NASA'S UAS INTEGRATION INTO THE NAS:
A REPORT ON THE HUMAN SYSTEMS INTEGRATION
PHASE 1 SIMULATION ACTIVITIES

Lisa Fern & R. Conrad Rorie, San Jose State University
R. Jay Shively, NASA Ames Research Center

In 2011 the National Aeronautics and Space Administration (NASA) began a five-year Project to address the technical barriers related to routine access of Unmanned Aerial Systems (UAS) in the National Airspace System (NAS). Planned in two phases, the goal of the first phase was to lay the foundations for the Project by identifying those barriers and key issues to be addressed to achieve integration. Phase 1 activities were completed two years into the five-year Project. The purpose of this paper is to review activities within the Human Systems Integration (HSI) subproject in Phase 1 toward its two objectives: 1) develop GCS guidelines for routine UAS access to the NAS, and 2) develop a prototype display suite within an existing Ground Control Station (GCS). The first objective directly addresses a critical barrier for UAS integration into the NAS – a lack of GCS design standards or requirements. First, the paper describes the initial development of a prototype GCS display suite and supporting simulation software capabilities. Then, three simulation experiments utilizing this simulation architecture are summarized. The first experiment sought to determine a baseline performance of UAS pilots operating in civil airspace under current instrument flight rules for manned aircraft. The second experiment examined the effect of currently employed UAS contingency procedures on Air Traffic Control (ATC) participants. The third experiment compared three GCS command and control interfaces on UAS pilot response times in compliance with ATC clearances. The authors discuss how the results of these and future simulation and flight-testing activities contribute to the development of GCS guidelines to support the safe integration of UAS into the NAS. Finally, the planned activities for Phase 2, including an integrated human-in-the-loop simulation and two flight tests are briefly described.

INTRODUCTION

In 2011 the National Aeronautics and Space Administration (NASA) began a five-year Project to address the technical barriers related to routine access of Unmanned Aerial Systems (UAS) in the National Airspace System (NAS; NASA, 2013). In it's formulation phase, the NASA UAS Integration into the NAS Project identified three key technical subproject areas to focus on: 1) Separation Assurance Sense and Avoid Interoperability (SSI), 2) Human Systems Integration (HSI), and 3) Communication. A fourth subproject, Integrated Test and Evaluation, supports the simulation and flight test activities of the other three subprojects. The execution of the UAS in the NAS Project was planned over two phases. The goal of the first phase was to lay the foundations for the Project by working with the UAS community to: 1) determine the barriers to routinely access the NAS and 2) identify the issues that need to be addressed to achieve integration. The goal of the second phase is to reduce those technical barriers through maturing research capabilities, development, modeling and simulation and live flight demonstration. The purpose of this paper is to review key activities within the HSI subproject in Phase 1.

At the project's inception, HSI formulated two overarching and highly interrelated objectives: first, to develop GCS guidelines for UAS access to the NAS, and second, to develop a prototype display suite within an existing Ground Control Station (GCS; Fern, Shively, Johnson, Trujillo, Pestana & Hobbs, 2011). The first objective addresses a critical barrier identified by HSI – the lack of GCS design standards or requirements for UAS operations in the NAS. The prototype GCS display suite is HSI's primary research capability and achieves three purposes for the subproject: 1) it serves as a test-bed for UAS pilot procedures and displays, 2) it provides data input for guidelines development, and 3) it provides an instantiated proof of concept of those guidelines. Of primary concern to HSI is how to present new information in the GCS in an integrated and intuitive manner in order to ensure manageable pilot workload, while at the same time increasing situation awareness.

Given the importance of the prototype GCS display suite to the ultimate success of the HSI subproject, early Phase 1 activities focused on the development of the GCS and other simulation capabilities to support human-in-the-loop (HITL) testing. Once an initial GCS test-bed capability was developed, a number of simulation experiments were conducted which provide the initial inputs to the database that will ultimately inform the GCS guidelines. This paper summarizes the prototype GCS and simulation development, as well as experimental testing activities that HSI conducted in Phase 1. The authors also discuss how the results of these and future simulation and flight-testing activities contribute to the development of GCS guidelines UAS integration into the NAS. Finally, the planned activities for Phase 2 are briefly described.

