenarios implemented in CAS-1 simulated ATC Sector DN/AR-7 South Flow, which is a portion of airspace delegated to DFW TRACON (D10). The scenarios were designed and situated in the selected airspace so as to enable various encounter geometries between the UA and intruder aircraft.

Dependent Variables

System Performance Metrics. Aircraft-to-Aircraft separation distances, operational errors and deviations, delays to aircraft in scenario, re-sequencing arrival aircraft, and voice communication errors, which included transposing information, call sign errors, repeats, and "say again" were recorded during each one-hour data collection run.

Human Operator Performance Metrics. Three different human operator performance metrics were examined. Among those three was the assessment of controller workload through the use of the Air Traffic Workload Input Technique (ATWIT) methodology. ATWIT was the tool used to measure mental workload in "real-time" by presenting auditory and visual cues that prompted the controller to press one of six ratings at fixed time intervals to indicate the amount of mental workload experienced at that moment (Stein, 1985). The response scale was built into the controller display software and had ratings from 1 to 6. A rating of 1 suggested "*minimal mental effort required*;" a rating of 2 suggested "*low mental effort required*;" a rating of 3 suggested "*moderate mental effort required*;" a rating of 4 suggested "*high mental effort required*;" a rating of 5 suggested "*maximal mental effort required*;" and, a rating of 6 suggested "*intense mental effort required*." In addition, another performance metric collected involved post encounter verbal queries that were gathered to evaluate controller acceptability of HMD spacing parameters. Controllers were asked to rate HMDs based on a scale from 1-5. Table 2 shows the scaled used and defines each of the acceptability ratings. Lastly, an "end-of-hour questionnaire" was administered to each subject controller at the conclusion of each one-hour data collection session.

Facilities, Software, and Hardware

The experiment was conducted in a dedicated facility located at Stinger Ghaffarian Technologies (SGT), near NASA LaRC in Hampton, Virginia. The facility ran a UAS modified version of the Multi Aircraft Simulation System (MACS) software (Prevot, 2002). MACS is an environment for developing, setting up, and running real-time controller and pilot-in-the-loop simulations; it was configured to emulate the existing Air Traffic Management (ATM) system. The modified version of MACS included incorporation of UAS aircraft models with the addition of Stratway+ algorithms to drive the Electronic Horizontal Situation Indicator (EHSI), known as bands, which indicated a range of headings that would result in a loss of well-clear with one or more intruder aircraft. Muñoz, Narkawicz, Chamberlain, Consiglio, and Upchurch (2014) provide additional information regarding self-separation algorithms. The subject controller's workstation closely resembled the workstations that are currently used in FAA field facilities. STARS functionality was included in this experiment but with limitations. The implementation team included personnel from SGT, Adaptive Aerospace Group (AAG), and Intelligent Automation Inc. (IAI).

Table 2.
Horizontal miss distance acceptability rating scale.

	Horizontal Miss Distance Rating Scale Definition
Rating Scale	
1	Much too close; unsafe or potentially so; cause or potential cause for issuance of a traffic alert
2	Somewhat close; some cause for concern
3	Neither unsafely close nor disruptively large; did not perceive the encounter to be an issue
4	Somewhat wide, a bit unexpected; might be disruptive or potentially disruptive in congested airspace and/or with high workload
5	Excessively wide, unexpected; disruptive or potentially disruptive in congested airspace and/or with high workload

Results

Horizontal Miss Distances

Subject controllers were verbally asked to rate HMDs on a scale from 1-5, as shown in Table 2, based on their acceptability of the HMD spacing parameter.

Opposite-direction encounters. Illustrated in Figure 3, the ratings for the opposite-direction encounter geometry show that HMDs with a spacing parameter of 3.0 NM were considered unacceptable due to either being "*somewhat wide*" or "*excessively wide*." In addition, the graph also shows that the HMDs that the controllers' found to be acceptable were the ones in the 1.0 and 1.5 NM range with 80% of ratings suggesting 1.5 NM being the most acceptable among the two.

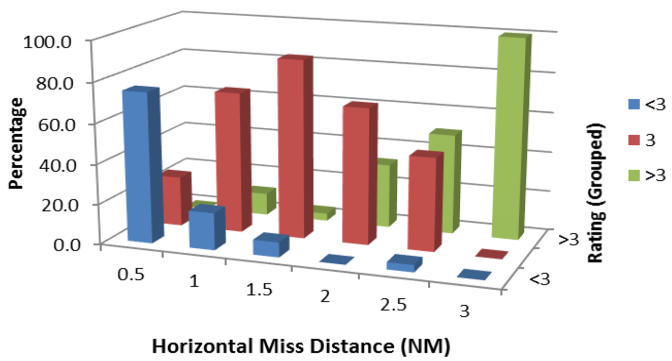

Figure 3. Subject controllers' ratings for HMD spacing parameters for the opposite-direction encounter geometry.

Overtake encounters. Figure 4 illustrates the ratings for the overtake encounter geometry. The graph shows that the highest percentages, with a rating of 3, were at the 1.0, 1.5, and 2.0 HMD spacing parameters. In addition, the graph also shows that a rating of more-than 3 was given for HMDs with a 2.5 or 3.0 spacing parameter.

