

NASA/TM-2015-218763



NASA Controller Acceptability Study 1(CAS-1) Experiment Description and Initial Observations

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May 2015

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Acknowledgments

Large research simulation experiments often have many contributors extending well beyond the authors on a corresponding research report, and in this regard the CAS-1 experiment is certainly no exception. CAS-1 required a tremendous amount of background preparation and operations support across a wide variety of technical disciplines, and the authors are extremely grateful for the assistance of a dedicated and talented research team. Anthony Narkawicz, George Hagen and Jason Upchurch of NASA Langley Research Center's Safety Critical Avionics Systems Branch provided valuable insight and contributions to the development of the Stratway+ SS guidance algorithm. Many members of NASA's Langley Information Technology Enhanced Services (LITES) contract provided extensive support across a wide array of technical areas, including development of display concepts, procedures, software, simulation facilities, pilot and controller training materials, and flight scenarios; training support for staff pilots and subject controllers; and operations support of numerous simulation data collection sessions as well as dry runs and dress rehearsals. The authors would especially like to thank the following LITES research team members: Pierre Beaudoin, Anna Dehaven, Keith Hoffler, Steve Hylinski, Joel Ilboudo, Kristen Mark, Robb Myer, Gaurev Sharma, Jim Sturdy, Dimitrie Tsakpinis, and Paul Volk as well as numerous additional support and management personnel. CAS-1's success would not have been possible without the talent, hard work and dedication of these research team members.

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Abstract

This paper describes the Controller Acceptability Study 1 (CAS-1) experiment that was conducted by NASA Langley Research Center personnel from January through March 2014 and presents partial CAS-1 results. CAS-1 employed 14 air traffic controller volunteers as research subjects to assess the viability of simulated future unmanned aircraft systems (UAS) operating alongside manned aircraft in moderate-density, moderate-complexity Class E airspace. These simulated UAS were equipped with a prototype pilot-in-the-loop (PITL) Detect and Avoid (DAA) system, specifically the Self-Separation (SS) function of such a system based on Stratway+ software to replace the see-and-avoid capabilities of manned aircraft pilots. A quantitative CAS-1 objective was to determine horizontal miss distance (HMD) values for SS encounters that were most acceptable to air traffic controllers, specifically HMD values that were assessed as neither unsafely small nor disruptively large. HMD values between 0.5 and 3.0 nautical miles (nmi) were assessed for a wide array of encounter geometries between UAS and manned aircraft. The paper includes brief introductory material about DAA systems and their SS functions, followed by descriptions of the CAS-1 simulation environment, prototype PITL SS capability, and experiment design, and concludes with presentation and discussion of partial CAS-1 data and results.

CAS-1 results included a total of 1176 controller assessments of all encounter geometries and HMD, and showed that a SS HMD value of 1.5 nmi had the highest acceptability rating with a striking degree of agreement among the controller volunteers. More generally, most controllers assessed HMD values between 1 and 2 nmi to be acceptable across all encounter geometries. There was more variability in controller assessments of 0.5 nmi HMD encounters but a significant number of these assessments considered this HMD value to be too small and potentially unsafe. HMD values larger than 2 nmi were generally assessed as increasingly disruptive to orderly traffic flow. These results should be useful to inform the development of operational performance standards for DAA SS functions. For example, it may be appropriate for standards to specify that SS functions should always indicate that SS maneuvering is necessary for encounters that will result in projected HMD values less than 1 nmi, and never indicate a required SS maneuver if the projected HMD is greater than 2 nmi.

All 14 air traffic controller volunteers were favorably impressed with the PITL SS concept as simulated and presented to them, and considered the concept to be viable from an ATC perspective under the assumption that acceptable SS HMD values are employed. CAS-1 staff pilots also assessed the concept favorably and considered the simulation time valuable in identifying enhancements for future refinements of the concept. These controller and pilot assessments were significant since CAS-1 was the first sustained opportunity to exercise the Stratway+ instantiation of the PITL SS concept in a realistic controller-pilot simulation that was representative of the moderate-complexity, lower-altitude Class E airspace that will pose one of the most challenging environments for DAA-equipped UAS.

Introduction

As described in references [1], [2], [3] and other documents, a Detect and Avoid (DAA, also known as Sense and Avoid or SAA) system is envisioned to have up to two functions: a self-separation (SS) function to enable its associated Unmanned Aircraft System (UAS) to stay well clear of other aircraft, and a possibly-optional collision avoidance (CA) function to prevent collisions if all other means of separation fail. The SS and CA functions are further envisioned to each be comprised of the following sub-functions: Detect, Track, Evaluate, Prioritize, Declare, Determine, Command and Execute (references [1-4]; see Figure 1). Some of these sub-functions may be performed by automation and some by the UAS pilot, depending on the function (SS or CA) and the overall DAA architecture. As described in references [2], [4] and subsequently [5], the SS function is envisioned to allocate at least the Determine and Command sub-functions to the UAS pilot, consistent with current manned-aircraft see-and-avoid

operations where the pilot in command (PIC) is responsible for determining and commanding appropriate avoidance action, if any, based on relevant visual information and ATC communication. The SS sub-functions preceding Determine will collectively provide the UAS pilot with information elements and/or decision aids sufficient to replace the missing out-the-window visual information and enable the pilot to make safe and efficient SS maneuver decisions.

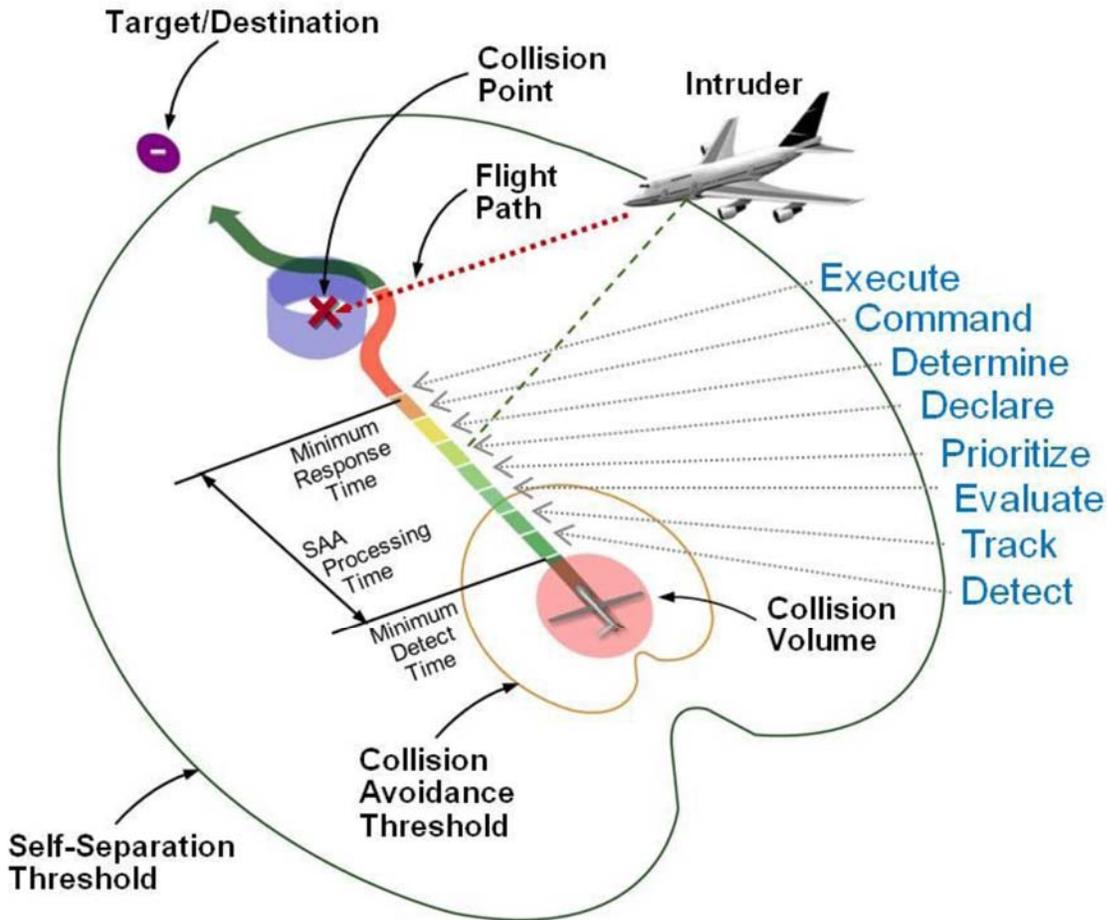


Figure 1. DAA Sub-Functions, Thresholds and Volumes

As shown in Figure 1, the SS and CA functions will each have a defined space/time threshold – a self-separation threshold (SST) and collision avoidance threshold (CAT), respectively – which will cause the function to Declare that avoidance maneuvering may be necessary if an intruder aircraft crosses the respective threshold (note that for convenience the DAA community typically references these thresholds or boundaries in the singular, i.e., “the SST” or “the CAT” although in practice a uniquely-shaped SST and CAT boundary would be computed for each unique intruder encounter geometry, based on the time and space parameters defining the respective thresholds). For a representative CA function such as TCAS II (references [6] and [7]) an intruder crossing the CAT would result in presentation of visual and aural Resolution Advisory (RA) warning declarations to the flight crew (e.g., “Climb, Climb”) with the objective of avoiding collision with the intruder, or more precisely, to avoid entry of the intruder into the collision volume (CV) around the Ownship. This CV is typically defined as a cylinder centered about the Ownship with a radius of 500 feet and height of 200 feet, and the CV penetration rate is considered a

performance measure for the effectiveness of various TCAS II versions and other CA functions. Reference [2] proposed the definition of a self-separation volume (SSV) to be used similarly for the SS function; that is, the SS function would provide guidance and/or alerts sufficient to enable the PIC to keep intruders clear of the SSV, and the SSV penetration rate would be considered a performance measure for the SS function (reference [3] subsequently proposed a similar concept but labeled the SSV functional boundary as Well Clear Violation (WCV)).

