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UAS-NAS

Stakeholder Feedback Report

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Prepared by:

Debra Randall 9-26-16

Debra Randall Date
Project Chief Systems Engineer, NASA AFRC

9-26-16

Jim Murphy Date
Integrated Test and Evaluation Co-Project Engineer, NASA ARC

Approved by:

for Robert D. Sakahara 9-26-16

Laurie Grindle Date
Project Manager, NASA AFRC

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1 INTRODUCTION

The need to fly UAS in the NAS to perform missions of vital importance to national security and defense, emergency management, science, and to enable commercial applications has been continually increasing over the past few years. To address this need, the NASA Aeronautics Research Mission Directorate (ARMD) Integrated Aviation Systems Program (IASP) formulated and funded the Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project (hereafter referred to as UAS-NAS Project) from 2011 to 2016. The UAS-NAS Project identified the following need statement: The UAS community needs routine access to the global airspace for all classes of UAS. The Project identified the following goal: To provide research findings to reduce technical barriers associated with integrating UAS into the NAS utilizing integrated system level tests in a relevant environment.

The project goal was accomplished through the development of system-level integration of key concepts, technologies and/or procedures, and demonstrations of integrated capabilities in an operationally relevant environment with the following objectives:

- Develop research findings (including validated data, algorithms, analysis, and recommendations) to support key decision makers in establishing policy, procedures, standards and regulations, enabling routine UAS access in the NAS.

- Develop UAS design and performance criteria necessary for airworthiness certification.

- Establish the infrastructure for the integrated test and evaluation (IT&E) environment for UAS Integration in the NAS simulations and flight demonstrations.

1.1 Purpose

This Stakeholder Feedback Report will provide a summary of the collaborations between the UAS-NAS Project and its primary stakeholders, the Federal Aviation Administration (FAA) and the RTCA Special Committee (SC)-228 Minimum Operational Performance Standards for Unmanned Aircraft. It will demonstrate how the UAS-NAS Project used the feedback from stakeholders to impact their research and contribute to solving the technical challenges of routinely flying UAS in the NAS.

1.2 Scope

The report is structured to cite specific examples of how the UAS-NAS project and its stakeholders collaborated to increase the relevancy of the flight test and simulation environment and the resulting outcomes. Each example provides a brief description of an activity, which received feedback from a stakeholder, the general nature of the feedback, and how the feedback was integrated into the project technical portfolio or infrastructure development. It is expected that the reader have familiarity with the UAS-NAS Project's organization, technical activity details, and infrastructure development. Documentation is readily available to understand these aspects of the project.

1.3 Reference Documentation

Document Number	Document Title
UAS-PRO-1.1-001-003	Project Plan Phase 1
UAS-PRO-1.1-004-001	Project Plan Phase 2
UAS-PRO-1.1-002-002	Change Management Plan
UAS-PRO-1.1-005-001	Project Requirements Document (PRD)
UAS-PRO-1.1-006-001	Technology Transfer Plan
UAS-PRO-1.1-008-001	Integrated Human in the Loop (IHITL) Test Report
UAS-PRO-1.1-006-001	Flight Test Series 3 (FT3) Test Report
UAS-PRO-1.1-009-001	Flight Test Series 4 (FT4) Test Report
UAS-OR-7.0-001-001	Relevant Environment Report

2 Stakeholder Feedback

The Stakeholder Feedback report is one of three reports included in the UAS-NAS Project's Comprehensive Relevant Environment Evaluation milestone. The other two reports are the Flight Test Series 4 (FT4) Test Environment Report and the Live Virtual Constructive (LVC) Infrastructure and Capabilities Summary. The FT4 Relevant Environment Evaluation Report describes the LVC environment used to support the last series of flight-testing conducted by the project, with emphasis on the flow of data throughout the system and analyses of observed latencies. The LVC Infrastructure and Capabilities Summary documents the LVC Capabilities and presents its design for potential use by other projects. In addition, the UAS-NAS Project completed the LVC Characterization report describing the distributed message passing latencies and the Integrated Human in the Loop (IHITL) Test Report that contained a description of the LVC construct used for the IHITL simulation. Together these documents provide the description and system–level detail that supports the evaluation of the relevancy of the test environment provided by the LVC infrastructure.