SIMULATION DEVELOPMENT

In order to support HITL testing of the prototype GCS display suite, a robust simulation environment was needed to provide a realistic emulation of key features of the current

NAS. The simulation architecture employed in HSI's HITL simulations has evolved over the course of Phase 1, utilizing existing air traffic simulation software as well as new tools developed by other UAS in the NAS subprojects. The prototype GCS and supporting simulation software are described below.

Vigilant Spirit Control Station (VSCS)

At the beginning of the Project, the HSI subproject needed to identify a suitable UAS GCS to provide the core functionality of the prototype GCS and display suite. Initially, the HSI subproject utilized the Multiple UAS Simulator (MUSIM) developed by the U.S. Army. MUSIM is a medium fidelity simulator that was designed to conduct applied research on the supervisory control of multiple UAS (see Fern & Shively, 2009 for an example).

Although MUSIM provided a flexible test bed for rapid prototyping of displays, it lacked the necessary sophistication, such as realistic control and navigation displays, health and status monitoring, etc., required of a GCS that would eventually be taken to flight test. Alternatively, currently fielded GCSs are highly proprietary with significant procedural and technical barriers that prevent the development and integration of prototype displays. The compromise between a highly flexible and changeable test bed and a rigid proprietary GCS came from the Air Force Research Laboratory's (AFRL) Vigilant Spirit Control Station (VSCS; Feitshans, Rowe, Davis, Holland & Berger, 2008). VSCS is a mature GCS that has been used to control multiple UAS in both simulation and flight tests. VSCS provides a robust yet flexible pilot interface as well as critical technology to support future flight-testing activities. A specific version of VSCS is being developed by HSI in collaboration with AFRL to support its research, prototyping, and guidelines development activities. The current version employs single UAS control and includes a NAS-compatible database that allows pilots to fly filed flight plans based on known navigational aids. VSCS provides the primary display features of the GCS and also generates the UAS target and its associated trajectory. Figure 1 shows the primary VSCS display for the most recent simulation – the Tactical Situation Display (TSD) that displays the UAS ownship and mission route over a moving map. Work is just beginning on developing integrated traffic displays on the TSD that will support the pilot tasks necessary for maintaining self-separation and collision avoidance.

Cockpit Situation Display (CSD)

The prototype GCS also includes the Cockpit Situation Display (CSD). The CSD, a separate software application from the VSCS, is a 3D volumetric display capable of displaying the locations and 4D trajectories of both ownship and surrounding traffic (Granada, Dao, Wong, Johnson, & Battiste, 2005). HSI has limited some of the CSD's capabilities to better align with the group's research goals. Namely, the CSD has been limited to 2D display orientations and has been prevented from displaying the trajectories of non-ownship traffic, which assumes the adoption of NextGen technologies by the surrounding aircraft. The CSD also has built in logic for displaying conflict alerts and resolution maneuvers which has been replaced with conflict detection and alerting parameters as defined by the Sense and Avoid Processor (SAAProc), a tool developed by the SSI subproject.
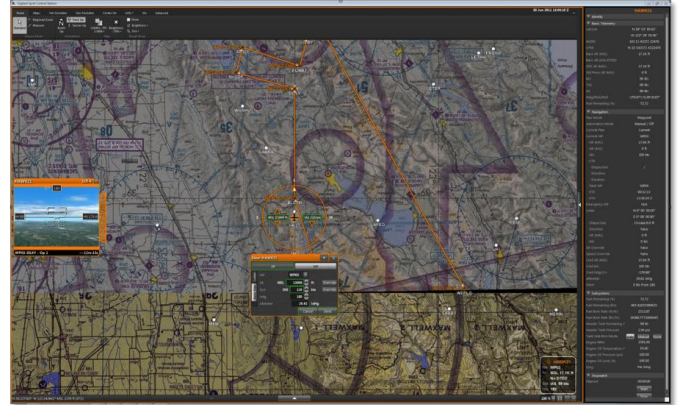

Figure 1. Vigilant Spirit Control Station tactical situation display (AFRL/RH). Distribution A: Approved for public release; distribution unlimited. 88ABW Cleared 3/18/2013; 88ABW-2013-1303.