Reference [2] asserted that the SSV should be large enough to avoid (or minimize): 1) corrective RA issuance by TCAS-equipped intruders (or by a TCAS CA system onboard the Ownship); 2) safety concerns for air traffic control (ATC) personnel; and 3) undue concern for pilots of proximate see-and-avoid aircraft. The SSV should also be small enough to minimize disruptions to traffic flow. Determination of minimum and maximum acceptable SSV sizes will inform the design space for required DAA surveillance accuracy and for acceptable overall SS function performance.

In order to minimize TCAS corrective RA issuance, reference [2] proposed a SSV functional shape and minimum size based on the TCAS II corrective RA CAT, with the shape and size parameterized by threshold values of the TCAS-like variables of modified tau (ModTau), distance modification (DMOD), projected horizontal miss distance (HMD) at closest point of approach (CPA), vertical threshold (ZTHR) and time to co-altitude (TCOA). This parameterized SSV shape has been codified in software along with a predictive algorithm (Stratway+) that can provide SS maneuver guidance to the UAS PIC to keep this SSV clear of intruders (references [8] through [11]), but several challenges still remain. Two of the challenges were addressed by the Controller Acceptability Study 1 (CAS-1) experiment, conducted in Winter-Spring 2014 by NASA Langley Research Center personnel and described in this paper:

1. The pilot-in-the-loop (PITL) SS concept described in references [2], [4] and [5] had not been tested in a human-in-the-loop (HITL) simulation representative of challenging current-day National Airspace System (NAS) operations with actual pilots and air traffic controllers; and
2. Threshold values of SSV parameters such as HMD that were generally acceptable to ATC personnel, both for safety perceptions and for orderly and efficient traffic flow in a realistic ATC environment, were unknown.

The following sections of this paper describe the CAS-1 simulation environment, PITL SS concept instantiation in the simulation, and experiment as designed to address these two challenges, followed by additional sections to describe some of the CAS-1 results and conclusions.

Simulation Environment and PITL SS Concept Instantiation

The CAS-1 simulation environment was based on the Multi Aircraft Control System (MACS) software platform. MACS was originally developed by Dr. Tom Prevot and his team at NASA Ames Research Center (references [12] and [13]), and this very capable software platform enables HITL simulations of realistic air traffic scenarios with many aircraft operating in structured airspace representative of today's NAS. A MACS simulation environment is typically comprised of multiple PC-based workstations networked together with each station running an instantiation of MACS and staffed by an operator. The operators can be simulation staff, pilots, and/or controllers, and the MACS instantiations can be configured to present simulation manager/traffic generator station, aircraft station, or ATC station simulations to the respective operators. The simulation manager/traffic generator station initiates all aircraft into the simulation via a pre-defined scenario script, enables the transfer of some of these aircraft

to pilots at aircraft stations via script or human operator intervention (other aircraft are auto-flown via pre-defined flight plans), enables manual or automated removal of aircraft from the scenario (e.g., upon landing) and allows for overall scenario control by the operator. The aircraft stations can be set up either to present displays/controls of a single aircraft (such as for a PITL study where the pilot is the subject of the experiment) or to enable control/monitoring of multiple aircraft. The multi-aircraft station capability is used to enable efficient controller-in-the-loop simulations, so that several staff pilots, each at a multi-aircraft station, can collectively simulate many participating aircraft in a subject controller's sector. The ATC stations can simulate either a terminal radar approach control (TRACON) station (i.e., STARS, or Standard Terminal Automation Replacement System) or an air route traffic control center (ARTCC) en route station (i.e., DSR, or Display System Replacement). Multiple ATC sectors can be simulated, so that in a controller-in-the-loop study such as CAS-1 the ATC subject would control traffic at an ATC station simulating his or her subject sector, and other staff controllers would operate other ATC stations simulating the adjacent TRACON and/or ARTCC sectors.

The MACS version used for CAS-1 was enhanced with additional capabilities developed by NASA Langley personnel to enable simulation of DAA/SS-equipped UAS and the PITL SS concept. These capabilities included the addition of UAS vehicle models; configurable simulation of command-and-control (C2) link delays; Automatic Dependent Surveillance – Broadcast (ADS-B) In/Out surveillance modeling at the message level; and prototype SS guidance capability with associated UAS Ground Control Station (GCS) pilot displays, based on Stratway+ software (references [8-11]) and modifications to the MACS multi-aircraft station capability, respectively. An extensive multi-channel voice communication system was also developed, to simulate aircraft-controller party-line communication on the subject sector frequency with configurable delay for UAS aircraft, and also to simulate the land-line communication channels between adjacent controllers. These additional capabilities, as they were configured for CAS-1, are briefly described next.

A number of UAS vehicle dynamic models were developed by Intelligent Automation, Inc. (IAI) in 2012-2013 under contract with NASA Langley and incorporated into the MACS version used for CAS-1, and three of these models were used in the CAS-1 simulations. These three models approximated the typical operational (versus aerodynamic-performance-limited) performance rates and speeds of the General Atomics Predator A and Predator B/Reaper and the Northrop-Grumman Global Hawk aircraft when using a terrestrial (versus satellite) C2 link. The simulated C2 link delay was set to zero for CAS-1, which also more closely simulates the performance of a terrestrial versus satellite C2 link. The voice communication delay for CAS-1 was also configured to zero for UAS and all other simulated aircraft, although the actual delay was approximately 100-150 milliseconds due to the voice-over-internet-protocol (VoIP) implementation of the communication simulation. This is again consistent with typical nominal performance of terrestrial C2 links that also carry relayed voice communications.

The ADS-B In/Out surveillance modeling capability was used in CAS-1 to simulate the Detect and Track sub-functions of the UAS SS function. The modeling capability itself is extensive and includes modeling at the message level (versus assembled report level) of both 1090 MHz Extended Squitter (1090-ES)- and Universal Access Transceiver (UAT)-equipped ADS-B Out aircraft and associated ADS-Rebroadcast (ADS-R) spatial-limit and delay modeling, as well as modeling of Traffic Information Service-Broadcast (TIS-B) capability (for detection of unequipped intruders) and various levels of 1090 MHz interference modeling. However, for CAS-1 the model was configured such that all aircraft were 1090-ES ADS-B In/Out-equipped with ideal detection accuracy, no 1090 MHz interference, and unlimited detection range. That is, ideal SS Detect and Track sub-function performance was assumed and simulated for CAS-1.

SS guidance capability was provided to the UAS pilot in CAS-1 by Stratway+ software. The functional parameterized shape of the SSV (references [2, 8-11]) was codified within Stratway+ as well as default threshold values for the parameters ModTau, DMOD, HMD, ZTHR and TCOA. These default threshold

values were identical to those for TCAS II (reference [7]) but could be overridden via explicit inputs to Stratway+, and in fact for CAS-1 the threshold values for DMOD and HMD were manipulated as independent variables (IVs) and explicitly input to Stratway+ for all SS encounters. Additional inputs to Stratway+ included Ownship position, velocity, winds, and performance rate data (e.g., nominal turn rate, from the vehicle model); intruder positions and velocities; and a specified SS look-ahead time (LAT) value. Stratway+ used these data to compute conflict prevention bands (“bands”) for heading, airspeed and vertical speed. These computed bands, if any, would then be displayed on the pilot’s heading, airspeed, and vertical speed indicators, respectively, to show which respective values would cause one or more intruders to penetrate the SSV within the specified LAT. LAT was set to 70 seconds for CAS-1.

Figure 2 shows a photograph of the navigation display (ND) of a MACS multi-aircraft UAS GCS station during a simulation with multiple aircraft near the (currently-selected) Ownship, depicted as the bold white chevron at the center of the range rings. The view is track-up but for CAS-1 the wind field was always assumed zero, so track and heading are the same (165 degrees magnetic in Figure 2) as are groundspeed (GS) and true airspeed (TAS) (157 knots in this case). The range is set to 10 nautical miles (nmi), indicated by the white “5” next to the half-scale range ring, and the closest intruder laterally is shown at the 9 o’clock position and 3 nmi range, westbound but 2800’ above the Ownship and thus not a factor (note that MACS colors intruders white if within 500’ vertically of Ownship, and blue or green if more than 500’ above or below, respectively). Stratway+ amber heading bands are visible from 174 to 273 degrees and are caused by the co-altitude eastbound intruder (N5457B) at 2 o’clock and 5 nmi.



Figure 2. SS Heading Bands Example: Crossing intruder, no conflict (yet)

The Stratway+ heading bands in Figure 2 can be interpreted by the UAS pilot as follows: the current heading of 165 degrees is conflict-free from a SS perspective, but the new heading after the planned turn at the VELCI waypoint will cause the SSV to (just) be penetrated by an intruder (N5457B in this case) within the LAT of 70 seconds. A slight modification to the right turn, for example to only 173 degrees, should avoid SSV penetration, but further right turns will cause SSV penetrations, up until a very significant right turn to 273 degrees or greater. Note that this very significant right turn, while probably not operationally desirable, can still be made at the nominal turn rate from the vehicle performance model (approximately 2 degrees per second in this case) and the SSV will not be penetrated, if the turn is Commanded within the (configurable) reaction time allocation for the pilot (this reaction time is also an input to Stratway+ for use in bands computations and was set to 5 seconds for CAS-1).