The UAS-NAS Project key stakeholders are the FAA and the UAS community represented through RTCA SC-228. The project regarded its collaboration with the FAA and SC-228 as very important. The feedback from stakeholders served to help shape research and ensure relevancy to simulation and flight testing. Thus making the outcomes more impactful on the UAS community. Through NASA processes, the project's Phase 2 research portfolio and simulation and flight test schedules were solidified and aligned with the SC-228 Phase 1 Detect and Avoid (DAA) and Command and Control (C2) Minimum Operational Performance Standards (MOPS) Terms of Reference (ToR). Throughout the maturation of specific simulation and flight test planning, the UAS-NAS Project researchers coordinated closely with the FAA and members of SC-228 to elicit feedback and ensure their data collection efforts continued to align with MOPS development and Verification and Validation (V&V) needs.

2.1 Federal Aviation Administration

The FAA has been a key partner of the UAS-NAS Project since its early formulation in

2010. At that time the UAS-NAS Project under the management of the IASP (formerly the Integrated Systems Research Program (ISRP)) worked closely with the FAA's Unmanned Aircraft Program Office (UAPO) and the FAA Technical Center. After the enactment of the FAA Modernization and Reform Act of 2012, the FAA reorganized creating the UAS Integration Office (UASIO) to replace the UAPO. The UAS-NAS Project continued to coordinate with the FAA through the UASIO as the focus of the research coordination shifted to RTCA. In addition, the UAS-NAS Project worked closely with the FAA's Airborne Collision Avoidance System for Unmanned Systems (ACAS Xu) program, which is organized within the Traffic Alert and Collision Avoidance System (TCAS) Program Office,

The sections below describe the specific activities the UAS-NAS Project had with the different FAA organizations and how those interactions impacted the Project research.

2.1.1 UAS Integration Office/FAA Technical Center/Air Traffic Organization (ATO)

The UAS-NAS Project leveraged Executive and VIP[*] days to inform status and provide demonstrations of key technical activities to various stakeholders, which included the FAA. The project executed the integrated human in the loop (IHITL) simulation during the summer 2014. As stated in the IHITL Test Report[1] the IHITL simulation provided data to the UAS-NAS Project researchers to evaluate the state of the simulation environment development by integrating and testing key DAA technologies into a research Ground Control Station (GCS). The primary technical goals for the IHITL were to: 1) evaluate and measure the effectiveness and acceptability of DAA systems (algorithms and displays) to inform and advise UAS pilots; and 2) evaluate and measure the interoperability and operational acceptability of UAS integration concepts for operating in the NAS. A third Project goal was to characterize the simulation and test environment in order to evaluate the state of the simulation architecture with respect to future UAS research activities including simulations and flight test.

The FAA UASIO Program Manager attended the Executive Day for the IHITL. Project researchers and engineers first briefed an overview of the Project followed by an overview of the IHITL experiment, which included the objectives, configuration, and expected outcomes.

The IHITL configurations leveraged retired air traffic controllers in both the subject and participant roles during the experiment. Air traffic controllers interacted with the UAS pilot as well as other simulated aircraft flying in the simulated airspace. Retired controllers were leveraged to increase the relevancy of the simulation environment. Retired ATC were used due to the challenges in scheduling active ATC.

Feedback from the UASIO Program Manager recommended the use of National Air Traffic Controllers Association (NATCA) otherwise, known as active controllers, in future activities to further increase relevancy of the environment and increase early

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[*] Executive and VIP days were conducted by the Project to provide an opportunity for NASA, stakeholder, and test partner management to observe a flight test or simulation test day. Project personnel provided presentations of the research objectives and system under test, and a demonstration.

participation of the FAA to understand, provide feedback, and endorse test results, if appropriate.