Multi Aircraft Control Station (MACS)

The MACS simulation software provides the general airspace simulation environment. MACS is a medium-fidelity computer application designed to emulate ground- and air-side operations (Prevot, 2002). MACS has been configured specifically for HSI's research needs, allowing experimenters to tailor the simulated airspace, manned traffic patterns, and Air Traffic Control (ATC) displays to address specific research questions. MACS provides an approximation of a current-day en-route controller display, as well as pseudo pilot stations where confederates are able to dynamically control simulated aircraft in order to comply with real-time controller clearances. MACS also functions as the simulation's traffic generator, allowing for both the development and playback of simulated manned traffic targets. MACS targets are broadcast in conjunction with the Aeronautical Data link and Radar Simulator (ADRS), which propagates the traffic information generated by the MACS Simulation Manager to the remaining instances of MACS. The controller display, pseudo pilot stations, and traffic scenarios are deliberately configured to maximize realism and overall simulation flexibility.

Sense and Avoid Processor (SAAProc)

The SAAProc receives trajectory information from ownship as well as state information from all simulated manned targets produced by the MACS software. The SAAProc determines whether or not a given target is to be displayed on the CSD [typically using an Automatic Dependent Surveillance-Broadcast (ADS-B) sensor range of 80nm laterally and 4000 feet above or below ownship]. Targets that fall within this range are considered intruders and are subsequently provided for display on the CSD (or on the VSCS TSD in the future). The SAAProc concurrently queries all intruders for potential conflicts with ownship. Detected

conflicts are assigned a threat level and presented as such via the CSD. The SAAProc also has the ability to generate lateral and vertical resolution maneuvers.

Simulation Architecture

MACS, ADRS VSCS, CSD and SAAProc are all connected via the Live, Virtual, and Constructive (LVC) Gateway (for a discussion of the LVC simulation environment, see Murphy, 2014). The LVC Gateway is configured to port ownship trajectory information from VSCS to ADRS, which then propagates the data to the various instances of MACS. This allows for the VSCS aircraft to be displayed on the ATC displays. The LVC Gateway also accepts all state information broadcast by MACS and ADRS, sending the simulated manned traffic data to the SAAProc. As described above, the SAAProc filters the information for potential intruders and conflicts with ownship, ultimately outputting the results to the LVC Gateway. Finally, the LVC Gateway ports any targets labeled as intruders or conflicts to the CSD, which presents surrounding traffic according to the prescribed alerting logic. Figure 2 provides a simplified, high-level diagram of this architecture.
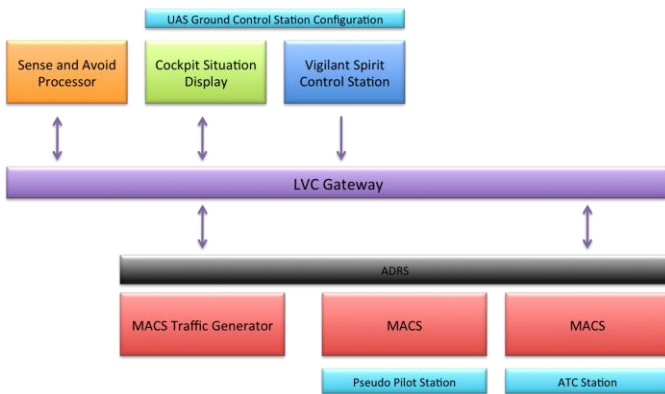

Figure 2. The simulation architecture used to support HSI HITL simulations with the prototype GCS.

SIMULATION EXPERIMENTS

In Phase 1, HSI completed three simulation experiments utilizing the above architecture with the prototype GCS display suite. Two of the simulations examined UAS pilot performance in various operating conditions, while the third examined the effect of UAS operations on ATC.