Figure 3. SS Heading Bands Example: Crossing intruder, with conflict after turn at VELCI

Figure 3 shows a photograph of the ND a short time after the situation in Figure 2 and zoomed to the 5 nmi scale, after the pilot ignored the heading bands and executed the unmodified turn at VELCI. Stratway+ has now “Declared” a SS conflict with N5457B and its chevron is now colored amber to so indicate that it will penetrate the SSV within the LAT. A slight left turn to 173 degrees or less will still result in passing ahead of the intruder and avoiding the SSV penetration, but as the encounter has progressed the option to turn right and go behind is no longer available. The vertical speed band is presented on the vertical speed tape of the Primary Flight Display (PFD) and is not shown here, but in this example briefly indicated that a high-vertical-rate climb or descent would have also avoided SSV penetration, by achieving ZTHR of vertical separation. Stratway+ showed this climb or descent option

becoming unviable via the vertical speed band shortly after the situation shown in Figure 3, as the encounter progressed further and the required vertical rate would exceed the vehicle’s performance capability. Note that in this example a slight left-turn modification to the flight plan after VELCI is the obvious best operational choice for avoiding SSV penetration by the intruder (i.e., “remaining well clear”), but a key aspect of the PITL SS concept described here is to present the UAS pilot with all available options – left, right, up, down, even a possible speed change – and allocate the SS Determine and Command sub-functions (i.e., what action to take, if any) to the pilot and his or her judgment in concert with ATC coordination.

In addition to the Stratway+ bands, UAS pilots in CAS-1 were presented with an alphanumeric display which showed a list of all intruders within 15 nmi of the Ownship and on a converging course. An example of this display is shown in Figure 4. The top of the alphanumeric display shows the current threshold values of ZTHR and HMD if they have been overridden (-999999 otherwise) so in this case Stratway+ is presenting bands for a SSV with 2.5 nmi HMD (note that for CAS-1 and all prior and subsequent work to date, the HMD and DMOD thresholds were always set equal to each other, so in this example the DMOD threshold is also 2.5 nmi). The list shows converging intruders by call sign along with their current range, estimated range at CPA and estimated time to CPA. These last two values proved useful to UAS pilots in achieving encounters with very precise HMD, and gave them an approximate idea of how much time they had left to negotiate a SS maneuver with ATC before SSV penetration was inevitable.

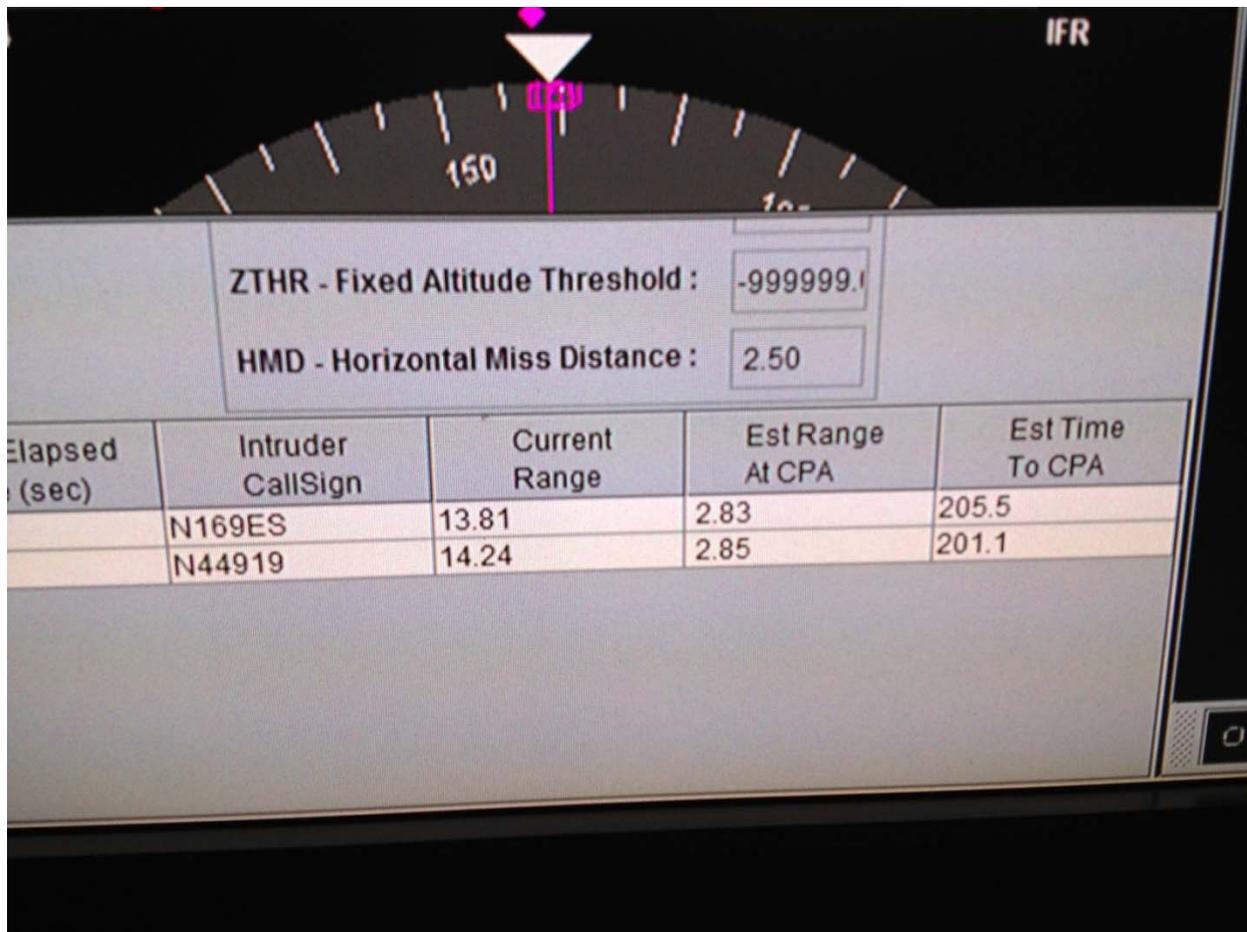


Figure 4. CAS-1 UAS GCS Display of Nearby Converging Intruders

Both UAS and manned aircraft pilots in CAS-1 were also provided with a separate moving map display for enhanced situation awareness. An example of this display is shown in Figure 5 with a close-up view shown in Figure 6. This example shows the centered Ownship position overlaid on a North-up view of a Visual Flight Rules (VFR) Sectional Chart representing the current airspace, but additional options included a Track-up view and various satellite imagery or street map underlays. The airspeed tape, altitude tape and vertical velocity indicator (VVI) were positioned on the left and right sides of the moving map, respectively, as can be seen in Figure 5, and a heading indicator rose was drawn around the Ownship position as can be seen more clearly in Figure 6. Intruder aircraft were also depicted on the moving map, such as the intruder shown near the upper right corner of Figure 6 over Rockwall Airport, and such depictions were useful if a controller issued a traffic advisory relative to a ground feature such as an airport or VFR checkpoint (e.g., “Traffic ... southeast-bound over Rockwall”). In the example shown the Ownship was not in a current or potential SS conflict with any intruders and no Stratway+ bands were present, but in cases where bands were present they would be redundantly displayed on the moving map’s airspeed tape, VVI and heading indicator rose as well as on the MACS PFD and ND, again for enhanced pilot situation awareness.