Crossing encounters. Figure 5 illustrates the ratings for the crossing encounter geometry. The graph affirms that the controllers found the 1.0 and 1.5 NM HMD spacing parameters to be the most acceptable by giving a large majority of encounters, with those specific spacing parameters, a rating of 3 indicating that they were "*neither unsafely close nor disruptively large*" and "*did not perceive the encounter to be an issue*." HMDs of 2.5 NM had comparable percentage ratings of 3 and more-than 3. Furthermore, as was the case with the other two encounter geometries, HMDs with 3.0 NM spacing parameters, received a majority of ratings of more-than 3, indicating that those encounters were either "*somewhat wide,*" or "*excessively wide*" and "*disruptive*."

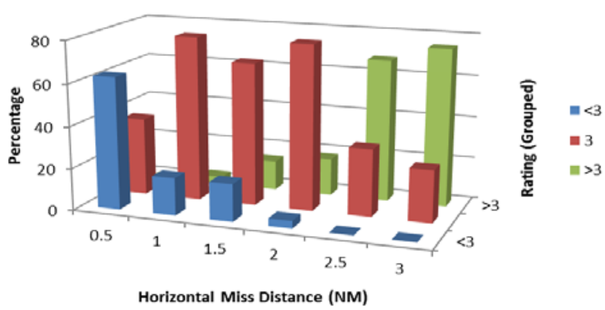

Figure 4. Subject controllers' ratings for HMD spacing parameters for the overtake encounter geometry.

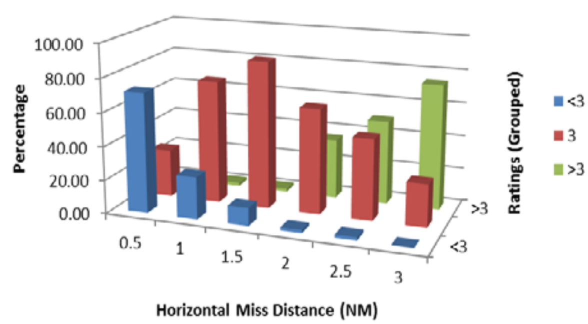

Figure 5. Subject controllers' ratings for HMD spacing parameters for the crossing encounter geometry. In this crossing encounter, the UA's speed was faster than the encounter aircraft.

In summary, the analysis of the data collected concludes that 1.0 to 1.5 NM were the most favored HMDs. It also concludes that the majority of subject controllers found that 0.5 NM to be considered "*much too close*" for all three encounter types. Furthermore, a majority of controllers found that 2.0 NM was not unreasonable but that 2.5 NM and above were considered disruptive.

Realism of Traffic Density and Workload Ratings

Careful consideration was taken in the design and realism of the simulation environment. Research was conducted to find the optimal traffic density allowable to achieve the aim of the study while maintaining as close to real-world densities as possible for a realistic simulation of the DFW East-side airspace. At the termination of each one-hour data collection run, an "end-of-hour questionnaire" was administered to each controller. Among the questions asked was one regarding the realism of the traffic density; controllers were asked to "*rate the realism of the traffic density of the simulation during the preceding hour*." The following responses are collective for all subjects for all six one-hour data collection runs: 0% of responses were that "*Traffic Density was significantly higher than in real operations*;" 1.2% of responses were that "*Traffic Density was somewhat higher than real world operations*;" 55.6% of responses were that "*Traffic Density was about the same as would be found in real world operations*;" 42.9% of responses were that "*Traffic Density was somewhat lower than real world operations*;" and

0% of responses were that "*Traffic Density was significantly lower than in real world operations*." Table 3 shows the average workload ratings, captured at five-minute intervals using the ATWIT methodology, for all subjects and for all data collection runs.

Table 3.
Average Air Traffic Workload Input Technique (ATWIT) Workload Ratings.

	ATWIT Time Intervals (*in seconds*)										
	300	*600*	*900*	*1200*	*1500*	*1800*	*2100*	*2400*	*2700*	*3000*	*3300*
Average Rating	1.37	1.79	1.84	1.68	1.93	1.89	2.15	2.37	2.08	1.89	2.01

Discussion

The CAS-1 research experiment employed a close-to-real world simulation of the DFW East-side airspace. The study focused on determining the effect of simulated DAA-equipped UAS on ATC workload, as well as, on the acceptability of maneuvers with differing HMD spacing parameters used in the DAA algorithms. The results of the study confirmed a clear favoring, from the ATC perspective, towards a particular HMD range, which was 1.0 and 1.5 NM; this range was still favored even when maneuvers were required to maintain those horizontal miss distances and appeared to be the optimal range for ATC acceptability. In addition, controllers found the DAA integration concept as presented to be absolutely viable. ATC workload ratings using the ATWIT method showed that the controllers considered the simulated workload to require minimal to low mental effort given their experience with the DFW sector.

Follow-on research studies in this series of experiments will focus on assessing the impact of modeled communication delays on the execution of SS procedures as defined in the CAS-1 experiment and the performance of the Stratway+ generated maneuver guidance in the presence of winds. In continuation of the aforementioned follow-on research, additional research studies will address minimum and maximum acceptable declaration times for projected well clear losses, from the perspectives of both the air traffic controller and the Unmanned Aircraft (UA) pilot. Data from the CAS-1 experiment and subsequent experiments are meant to play a crucial role in the FAA's establishment of rules, regulations, and procedures to safely and efficiently integrate UAS into the NAS.

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