Simulation 1: UAS Pilot Baseline Compliance

The main focus of HSI is to understand and measure the effect of various GCS interfaces on UAS pilot performance in the NAS under current and, expected near-term, operating conditions in order to provide the foundations of the GCS database and guidelines. The first HSI experiment sought to establish a minimum baseline performance for a UAS pilot operating under current Instrument Flight Rules (IFR) in positively controlled airspace (Fern, Kenny, Shively & Johnson, 2012). A primary concern surrounding the

integration of UAS in the NAS is transparency with manned aircraft – the onus is on UAS pilots to comply with current rules and regulations. Any deviations from current, normal operations require additional ATC attention and potentially increase workload. Subject Matter Expert (SME) controllers participating in the experiment reported that, compared to pilots of manned aircraft, the pilots who participated in the study were able to comply immediately and appropriately to ATC instructions. In addition, they felt the participant pilots had sufficient knowledge of the airspace and procedures, and were able to use the limited NAS-compatible database in the GCS to execute commanded maneuvers. ATC indicated that they used special handling procedures for the UAS 0-25% of the time, which was reported as being not notably different than current operations with manned aircraft.

The Fern et al. (2012) study also examined the effect of introducing a basic traffic display on pilot performance. The traffic display provided only minimal information on proximal traffic and their relative altitudes compared to ownship. No current UAS GCS operating in U.S. civil airspace include a traffic information display, however, in positively controlled airspace where ATC is responsible for safe separation, the presence of a traffic display was not expected to significantly impact pilot performance.

The results of this study confirmed the lack of an effect on pilots' ability to maintain safe separation from other aircraft; no significant differences were found in minimum horizontal and vertical distances between the display conditions, nor were there any significant differences in the number of losses of separation between the display and no-display conditions. However, pilots did report significantly higher situation awareness on five of the six dimensions measured when the traffic display was present. Further, both pilots and controllers reported easier voice communications with the display present, likely because it provided the pilots with a common picture of the airspace as ATC. Fern, et al. noted that the presence of a traffic display is more likely to affect pilots' ability to maintain separation and collision avoidance when ATC services are either not provided (such as in different classes of airspace), or when they fail. Future HSI research will examine some of these conditions.

Simulation 2: Effect of Contingency Management on ATC

As previously noted, much of the research focus within HSI is on UAS pilot performance and workload. However, a simulation experiment was conducted to examine the effects of currently employed UAS contingency procedures on ATC performance and workload (Fern, Rorie & Shively, 2014). UAS-specific contingencies such as a loss of the Command and Control (C2) link (i.e. "lost link") and autonomous emergency landing, which result from the unique communication architectures of UAS, present new challenges to the ATC environment. UAS contingency procedures may result in unexpected behaviors, such as a change of course or altitude without a clearance, that have the potential to greatly increase ATC workload. Increased ATC workload may in turn cause controllers to apply increased separation buffers

between the UAS and other aircraft, decreasing the efficiency of the airspace.

To test the effects of various contingency procedures on ATC, Fern et al. (2014) compared three lost link contingency scenarios and one emergency-landing scenario to a baseline scenario that contained no contingency event. The four different contingency procedures simulated in the study were modeled after procedures that are currently employed for UAS under Federal Aviation Administration (FAA) Certificates of Authorization. No significant differences were found on objective measures of sector safety or efficiency between the different contingency behaviors. Similarly, none of the contingency scenarios were found to significantly differ from the baseline scenario. Further, there were no significant differences in reported workload or situation awareness of the controller participants. In post simulation interviews, ATC participants indicated a preference for procedures that minimized deviations and/or provided them with sufficient time to manage nearby aircraft in advance of pre-planned deviations.

The lack of any significant differences between contingency conditions provides strong evidence of the flexibility and resilience of controllers and the ATC environment, as well as the feasibility of UAS integration into the NAS. However, Fern et al. (2014) acknowledge that the results need to be interpreted cautiously; future research is still needed to understand the boundaries of ATC performance, especially with respect to future UAS operations.

Simulation 3: Effect of Control Interfaces on UAS Pilot Performance

The most recent HSI simulation experiment investigated the effects of different control mode interfaces on pilot performance while responding to ATC clearances (Rorie & Fern, 2014). Current UAS vary widely in their primary methods of control, however most employ a waypoint-to-waypoint flight plan capability with a manual Hands on Throttle and Stick (HOTAS) mode and/or an ability to command heading and altitude holds or overrides. More important than the primary means of control within a GCS, is the design and implementation of the control mode interfaces; a poorly designed control interface has the potential to significantly impact pilot response times to ATC instructions or self-separation or collision avoidance alerting.