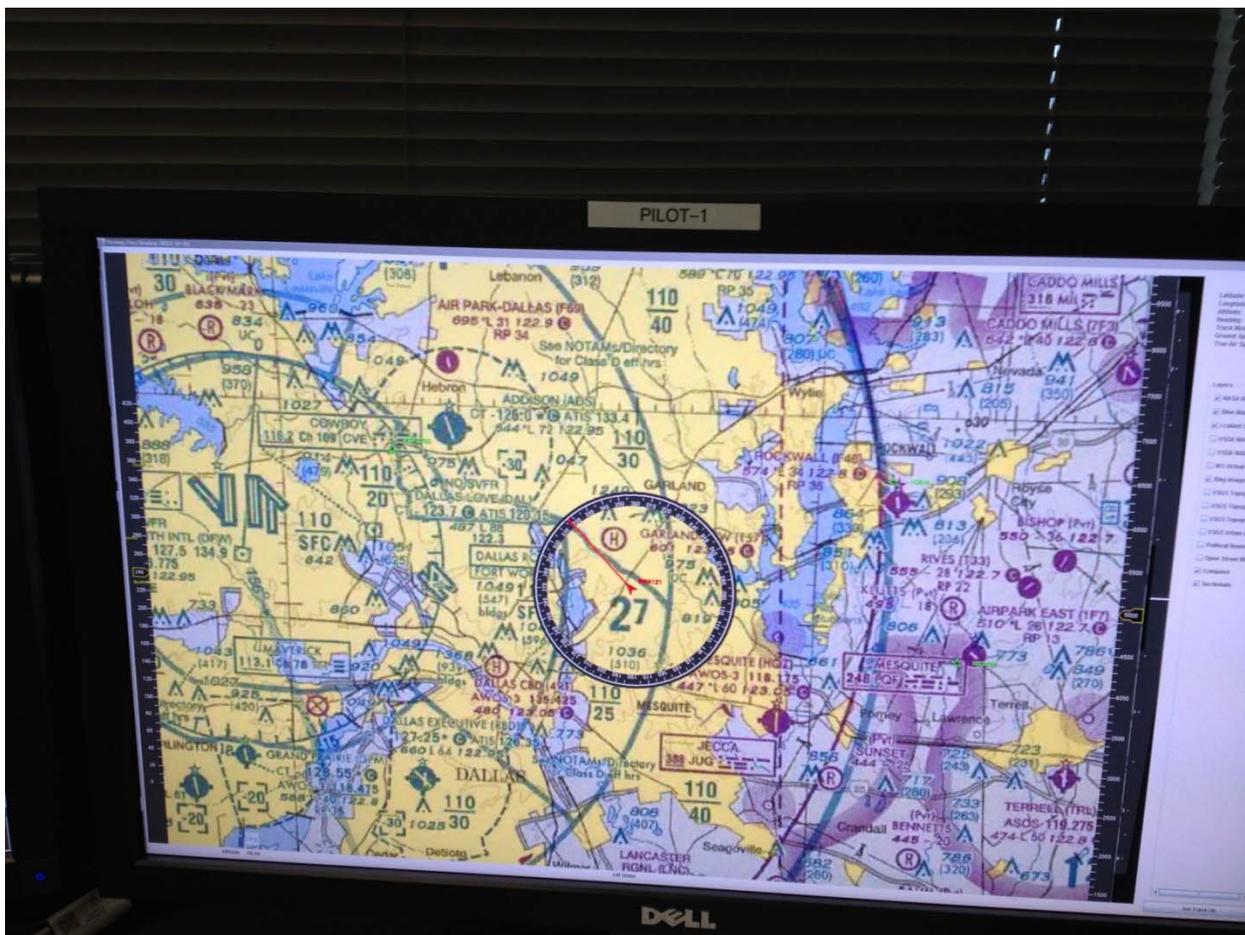


Figure 5. CAS-1 Moving Map Display for UAS and Manned Aircraft Pilots



Figure 6. Close-Up View of Moving Map Display

The aggregate objective of the PITL SS concept, primarily implemented by the Stratway+ bands but also with the converging-intruder alphanumeric display and moving map display as just described, is to restore “intelligent sight” (reference [2]) to the UAS pilot who does not have an out-the-window view of traffic and to enable that UAS pilot to make SS decisions and maneuvers in a manner comparable to the see-and-avoid decisions and maneuvers made by manned aircraft pilots. That is, during normal operations a manned aircraft pilot would execute see-and-avoid responsibilities by maintaining visual awareness of the traffic situation and exercising judgment based on that sight picture regarding any required ATC coordination and aircraft maneuvering to remain well clear of other aircraft. The PITL SS concept aims to enable a comparable level of normal-operations awareness and judgment for the UAS pilot, and in this sense the bands and other indications (e.g., amber intruder) are not necessarily intended as caution or warning alerts, but as SS guidance to enable normal-operations decisions and maneuvers.

CAS-1 Experiment Description

The CAS-1 experiment had both an exploratory and a quantitative objective. The exploratory objective was to evaluate the capability and viability of the prototype PITL SS concept instantiation, from the perspective of both subject air traffic controllers and CAS-1 staff research pilots, when the concept was exercised in a realistic, multi-aircraft simulation in light-to-moderate-density, moderate-complexity Class E airspace. The quantitative objective was to determine the range of HMD threshold values for the SSV

that was generally acceptable to air traffic controllers in this same Class E airspace. Significant effort was expended to generate simulation scenarios of sufficient complexity and traffic density to adequately represent today's NAS environment and to effectively address these two objectives. That is, the research staff recognized that a given PITL SS concept and/or SSV HMD threshold might work acceptably in an isolated, pair-wise encounter between a UAS and an intruder but fall short when immersed in a more realistic environment, and wanted to take sufficient steps to test in that more realistic environment.

CAS-1 was designed to address the following research questions for its quantitative objective, from the perspective of acceptability to air traffic controllers of a future environment with UAS DAA SS operations occurring in airspace shared with manned aircraft:

1. What DAA SS horizontal maneuvers/HMD are too small, resulting in issuance of traffic safety alerts or controller perceptions of unsafe conditions?
2. What DAA SS horizontal maneuvers/HMD are too large (excessive "well clear" distances), resulting in behavior the controller would not expect and/or disruptions to traffic flow?
3. Is there a range of acceptable DAA SS HMD that can be applied to the development of DAA algorithms? Is this range affected by encounter geometry and/or speed differential, and if so, how?

To address these research questions, 84 simulated SS encounters between a UAS and a manned aircraft were constructed with different encounter geometries, HMD, and speed differentials, and these SS encounters were then embedded throughout six one-hour simulated background traffic scenarios (14 encounters per one-hour scenario) representative of light-to-moderate-workload TRACON traffic (both Instrument Flight Rules (IFR) and VFR traffic) on a calm-wind, clear-weather day. All of the SS encounters were constructed to occur in lower-altitude Class E airspace (most at 3000' with some at 4000' or 6000'). This lower-altitude, Class E TRACON airspace is arguably some of the most challenging for a SS function, other than the traffic pattern area in the immediate vicinity of an airport, since it has significant complexity with arrivals, departures, over-flights, flight training, etc.; a mix of IFR and VFR traffic with some VFR aircraft not receiving air traffic services (i.e., not on the sector frequency and not subject to controller instructions); a high incidence of see-and-avoid/SS encounters; and significant traffic flow constraints that limit options for SS maneuvers, particularly for those requiring large HMD thresholds.

All of the six one-hour scenarios ("Hours") containing the SS encounters and background traffic were constructed in the DN/AR7 sector of the D10 TRACON. Dallas-Fort Worth International Airport (DFW) is the primary airport for the D10 TRACON; the DN/AR7 sector is in the northeast quadrant of D10 and handles south-flow traffic to/from satellite airports including Dallas Love Field (DAL), Addison (ADS) and McKinney (TKI) as well as other non-towered airports and lower-altitude en route or training flights in the sector (see figure 7). Simulated UAS operations included arrivals to and departures from TKI as well as overflights throughout the sector, some with a SS encounter and some not. The physical locations of the encounters were varied, i.e., on departure, arrival, or en route in different parts of the sector, not only to avoid predictability of encounters in the later Hours but also to allow the six Hours to be constructed with the encounters embedded into realistic background traffic flows. For experiment control all UAS SS encounters were with VFR aircraft not receiving ATC services (i.e., not on the sector frequency) so a subject controller could not preemptively and strategically "fix" a SS encounter before it had a chance to occur. In most cases these encounters were also designed so that the controller could not see it developing far in advance; for example, the VFR intruder might be departing from a non-towered field and "pop up" on radar within a couple of minutes of CPA for the encounter, or alternatively might turn from a practice area toward the UAS shortly before CPA.

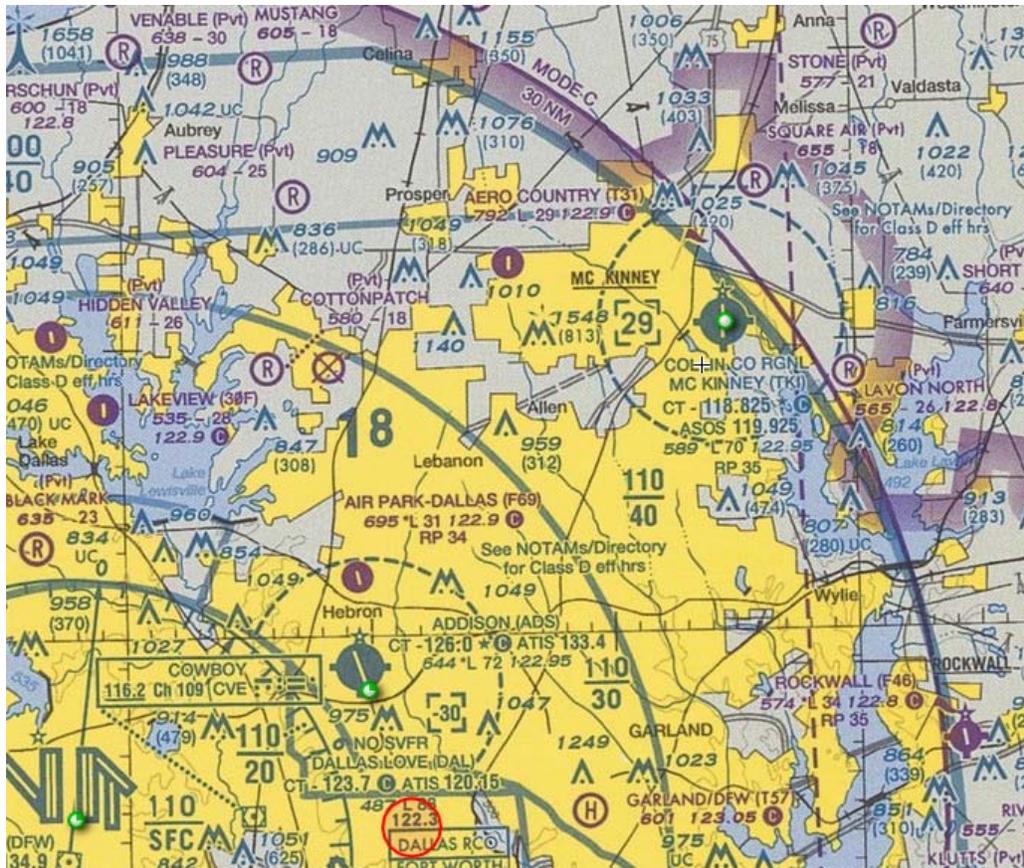


Figure 7. VFR Sectional Chart View – Approximate Location of DN/AR7 Sector

The CAS-1 experiment data collection simulations were performed from January through March 2014 at NASA Langley Research Center’s Stinger Ghaffarian Technologies (SGT) contractor facilities at 130 Research Drive in Hampton, Virginia. Fourteen retired air traffic control volunteers, all with D10 East-side training and experience, were recruited to control the simulated traffic scenarios and assess the acceptability of the different SS encounters. Most of the controllers had retired within the previous year and/or were still active as contract ATC instructors so were familiar with and proficient in D10 operations. None of the controllers had previous experience controlling UAS in their sectors. These ATC volunteers participated in CAS-1 data collection one-at-a-time, each for a two-day session. The first day of a session included approximately three hours of classroom and hands-on training and three one-hour data collection scenarios, and the second day included the remaining three one-hour scenarios and a debrief discussion of approximately one hour.