The Project worked with the FAA Technical Center to develop a process to identify the need and objectives of NATCA controllers supporting future UAS-NAS simulations and flight tests. As a result of this collaboration, the FAA Air Traffic Organization (ATO) provided NATCA controllers to support the following test activities: Part Task 5 (PT5) HITL simulation, Collision Avoidance-Self-Separation and Alerting Times (CASSAT) HITL simulation, and Flight Test Series 3 (FT3). The collaboration worked extremely well with the FAA provided qualified controllers to support tests.

Using active controllers ensured the interactions with the pilot were as close to real as a simulation could provide which increased the relevancy of the simulation and test environment. The FT3 Environment Report[2] contained a summary of the NATCA controller evaluations regarding the relevancy of the LVC for providing a realistic simulation and test environment with respect to air traffic control. It should be noted that since the UAS pilots were the subjects of the simulations and flight testing; the controllers were asked to act as confederate participants during FT3.

2.1.2 FAA Technical Center

As the FAA's center for research and testing of air traffic and aviation related concepts, the William J. Hughes Technical Center has the personnel with expertise in the conduct of testing aviation related areas, including DAA and C2. During the first year of the Project, FAA Technical Center personnel worked with IT&E Subproject members to supply real-time surveillance data. In 2013, an Annex to the FAA/NASA UAS Interagency agreement added support from the FAA to provide feedback on simulation and flight test planning activities conducted by the IT&E Subproject. This would provide stakeholders the opportunity to review the flight test plans objectives and approach, address their questions, and request their feedback and comments on actions that could be taken to increase the relevance of the test environment.

2.1.2.1 Integrated Human in the Loop

The first integrated event was the Integrated Human in the Loop (IHITL) simulation experiment. At a FAA/NASA Collaboration Meeting, NASA IT&E Subproject members briefed FAA Technical Center personnel regarding the IHITL simulation test plan and research objectives. The FAA provided real-time feedback to the IHITL simulation plan at this meeting.

2.1.2.2 Flight Test Series 3

In support of FT3, NASA IT&E Subproject personnel provided a draft version of the flight test plan, including the research objectives and system details to the FAA. NASA met with the FAA at the William J. Hughes Technical Center to discuss the flight test and the research objectives and provide a forum for discussion of FAA feedback in real-time. The FAA also provided written questions from the meeting and the review of the flight test plan to NASA. Each question was reviewed and responded to by the NASA IT&E Subproject.

2.1.2.3 Flight Test Series 4

For Flight Test Series 4 (FT4), the project scheduled separate objectives/requirements and design Technical Interchange Meetings (TIMs) with the test stakeholders. The IT&E Subproject leads and the Chief Systems Engineer captured notes from the meetings, consolidated the feedback, and worked with the stakeholders to disposition the comments. The disposition was conduct through teleconferences and written responses. The feedback helped inform the development of the flight test plans and execution.

2.1.2.1 FAA Tech Center Summary

The collaborative environment with the FAA Technical Center worked well. For the tests above, the UAS-NAS Project included Technical Center personnel in the technical reviews held prior to each test event. This allowed their feedback to be immediately discussed and understood by the entire simulation and flight test teams, which translated to a more effective communication process and the development of a more relevant simulation and/or flight test environment for each of the integrated tests. The maturation of the feedback process is an example of the development of a very collaborative working relationship with the project stakeholders.

2.1.3 ACAS Xu Program

In the early planning phase, the Project held FAA Collaboration Meetings with the FAA Technical Center. At these meetings, both the FAA and NASA personnel provided overviews of their respective technical research portfolios. During one of these meetings, it was recommended that the project consider collaboration on a 2014 Airborne Collision Avoidance System Xu (ACAS Xu) flight test. The collaboration would be beneficial to both the FAA and NASA. The FAA would have NASA’s assistance with securing local Edwards AFB air space and flight test infrastructure support, while NASA would gain the advantage of integrating a prototype DAA system on the NASA AFRC owned Ikhana UAS and executing an initial flight test as a risk reduction activity leading to the UAS-NAS Project’s first major flight test series, FT3.