Rorie & Fern (2014) examined the effects of three control mode interfaces on pilot response times when complying with ATC clearances: 1) Waypoint, 2) Auto-Pilot (with an electronic heading, speed, and altitude hold interface), and 3) Manual (with a HOTAS). Figure 3 shows the GCS set up for this study with the pilot operating in the Manual control mode. Comparing the three control mode interfaces, Auto-Pilot and Manual were both found to have significantly shorter compliance times compared to Waypoint (31s and 27s versus 54s, respectively). The benefit from Auto-Pilot was seen in the shortest time to initiate a response to an ATC clearance in the control interface compared to Manual and Waypoint (1s versus 4s and 6s, respectively). Where as the benefit from Manual was due to significantly shorter times to input an edit

(i.e. flight plan or trajectory change) compared to AP and Waypoint (1s versus 9s and 33s, respectively).

Overall the results of the Rorie & Fern study directly demonstrate the substantial effect that control mode interfaces can have on pilots' ability to comply immediately to ATC commands. Further, these results can be extrapolated to likely response times for pilots using various control mode interfaces to respond to self-separation and collision avoidance alerting, a critical component of any future Detect and Avoid (DAA) system for UAS.
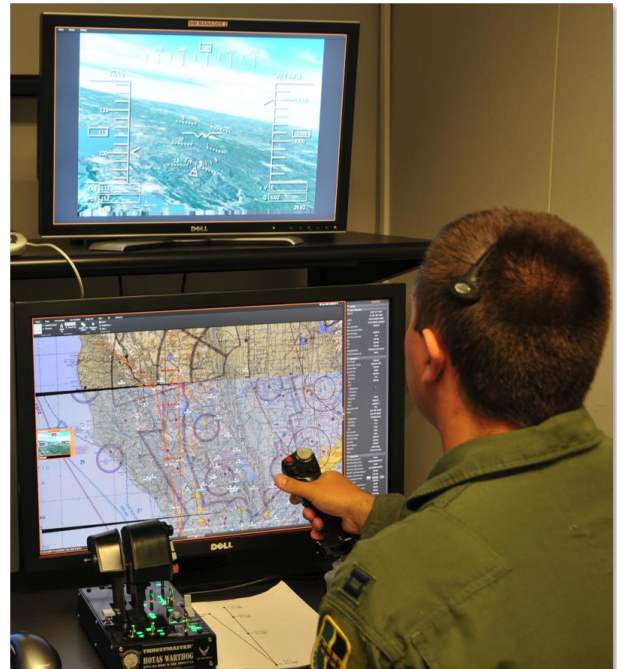

Figure 3. Simulation 3 GCS set up with the Manual HOTAS control mode.

GCS GUIDELINES DEVELOPMENT

The ultimate goal of HSI is to develop GCS guidelines that will enable safe and routine integration of UAS into the NAS. One key purpose of the prototype GCS display suite is to generate a database of simulation and flight test results that inform those guidelines. HSI is working with RTCA Special Committee 228 (SC-228) Minimum Operational Performance Standards (MOPS) for Unmanned Aircraft Systems (RTCA, 2013). RTCA established SC-228 at the request of the FAA to develop MOPS for DAA and C2 data link equipment. HSI participates in both the DAA and C2 working groups, and will identify and write the display and other human factors requirements relating to be the DAA and C2 systems for UAS, deriving many of those from the GCS database. For example, the results from Simulation 3 described above will help HSI and SC-228 to determine the minimum performance requirements for UAS control and navigation interfaces, based on what the group determines to be acceptable response time for pilots to respond to ATC clearances.

The final MOPS are scheduled to be completed in July 2016. Given that DAA and C2 do not encompass the entire GCS, HSI will also develop a separate requirements document

that will address human factors requirements for the entire GCS (specific to operation in the NAS).

CONCLUSION AND FUTURE ACTIVITIES

In Phase 1, the HSI subproject of NASA's UAS Integration into the NAS project began development of a prototype GCS display suite and a supporting simulation test environment. Three simulation studies utilizing that test environment examined both UAS pilot and ATC performance for a UAS operating in civil airspace under current ATC rules for manned IFR aircraft. Cumulatively, these three studies have increased the understanding of critical human factors affecting the integration of UAS into the NAS. Specifically, Simulations 1 and 3 have added considerably to the database and understanding of UAS pilot performance in civil airspace, which will be critical to developing GCS display and other human factors guidelines that will support safe integration of UAS into the NAS.