During the one-hour scenarios all simulated UAS and manned aircraft receiving ATC services from the subject controller were “flown” by instrument-rated pilots as part of the simulation team, and all adjacent sector positions or local controller positions at the towered airports within DN/AR7 were staffed by retired air traffic controllers, also part of the simulation team. Additional traffic was also visible to the controller but not on the sector frequency, including VFR aircraft that were in the sector but not receiving services, landing traffic for which the controller had already approved a frequency change to the tower (or common traffic advisory frequency for non-towered airports), traffic in adjacent or overlying sectors, and traffic overflying the sector (e.g., DFW arrivals); all of this traffic was handled by simulation staffers and/or the MACS automation capabilities.

CAS-1 made the following assumptions for the simulation scenarios and the subject controllers were briefed accordingly during their training:

1. A future UAS operating environment, consistent with assumptions in reference [5] and the FAA draft UAS ConOps, where appropriately certified DAA-equipped UAS would be operationally approved for operations under (only) IFR with the DAA's PITL SS function replacing manned aircraft pilots' see-and-avoid capability for the UAS while away from the immediate airport environment. Controllers were instructed to assume that the SS reliability was no better and no worse than current manned aircraft pilots' see-and-avoid ability.
2. Today's ATC environment with no new UAS-specific operational improvements and only minimal changes to procedures and phraseology to accommodate UAS operations in the same airspace used by manned aircraft.
3. Only nominal UAS DAA operations were simulated, i.e., no lost communications, lost C2 link or equipment failures were simulated and the communication and control latencies were minimized (approximately 100-150 ms communication delay which was the lower limit of the simulation environment).

CAS-1 independent variables included the encounter type (3 values: opposite-direction, overtake, or crossing), the SSV HMD (6 values: 0.5, 1.0, 1.5, 2.0, 2.5 or 3.0 nmi) and, for the crossing encounter type, the relative speed differential (5 values: intruder same speed as the UAS, or 40 or 80 knots slower or faster). This combination of independent variables resulted in 42 test conditions: 6 opposite-direction, 6 overtake and 30 crossing encounter types. A replicate of each test condition was constructed, resulting in the 84 simulated encounters previously mentioned.

The 42 test conditions were randomized in sequence and assigned 14 per hour to scenario Hours 1, 2 and 3, which were presented to the subject controllers (in different orders, e.g., 123, 231, etc., for each subject) on Day 1, so for Day 1 Hours a subject might see one SS encounter with a 1.0 nmi HMD, the next with a 3.0 nmi HMD and the next with a 0.5 nmi HMD, etc. For Hours 4, 5 and 6 on Day 2 the 42 replicate conditions were blocked with the same HMD values for a half-hour at a time, e.g., the first seven encounters in Hour 6 would all have 2.5 nmi HMD and the second seven encounters would all have 3.0 nmi HMD, with the encounter type and speed differential randomized in sequence. This blocking of HMD for Hours 4-6 was done to see if workload ratings were affected if, for example, all UAS in the sector required a large HMD and thus potentially had a larger aggregate effect on traffic disruption. As with Hours 1-3, Hours 4-6 were presented on Day 2 in different orders to different subjects.

The primary CAS-1 dependent metric was a direct assessment of HMD acceptability by the controller subjects immediately after each SS encounter. The assessment was based on a five-point scale as follows:

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

These assessments were elicited verbally and recorded by a retired controller subject matter expert (SME) who was part of the CAS-1 research team and sat next to each controller subject during the data collection runs. This SME was aware of each scripted SS encounter and was also monitoring the sector frequency and other subject controller tasks, so was able to elicit and record each assessment in a timely and non-obtrusive manner. Fractional assessments, e.g., "1.5" were allowed and sometimes assigned by subjects. Subjects were also encouraged, workload-permitting, to vocalize why they assigned a particular numeric

rating, particularly if the reason for the rating was non-obvious and/or if there were extenuating circumstances or additional remarks about the encounter. The controller SME also recorded any explicit action taken (vector, traffic advisory(s), safety alert, adjacent traffic re-route, etc.) by the subject related to each encounter, and noted any operational errors, deviations, significant voice communication errors, re-sequencing and/or other delays or unusual circumstances throughout all of the data runs. Additional dependent metrics included workload self-assessments using the Air Traffic Workload Input Technique (ATWIT) methodology at fixed intervals during the simulation and questionnaires at the end of each one-hour scenario.

This paper reports results of the direct controller assessments of HMD, partial findings from controller comments during the debriefing sessions, and both subject controller and CAS-1 staff evaluations of concept viability. These partial CAS-1 results are presented in the next section.

Partial Results and Discussion

A total of 1176 assessments of HMD were collected during the CAS-1 experiment across all subject controllers and data collection Hours. As expected there was some variability in controllers' subjective assessments of acceptable HMD for SS encounters, particularly for small-HMD encounters, but there was a striking degree of agreement across all encounter geometries that a 1.5 nmi HMD was most acceptable (i.e., ratings at or near "3": neither unsafely close nor disruptively large). More generally, most controllers found HMD values between 1 and 2 nmi acceptable across all encounter geometries. Figure 8 shows average controller acceptability ratings for all opposite-direction (OD) encounters and these trends are apparent in this figure.

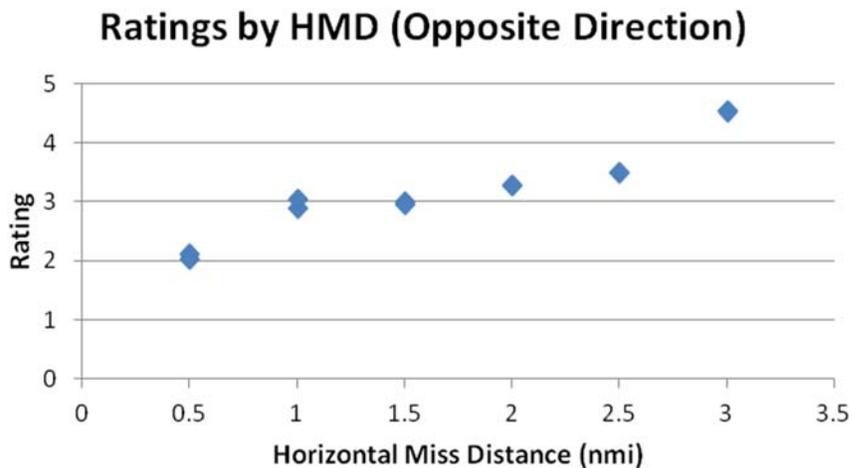


Figure 8. Controller Acceptability Rating Averages: Opposite Direction Encounters

All OD encounters had a "geometric CPA" of zero if no SS action was taken, i.e. these were all initially collision course geometries requiring the UAS pilot to execute a SS maneuver in order to achieve the desired HMD with the respective intruder, and to deviate off course by the full amount of the respective HMD. Due to the high closure rates, a relatively large heading change was required for a SS maneuver to achieve a large HMD (e.g., 3 nmi), and this required heading change would quickly increase (i.e., heading bands would rapidly "grow") if the pilot did not react soon after the first appearance of bands at the LAT

of 70 seconds. In some large-HMD cases there was not enough time for the UAS pilot to negotiate a SS maneuver with the controller before the bands indicated that a heading change of 40 degrees or more was required, and in these cases the UAS pilot made the maneuver first and informed the controller as soon as practicable afterward. Controllers stated in both their debrief comments and in contemporaneous comments immediately after large-HMD encounters that both the magnitude of deviation and the large heading changes were factors in their “excessively wide” ratings (i.e., ratings at or near “5”) for these encounters. They also noted that such large deviations and heading changes without an initial negotiation by the pilot contributed to the disruptiveness of the maneuver. Even in cases where the pilot negotiated the SS maneuver first, large-HMD maneuvers frequently required the controller to “point out” the traffic to adjacent sector controllers (e.g., when the UAS was near a sector boundary), question the UAS pilot about the required extent of his or her SS maneuver, issue traffic advisories to other aircraft in the vicinity or even to modify instructions to these aircraft (e.g., arresting a climb or descent through the UAS’s altitude or issuing a vector to keep separated from the UAS).

The three-dimensional plot in Figure 9 shows more detail behind the average rating data shown in Figure 8. This plot shows the frequency of a given rating for each of the six HMD values, and shows that nearly all of the 1.5 nmi HMD OD encounters received an acceptable “3” rating. The plot also shows the large number of “5” ratings (“excessively wide, unexpected; disruptive”) for 3 nmi HMD OD encounters.