The 2014 ACAS Xu collaboration provided the foundation for developing the encounter sets used in FT3 and FT4, as well as develop operational flight test procedures and mission rules to conduct air-to-air engagements in a safe and efficient manner. The ACAS Xu flight test provided the opportunity for the FAA and NASA to exchange flight test principles and best practices and cooperatively define and analyze hazard reports. Additionally the flight test operations team developed test procedures and mission rules that enabled execution of air-to-air collision avoidance encounters, including unmanned aircraft vs. unmanned aircraft encounters. The direct feedback from the FAA researchers and flight test conductors via this collaboration resulted in successfully planning and executing subsequent FT3 and FT4.

2.1.4 UAS Integration Office

The Human Systems Integration (HSI) subproject tasks included the development of human factor guidelines for UAS ground control stations as an additional resource to both RTCA SC-228 as well as the wider UAS community. The goal of the human factors guidelines was to cover a broader scope of ground control station design guidelines that fell outside of the RTCA SC-228 detect and avoid (DAA) and command and control (C2) minimum operational performance standards (MOPS). These guidelines supplemented the existing human factors literature by focusing on the unique aspects of UAS, or remotely piloted aircraft systems (RPAS), and the capabilities and characteristics of the remote pilot station that will be necessary to enable these aircraft to operate routinely in the NAS. Specific guidelines relating to the management of the command and control link were developed in close consultation with members of RTCA SC-228 C2 Working Group. Preliminary guidelines were distributed for comment in 2015.

In parallel to developing the guidelines, the HSI Project Engineer was selected by IASP, at the request of the UAS Integration Office, to support the International Civil Aviation Organization (ICAO) Remotely Piloted Aircraft Systems Panel (RPASP) that commenced deliberations in November 2014. A final set of human factors guidelines for UAS ground control stations was released by the UAS-NAS Project in 2016. The final version of the guidelines incorporated feedback from FAA human factors specialists and members of the ICAO RPASP. Among the changes was the adoption of standard ICAO terminology to align the guidelines with ICAO's RPAS integration efforts.

Coordinating with the FAA UASIO and the ICAO RPASP led to the ground control station guidelines being adjusted to support the international community.

2.2 RTCA SC-228

The UAS-NAS Project supported RTCA SC-203 for Unmanned Aircraft Systems WG's the first two years of the Project. In response to the FAA Modernization and Reform Act of 2012, influenced by the FAA reorganization, RTCA replaced SC-203 with SC-228 Minimum Performance Standards for Unmanned Aircraft System and Unmanned Aircraft focused on the two most significant technical barriers to flying UAS in the NAS and one limited operational use case. Project technical personnel embedded themselves into both the detect and avoid (DAA), and command and control (C2) working groups (WG). Embedding personnel in the WG's provided a very effective method to understand the technical issues and apply technical expertise to resolve the issues.

In working with the SC-228 Detect and Avoid (DAA) and Command and Control (C2) working groups, the project laid out a technical transfer process. The intent was to develop a process that allowed UAS-NAS Project team members to address key technical challenges required for SC-228 minimum operational performance standards (MOPS) through identification of technical topic, development of experimental designs, sharing the experimental/design plans within the working groups, getting stakeholder feedback, then sharing results of completed tasks within the working groups. This approach provided opportunity for the SC-228 working groups to provide feedback to the project team members during the planning stages, which ensured results and outcomes of the technical activities were more relevant. An exciting by product to this approach were the relationships across the agencies supporting SC-228 that developed over the past several years.

2.2.1 DAA Working Group

The DAA WG focused on defining the DAA system as it pertains to the scope outlined in the RTCA SC-228 Phase 1 Terms of Reference (ToR) for the Minimum Operational Performance Standards (MOPS) for Unmanned Aircraft Systems. NASA took a lead role in the DAA Working Group, collaborating closely with other members from across the UAS community. The effort included the development of the definition of “Well Clear”, investigation of the system performance characteristics in terms of latencies and uncertainties, analysis of the interaction of the pilot with their display environment, and execution of a series of data collection efforts designed to support Verification and Validation of these concepts.