The efforts of this project are just scratching the surface of work that needs to be done to fully integrate UAS and take full advantage of their unique capabilities. In Phase 2, HSI will continue to mature it's research capability, the prototype GCS, through continued development and testing. The next two planned simulations will focus on the design and implementation of DAA displays. This work includes: identifying the minimum information requirements for traffic displays, comparing standalone versus integrated displays, and evaluating advanced display concepts such as decision aiding and pilot guidance. Like Simulation 3 described above, these simulations will closely examine the effect of various DAA display conditions and elements on UAS pilot response times – a critical component to the overall safety of a UAS operating in civil airspace with other aircraft. In addition, HSI will test its prototype display suite configurations within a project-level integrated HITL simulation and two planned flight tests with the other subprojects (NASA, 2013). These integrated activities allow the three key technical subprojects (Communication, SSI, and HSI) to integrate their separate efforts and capabilities into a more robust and realistic test environment. The 2015 and 2016 flight tests, utilizing a manned surrogate aircraft equipped with key UAS technologies, will serve to validate the results of the simulation activities.

Farther term work will focus on higher levels of autonomy and integration with the advancing ATM system: NextGen. Simulation studies will continue to feed the efforts to develop the prototype display suite within VSCS and define GCS requirements for UAS integration into the NAS.

REFERENCES

Fern, L., Rorie, R. C., & Shively, R. J. (2014). UAS contingency management: the effect of different procedures on ATC in civil airspace operations. *Proceedings of the 14th Annual AIAA Aviation, Technology, Integration and Operations Conference,* Atlanta, GA, June 16-20.

Fern, L., Kenny, C., Shively, R. J., & Johnson, W. (2012). UAS integration into the NAS: an examination of baseline compliance in the current airspace system. *Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting*, Boston, MA, October 22-26.

Fern, L., Shively, R. J., Johnson, W., Trujillo, A., Pestana, M., & Hobbs, A. (2011). Human factors challenges facing UAS integration into the NAS. *Proceedings of the 16th International Symposium on Aviation Psychology,* Dayton, OH, May 3-5.

Fern, L. & Shively, R. J. (2009). A comparison of varying levels of automation on the supervisory control of multiple UASs. *Proceedings of AUVSI's Unmanned Systems North America 2009*, Washington, D.C., August 10-13.

Feitshans, G. L., Rowe, A. J., Davis, J. E., Holland, M., & Berger, L. (2008). Vigilant spirit control station (VSCS)—'The face of COUNTER'. *In Proceedings of AIAA Guidance, Navigation and Control Conf. Exhibition*, Honolulu, HI. AIAA Paper (No. 2008-6309).

Granada, S., Dao, A. Q., Wong, D., Johnson, W. W., & Battiste, V. (2005). Development and integration of a human-centered volumetric cockpit display for distributed air-ground operations. *Proceedings of the 12th International Symposium on Aviation Psychology*. Oklahoma City, OK, April 14-17.

Murphy, J. R. (2014). *Message latency characterization of a distributed, live, virtual, constructive simulation environment*. Manuscript submitted for publication.

National Aeronautics and Space Administration (2013). *Technology Development Project Plan*. Washington, D.C.: Government Printing Office.

Prevot, T. (2002) Exploring the many perspectives of distributed air traffic management: The Multi Aircraft Control System MACS in S.Chatty, J. Hansman, and G. Boy (Eds.) *Proceedings of the International Conference on Human-Computer Interaction in Aeronautics*, HCI-Aero 2002 AAAI Press, Menlo Park, CA.

Rorie, R. C. & Fern, L. (2014). UAS measured response: the effect of GCS control mode on pilot ability to comply with ATC clearances. *Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting,* Chicago, IL , October 27-31.

RTCA (2013). *Terms of Reference: RTCA Special Committee 228 Minimum Performance Standards for Unmanned Aircraft Systems*. Washington, D. C..