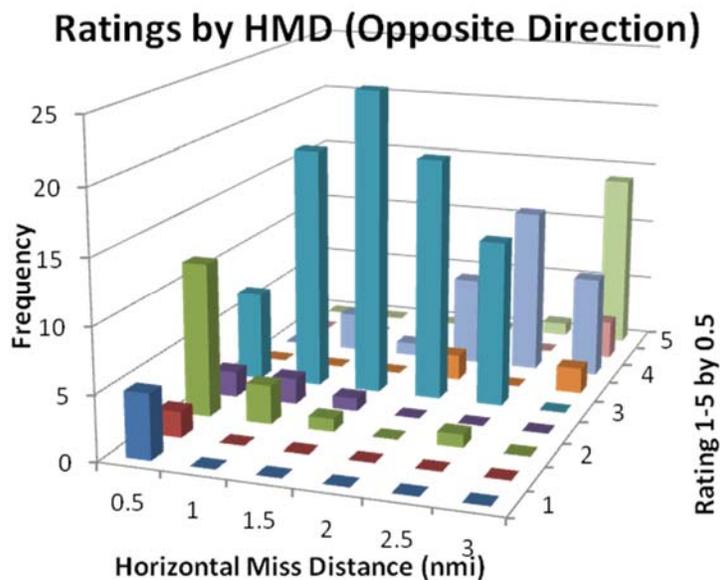


Figure 9. Plot of Frequency of Rating Responses: Opposite Direction Encounters

Much of the variability in controller subjective assessments of acceptable HMD occurred at the smaller end of the range, as can be seen on the plot in figure 9 for the 0.5 nmi HMD OD encounters. The plot shows that the average acceptability rating very near “2” (“somewhat close, some cause for concern”) shown in Figure 8 for 0.5 nmi HMD OD encounters is actually comprised of numerous “1” ratings (“much too close... unsafe... cause for issuance of a traffic alert”) as well as offsetting “3” ratings. This dichotomy was explored in some detail during the debrief sessions with the controllers and represents somewhat of a philosophical split in controller opinion. One cohort of controllers stated that if they had issued a traffic advisory to a (manned or UAS) pilot about an intruder and the pilot responded with “traffic in sight” (or “traffic detected” as the equivalent CAS-1 phrase used by SS-equipped UAS pilots), then the controllers felt that they had fulfilled their obligations and that subsequent separation from the

intruder was entirely the pilot’s responsibility (as supported by regulations), unless the pilot subsequently reported losing contact with the intruder. Another cohort stated that even if a pilot reported the traffic in sight (or detected for UAS) that the controllers still felt an obligation to monitor and intervene if the encounter appeared to be developing in an unsafe manner (one controller stated he felt a “moral obligation” to ensure safe operations in spite of the pilot’s legal obligation to ensure separation). This latter cohort tended to issue more “2” and “1” ratings to 0.5 nmi HMD encounters. Some of these controllers noted during the debrief sessions that they found these small-HMD encounters to be not only potentially unsafe but also disruptive, since they unnecessarily diverted controller attention away from other separation responsibilities elsewhere in his or her sector. It should be noted that nearly all of the participating controllers self-rated themselves during their debrief sessions as likely having a somewhat higher tolerance for small-HMD encounters than the controller population at large, due to their long experience with relatively high-density operations in the D10 TRACON. This subjective self-rating would tend to reinforce a conclusion that SS HMD values of 0.5 nmi for OD encounters may be too close for at least a subset of the controller population.

Figures 10 and 11 show acceptability rating averages and frequency of rating responses, respectively, for overtake (OV) encounters. These were encounters where a UAS was overtaking a VFR intruder by 40 knots on a collision (zero geometric CPA) course and deviated by the specified HMD value to stay clear of the intruder as it was passed. The results in these two figures show trends that are qualitatively similar to the OD encounters, but the small-HMD encounters have fewer “1” ratings and the large-HMD encounters have fewer “5” ratings. This phenomenon was explored to some extent in the debrief sessions and the most likely explanation is that the overtaking encounters had only a 40 knot closure rate and developed much more gradually than did the opposite-direction encounters. This likely led to a better comfort factor for controllers during a gradual, small-HMD overtake, and more time to compensate for the deviations of large-HMD overtakes. The slower closure rates also typically resulted in smaller, more acceptable heading changes to achieve the large-HMD deviations.

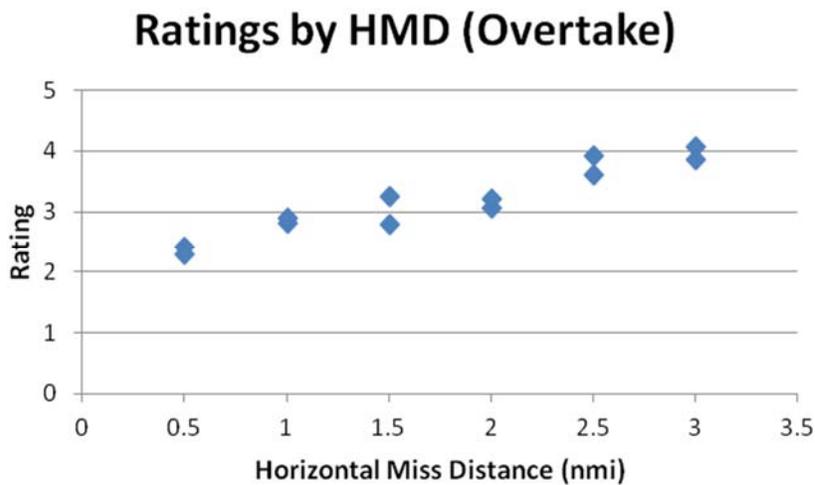


Figure 10. Controller Acceptability Rating Averages: Overtake Encounters

It should be noted from Figure 10 that there was slightly more rating variability from encounter to encounter with the same HMD, versus the OD encounter results shown in Figure 8. That is, the data points in Figures 8 and 10 each represent the average ratings across all 14 controllers for each encounter with a given HMD, even though those encounters occurred at different places in the sector across the six Hours. For example, as shown in Figure 8, the data points for all OD encounters with a 1.5 nmi HMD

basically lie on top of each other, with an average acceptability rating of “3” regardless of where the encounter occurred in the sector. In contrast, Figure 10 shows that some 1.5 nmi HMD OV encounters had average ratings slightly higher than “3” and others (occurring elsewhere in the sector) had ratings slightly lower than “3.” The reason for this slight variance is not immediately clear but is likely due to a deviation in one part of the sector being slightly more disruptive than in another part, due to traffic flow constraints and proximity to adjacent sector boundaries. Regardless of the reason, the OV encounter results in Figures 10 and 11 appear to support the conclusion that a 1-to-2 nmi HMD range is most acceptable to controllers.

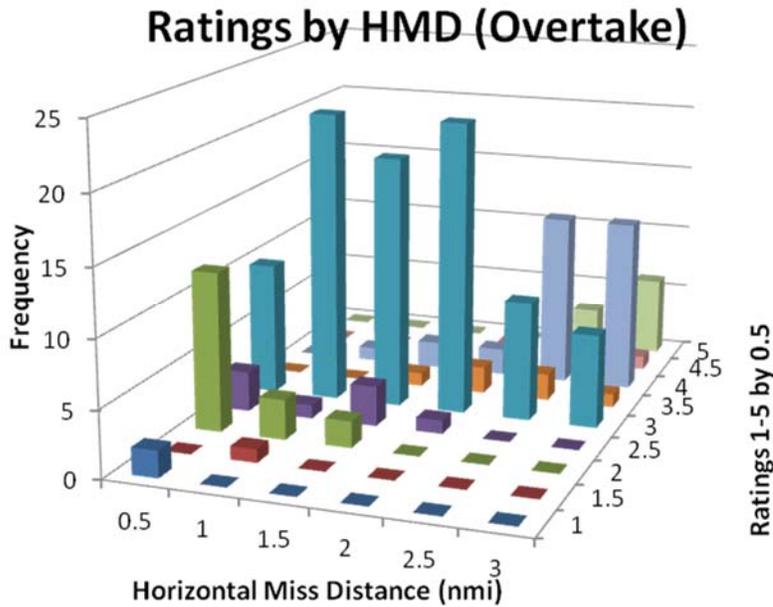


Figure 11. Plot of Frequency of Rating Responses: Overtake Encounters

Crossing (CR) encounters were treated somewhat differently than OD or OV encounters in two ways. First, the geometric CPA was non-zero for all CR encounters, so that if no SS action was taken the UAS would pass in front of the intruder by the amount of the geometric CPA. CR encounters with zero geometric CPA (i.e., collision course geometries) were not used because in almost all cases the obvious operational choice would then be to deviate behind the intruder, and technically there is no “well clear” requirement when passing behind an aircraft. However, there is a requirement to remain well clear when crossing in front of an aircraft, and setting up all CR encounters with non-zero geometric CPAs ensured that the SS encounters would result in the UAS passing in front of the intruder. The interactions between geometric CPA and SS HMD for CR encounters are explained further in the next paragraphs.

The second way that CR encounters were treated differently than OD or OV encounters is that the speed differential between the UAS and intruder was manipulated as part of the construction of encounter geometries. That is, for each of the six SS HMD values, five CR encounters were constructed with the UAS either having the same speed as the intruder, or 40 or 80 knots slower or faster. In all CR encounters with a SS HMD of 1.5 nmi or less, the encounter was constructed with a geometric CPA equal to the HMD, so that no SS maneuver was required to achieve the HMD. For example, for all CR encounter cases with 0.5 nmi SS HMD the encounter geometry was set up with a 0.5 nmi geometric CPA, regardless of the speed differential between the UAS and intruder. In these cases the UAS would cross in

front of the intruder with 0.5 nmi HMD and with no SS maneuver action required or requested. If the subject controller issued a traffic advisory for the crossing traffic (almost always the case for small-HMD encounters) the UAS pilot would respond with either “traffic detected, no factor” or just “traffic detected” and take no action (unless subsequently issued a traffic alert instruction by the controller).