For each of these tests, the NASA researchers worked closely with stakeholders within the DAA WG at weekly teleconferences to help define the test objectives and data collection requirements. These were also briefed at the SC-228 quarterly meetings to invite further comments from the SC-228 community at large, ensuring a vetted test plan. The sub-sections below provide detail of interactions with our stakeholders to elicit feedback regarding these tests and data collection efforts that were in addition to the standard DAA WG process.

2.2.1.1 PT5

The Part Task 5 (PT5) HITL simulation built upon previous UAS-NAS Project simulations to refine the minimum DAA display and guidance requirements for the draft DAA MOPS. The SC-228 WG-1 DAA co-chairs were invited to attend a team meeting at NASA Ames Research Center during the planning phase of the simulation. Feedback on the experimental design and test set up was provided and the team subsequently implemented several of the recommendations that were made.

During the execution of PT5, the HSI team organized two separate demonstration days to allow SC-228 technical representatives, managers and their FAA customers to witness and provide feedback on the system set-up and test conditions. These meetings allowed the stakeholders to watch subjects under test as well as try the system for themselves. These demonstrations showed the fidelity of the test system and encounter scenarios and were very well received, leading SC-228 to accept the results from simulations for supporting display and pilot guidance without the need for separate flight test validation.

Results from PT5 were analyzed by the NASA DAA researchers and presented to the DAA WG and wider SC-228 community at the following quarterly meeting. This gave the stakeholders a final chance to review NASA results before accepting the draft MOPS that were developed based on PT5 outcomes.

2.2.1.2 Collision Avoidance-Self-Separation and Alerting Times (CASSAT) HITL

The CASSAT HITL was the third in a series of experiments by the NASA Langley Self Separation/Sense and Avoid Interoperability (SSI) subproject to assess critical elements of a DAA concept for integration of UAS in the NAS. As mentioned earlier, the CASSAT *experiment leveraged active air traffic controllers to support the HITL as subjects to get their inputs on the relevancy of the UAS integration concept. The experiment also included pilots as subjects to get their perspective of the minimum and maximum acceptable declaration times for projected losses of well clear. The experiment design was based on the development of a DAA concept, conclusions of the earlier experiments in the series (Controller Acceptability Study (CAS) 1 and CAS 2), and the inputs from members of the SC-228 DAA WG. The outcomes of the CASSAT HITL confirmed the SC-228 alerting structure was a good choice for the UAS community.*

2.2.1.3 Flight Test

Learning from the ACAS Xu flight test, a NASA led Operations Working Group (OWG) and a System Safety Working Group (SSWG) were created as a collaborative meeting for the stakeholders and participants of FT3 and FT4 to discuss ground and flight operation topics. The OWG planned each of the FT's, addressed safety concerns, defined FT requirements, developed and prioritized the FT encounter matrix, and developed FT procedures and flight cards. The OWG met regularly with all FT3 and FT4 participants increasing in frequency to twice a week during the final weeks prior to flight testing. The SSWG addressed safety hazards and risks. Members of the SC-228 DAA WG, who were also participants in the flight test, attended both meetings and provided valuable inputs to help shape the flight tests.

During planning for FT4, the SC-228 verification and validation (V&V) sub-working group (sWG) was invited to participate in the FT4 OWG. As integral members of the FT4 OWG, the SC-228 DAA V&V sWG provided direct feedback into the development of the requirements, encounter test matrix, flight test procedures, and real-time flight test adjustments. The V&V sWG reviewed the initial set of 211 encounters and generated 50 additional complementing encounters that allowed the sWG to collect additional flight test data to support V&V of the DAA and radar MOPS. The SC-228 V&V sWG contributed to the execution of a more complete FT4 that influenced MOPS development and validation.

Specific SC-228 contributions included:

- Multi - intruder scenarios that taxed sensor tracker fusion functionality and the system's ability to resolve closely spaced intruder aircraft
- Different sensor selections/combinations including cooperative and non-cooperative type encounters (primary radar only)
- Various intruder equipage including mode C only intruder
- Developed different maneuvers not required by other stakeholders to stress the system under test which included directing the pilot not take corrective action until safe separation warning alert was triggered
- Operational encounters providing the pilot more flexibility on how he responded to maneuver guidance

These SC-228 specific encounters stressed the DAA system and led to the collection and analysis of flight data to contribute to the DAA MOPS.