Figures 12 and 13 show acceptability rating averages and frequency of rating responses, respectively, for CR encounters where the UAS was faster than its intruder. In all CR encounters where the UAS was the same speed or faster than its intruder and the HMD was greater than 1.5 nmi, the geometric CPA of the encounter was fixed at 1.5 nmi. For example, in the 3 nmi HMD CR encounter data shown in Figures 12 and 13, the UAS would have crossed in front of the intruder by 1.5 nmi if no SS action was taken, but the bands commanded a further turn away from the intruder and the UAS pilot requested this turn to achieve a 3 nmi HMD (i.e., a 1.5 nmi deviation from course).

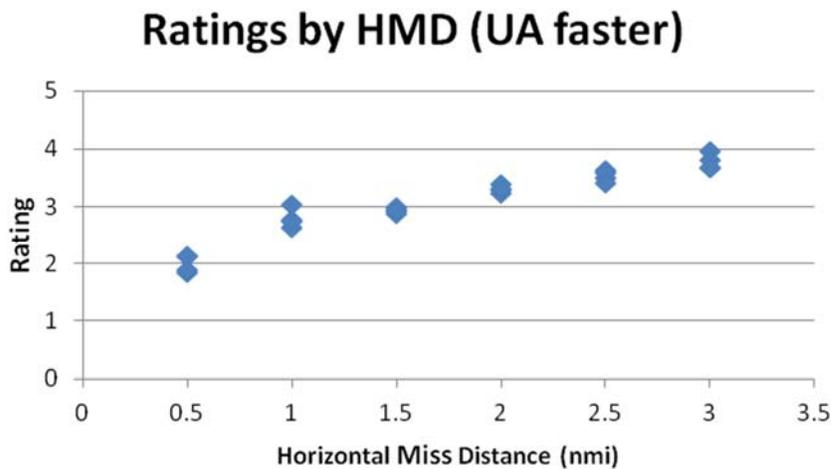


Figure 12. Controller Acceptability Rating Averages: Crossing Encounters, UA Faster

The controller acceptability results shown in Figures 12 and 13 for CR encounter HMD are consistent with results for OD and OV encounters: HMD values between 1 and 2 nmi appear most acceptable to controllers. Figure 13 shows that even when the UAS was faster than its intruder, a significant number of “2” or “1” ratings resulted for 0.5 nmi HMD crossing encounters, indicating significant controller discomfort with these small HMD values. Figure 13 also shows a lower number of “5” ratings for 3 nmi HMD than resulted for OD or OV encounters, but this is likely due to the smaller total path deviations required to achieve 3 nmi of HMD in the CR encounters. That is, a 3 nmi HMD for an OD encounter would require a full 3 nmi deviation from the UAS flight path, whereas a 3 nmi HMD for a CR encounter would only require a 1.5 nmi deviation due to the 1.5 nmi geometric CPA built into the encounter geometry.

Ratings for Crossings (UA Faster)

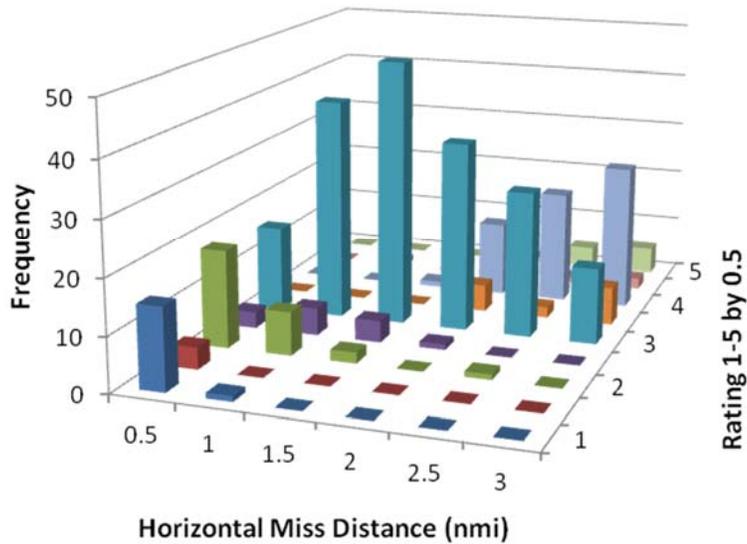


Figure 13. Plot of Frequency of Rating Responses: Crossing Encounters, UA Faster

Figures 14 and 15 show acceptability rating averages and frequency of rating responses, respectively, for CR encounters where the UAS was slower than its intruder. In these cases the geometric CPA for the encounter was set equal to the SS HMD for all values of HMD, so that no SS maneuver action was required to achieve HMD in any case. There were two reasons for this decision. First, it was not clear a priori how much HMD would be required for controller comfort when passing in front of a faster intruder (significantly faster in the 80 knot speed differential case), so the decision was made to explore HMD values all the way out to 3 nmi to find this comfort-factor limit. Second, turning away from a much faster intruder to increase HMD generally doesn't work out well from an encounter geometry perspective and thus was not attempted when constructing scenarios. In real-world crossing encounters where insufficient distance would exist when passing in front of a faster intruder (e.g., a Piper Cub contemplating a cross in front of a Boeing 747 with insufficient HMD) the maneuver is (hopefully) just not attempted, and the slower aircraft typically orbits until the faster aircraft passes, or passes (above and) behind.

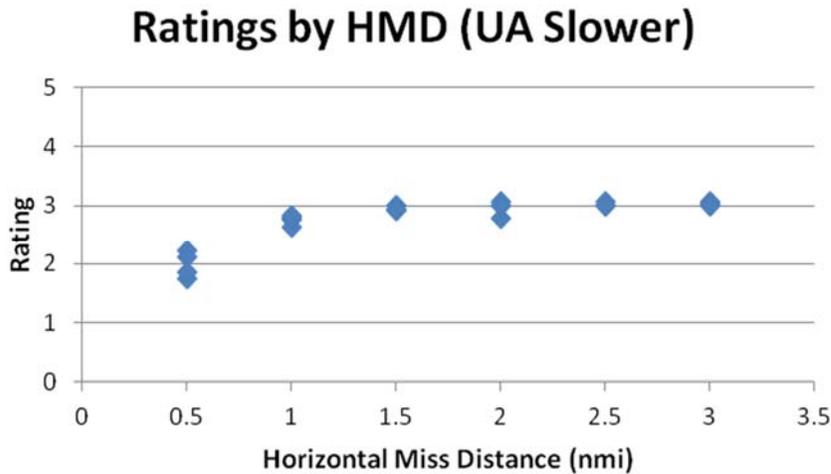


Figure 14. Controller Acceptability Rating Averages: Crossing Encounters, UA Slower

The controller acceptability results shown in Figures 14 and 15 for small-HMD CR encounters are consistent with results for other encounters with small HMD values. That is, a significant number of “2” or “1” ratings resulted for 0.5 nmi HMD crossing encounters, indicating significant controller discomfort with these small HMD values. Interestingly, most of the “too close” ratings disappeared for CR encounters with at least 1 to 1.5 nmi of HMD, even when passing in front of significantly faster intruders. Effectively none of the large-HMD encounters received a rating larger than “3” (i.e., no “too wide” ratings) because none of these encounters required a maneuver to achieve the large HMD. In other words, the UAS and intruder were just two aircraft in the airspace, flying past each other with a large HMD but no requested maneuver. The acceptability rating of “3” is appropriate in this case and fits the “3” rating description of “...did not perceive the encounter to be an issue.” The few “4” ratings for these large-HMD cases were due to misunderstanding of the training on this issue by the first subject, and subsequent training was modified to emphasize that encounters requiring no maneuver by the UAS should not receive ratings higher than “3” since by definition the non-maneuver is not disruptive.

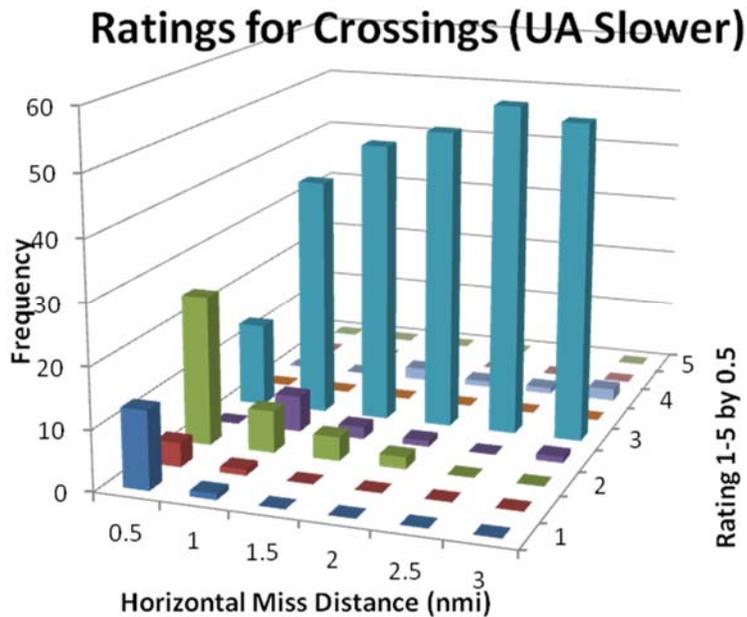


Figure 15. Plot of Frequency of Rating Responses: Crossing Encounters, UA Faster

As previously stated, the exploratory objective of CAS-1 was to evaluate the capability and viability of the prototype PITL SS concept instantiation, from the perspective of both subject air traffic controllers and CAS-1 staff research pilots. To that end, the subject controllers were asked during their debrief sessions if they thought the concept was viable from their perspective as a controller, with the caveat that the final SS HMD thresholds would be set to values that received acceptable (at or near “3”) ratings. The results were unanimously positive. Controller responses included the following:

- “definitely viable”
- “absolutely viable”
- “really impressed, way beyond expectations” [from before arriving and seeing the concept]
- [concept worked] “surprisingly well”
- “impressed with it”
- “don’t see any controller having an issue with” [the concept as presented in CAS-1]

Many of the remarks such as these were volunteered by the controllers during their debrief sessions prior to being explicitly asked about concept viability. In hindsight these results are not overly surprising for several reasons. First, the PITL SS concept was intentionally designed to operate as similarly as possible to the see-and-avoid operations of manned aircraft pilots – from a subject controller’s perspective the only significant difference was phraseology, with “traffic detected” being used by UAS pilots instead of “traffic in sight” for manned aircraft. Second, controllers quickly realized that, as configured for CAS-1, UAS had perfect surveillance capabilities and always “detected” aircraft issued in a traffic advisory, so a sense of confidence was likely built that might not be as great in a real-world deployment of SS-equipped UAS that don’t always detect all intruders every time. Third, the UAS pilots were part of the CAS-1 staff and knew about all of the scripted encounters in advance, so any SS pilot blunders and “surprise factor” reactions that might occur in real-world operations were absent for CAS-1. Still, even with these caveats, the CAS-1 results provide an important validation of the PITL SS concept as outlined in reference [2] and instantiated as described in this paper.

CAS-1 staff pilots and researchers learned a great deal about operating details of the PITL SS concept in a real-world Class E airspace environment and these lessons are being applied to the spiral development of future concept refinements and instantiations. Two specific lessons are as follows: first, a means to reliably inform the pilot of time remaining, if any, to negotiate a SS maneuver with ATC would be highly advantageous. That is, Stratway+ bands appear when an intruder is within the LAT of penetrating the SSV, but a reliable indication of time remaining until the so-called SS Execution Threshold (SET), i.e., threshold beyond which no SS maneuver can avoid SSV penetration, did not exist in the CAS-1 instantiation of the concept. Second, Stratway+ has no knowledge of intruder intent and this lack of knowledge can lead to some false alerts. A particularly troublesome example of these false alerts is the case of an aircraft nearby laterally that is descending to an altitude 500' or 1000' above the Ownship and then leveling. This will cause Stratway+ to provide bands across all 360 degrees of heading and bands on the VVI that indicate a descent is necessary; these bands all disappear (except for a "don't climb" band on the VVI for an intruder 500' above) once the intruding aircraft levels at its new altitude. In many of these cases the UAS pilot is aware of the intruder's intent to level off, either by monitoring the party-line sector frequency and/or through explicit communication with the controller. Possible means for conveying this information to the Stratway+ SS guidance algorithm are under consideration for future refinements to the concept.

Conclusions

The data presented in the previous section show that when the UAS PITL SS capability described in this paper was simulated in moderate-complexity Class E airspace operations concurrent with light-to-moderate manned aircraft traffic, a SS HMD value of 1.5 nmi had the highest acceptability rating among all CAS-1 air traffic controller volunteers across all encounter geometries – opposite-direction, overtake, and crossing encounters with a wide range of speed differentials between the UAS and intruder aircraft. A total of 1176 controller assessments were obtained across all encounter geometries with a striking degree of agreement among the controller volunteers about the acceptability of 1.5 nmi HMD. More generally, most controllers assessed HMD values between 1 and 2 nmi to be acceptable (neither unsafely close nor disruptively large) across all encounter geometries. There was more variability in controller assessments of 0.5 nmi HMD encounters but a significant number of these assessments considered this HMD value to be too small and potentially unsafe. HMD values larger than 2 nmi were generally assessed as increasingly disruptive to orderly traffic flow. These results should be useful to inform the development of operational performance standards for DAA SS functions. For example, it may be appropriate for standards to specify that SS functions should always indicate that SS maneuvering is necessary for encounters that will result in projected HMD values less than 1 nmi, and never indicate a required SS maneuver if the projected HMD is greater than 2 nmi.

All 14 air traffic controller volunteers were favorably impressed with the PITL SS concept as simulated and presented to them, and considered the concept to be viable from an ATC perspective under the assumption that acceptable SS HMD values are employed. CAS-1 staff pilots also assessed the concept favorably and considered the simulation time valuable in identifying enhancements for future refinements of the concept. These controller and pilot assessments were significant since CAS-1 was the first sustained opportunity to exercise the Stratway+ instantiation of the PITL SS concept in a realistic controller-pilot simulation that was representative of the moderate-complexity, lower-altitude Class E airspace that will pose one of the most challenging environments for DAA-equipped UAS.

References

1. Sense and Avoid (SAA) for Unmanned Aircraft Systems (UAS). Prepared by: FAA sponsored Sense and Avoid Workshop; aka SAA First Caucus Workshop Report. October 9, 2009
2. Consiglio M., Chamberlain J., Muñoz C., and Hoffer K. Concept of Integration for UAS Operations in the NAS. 28th International Congress of the Aeronautical Sciences, Brisbane, Australia, 23-28 September 2012
3. Sense and Avoid (SAA) for Unmanned Aircraft Systems (UAS) Second Caucus Workshop Report. Prepared by: FAA sponsored Sense and Avoid Workshop. January 13, 2013
4. RTCA SC-228 Working Group 1 Document No. WG1-WP02-09 DAA Architecture Scope Considerations. Submitted by: Chamberlain J. and Consiglio M. August 12, 2013
5. RTCA Paper No. 074-14/PMC-1200 Detect and Avoid (DAA) White Paper. Prepared by: SC-228. March 18, 2014
6. Introduction to TCAS II version 7.1. Prepared by U.S. Department of Transportation Federal Aviation Administration. February 28, 2011
7. RTCA-DO-185B, Minimum operational performance standards for traffic alert and collision avoidance system II (TCAS II). Prepared by RTCA SC-147. July 1, 2009
8. Anthony Narkawicz, César Muñoz, and Gilles Dowek, [*Provably Correct Conflict Prevention Bands Algorithms*](#), [*Science of Computer Programming, Volume 77, Issues 10-11, pp. 1039-1057*](#), September 2012
9. César Muñoz, Anthony Narkawicz, and James Chamberlain, [*A TCAS-II Resolution Advisory Algorithm*](#), Proceedings of the AIAA Guidance, Navigation, and Control Conference (GNC), AIAA-2013-4622, Boston, Massachusetts, August 2013
10. Anthony Narkawicz, César Muñoz, Jason Upchurch, James Chamberlain, and María Consiglio, [*A Well-Clear Volume Based on Time to Entry Point*](#), Technical Memorandum, NASA/TM-2014-218155, January 2014
11. César Muñoz, Anthony Narkawicz, James Chamberlain, María Consiglio, and Jason Upchurch, [*A Family of Well-Clear Boundary Models for the Integration of UAS in the NAS*](#), Proceedings of the 14th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, AIAA-2014-2412, Atlanta, Georgia, 2014
12. Thomas Prevot, Exploring the Many Perspectives of Distributed Air Traffic Management: The Multi Aircraft Control System MACS, HCI-02 Proceedings, American Association for Artificial Intelligence (AAAI), 2002.
13. <http://humansystems.arc.nasa.gov/groups/aol/technologies/macs.php>

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1. REPORT DATE (DD-MM-YYYY) 01-05 - 2015		2. REPORT TYPE Technical Memorandum		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE NASA Controller Acceptability Study 1(CAS-1) Experiment Description and Initial Observation				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
				5d. PROJECT NUMBER	
6. AUTHOR(S) Chamberlain, James P.; Consiglio, Maria C.; Comstock, James R., Jr.; Ghatas, Rania W.; Munoz, Cesar A.				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER 475122.02.07.08.06.03	
				8. PERFORMING ORGANIZATION REPORT NUMBER L-20548	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, VA 23681-2199				10. SPONSOR/MONITOR'S ACRONYM(S) NASA	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001				11. SPONSOR/MONITOR'S REPORT NUMBER(S) NASA-TM-2015-218763	
				12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 03 Availability: NASA STI Program (757) 864-9658	
13. SUPPLEMENTARY NOTES					
14. ABSTRACT This paper describes the Controller Acceptability Study 1 (CAS-1) experiment that was conducted by NASA Langley Research Center personnel from January through March 2014 and presents partial CAS-1 results. CAS-1 employed 14 air traffic controller volunteers as research subjects to assess the viability of simulated future unmanned aircraft systems (UAS) operating alongside manned aircraft in moderate-density, moderate-complexity Class E airspace. These simulated UAS were equipped with a prototype pilot-in-the-loop (PITL) Detect and Avoid (DAA) system, specifically the Self-Separation (SS) function of such a system based on Stratway+ software to replace the see-and-avoid capabilities of manned aircraft pilots. A quantitative CAS-1 objective was to determine horizontal miss distance (HMD) values for SS encounters that were most acceptable to air traffic controllers, specifically HMD values that were assessed as neither unsafely small nor disruptively large. HMD values between 0.5 and 3.0 nautical miles (nmi) were assessed for a wide array of encounter geometries between UAS and manned aircraft. The paper includes brief introductory material about DAA systems and their SS functions, followed by descriptions of the CAS-1 simulation environment, prototype PITL SS capability, and experiment design, and concludes with presentation and discussion of partial CAS-1 data and results.					
15. SUBJECT TERMS Acceptability; Air traffic controllers; Airspace; Controllers; Experiment design					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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