2.2.1.4 Part Task 6

Part Task 6 (PT6) HITL simulation was originally designed to verify results from the previous HITL simulations as well as inform the DAA display selection for FT4 testing. However, due to issues with the surrogate aircraft meeting the necessary capabilities to conduct a "full mission" flight test, NASA researchers worked with the FAA and SC-228 to determine the impact of not collecting pilot performance data during flight to validate the DAA display, alerting and maneuver guidance MOPS. Based on the positive feedback from the PT5 simulation, PT6 was accepted by the FAA DAA Co-chair as a suitable and contributing V&V effort for pilot display, alerting, and maneuver guidance for the final DAA Phase 1 MOPS.

During the planning of PT6, SC-228 asked NASA to conduct a HITL simulation to examine the issues associated with the optional integration of the Traffic alert and Collision Avoidance (TCAS) II system with the DAA system for the Phase 1 MOPS. In response to this request, NASA hosted the TCAS Interoperability Workshop at NASA Ames Research Center in the fall of 2015. The workshop was attended by NASA researchers from the UAS-NAS project, key technical experts and the co-chairs from SC-228, representatives and engineers from the FAA TCAS Program Office, and human factors experts from the FAA and Air Force Research Laboratory (AFRL). The goal of this workshop was to develop a DAA-TCAS II interoperability concept and to define the NASA DAA-TCAS II interoperability testing. This expanded the role of PT6 by adding an additional "mini-HITL simulation" that was designed to evaluate the interoperability of DAA and TCAS alerting and guidance concepts under different encounter geometries and conditions.

The DAA-TCAS II Interoperability mini-HITL simulation was used as an opportunity to bring in SC-228 stakeholders to evaluate both the system set-up and encounter scenarios, as well as provide feedback on the utility of the collected data. Due to the aggressive schedule to inform the DAA MOPS, throughout the planning for the mini-HITL simulation and the PT6 Full Mission simulation, NASA researchers continued to refine their experiment plans during the weekly DAA WG teleconferences and SC-228 meetings.

Subsequent to PT6 data collection, the ground control station system was demonstrated to a Representative from the FAA's Flight Standards organization. The purpose of this demonstration was to allow FAA Flight Standards to evaluate the suitability of the DAA operational concept and the ground control station DAA displays for future pilot operations. The demonstration provided an opportunity for FAA Flight Standards to get an early look at how UAS pilots might execute the traffic avoidance function in the future, and to identify potential issues for UAS integration into the NAS that still need to be addressed by SC-228 and/or the FAA.

Utilizing the feedback from the demonstration and from all of the FAA and SC-228 interactions, NASA was able to collect data that proved to be a valuable input for the Phase 1 DAA MOPS V&V.

2.2.1.5 DAIDALUS V&V, Sensor Uncertainty Study, and E2V2

The NASA Langley SSI team laid out plans beginning in 2013 to support a series of studies to assess the performance trade space between UAS and DAA systems. In 2014 the team completed their first batch and human-in-the-loop (HITL) studies assessing the interaction between UAS maneuver parameters and DAA system requirements to provide data for the DAA MOPS on the tradeoffs between UAS and SAA systems performance. In 2015, two more HITL studies were completed to refine SAA system requirements based on operational interaction with air traffic controllers. They had planned a follow-on study in 2016 to assess the impact of sensor errors and uncertainty. However, after completing the 2014 and 2015 studies, the Langley team realized that other important efforts could contribute more significantly to the SC-228 DAA MOPS. The Langley team met with the other UAS-NAS technical leads and the SC-228 Leadership to discuss potential changes to their fiscal year (FY16) technical portfolio. The team determined additional value would be gained by modifying the focus of the main 2016 study to develop mitigations for the noise and uncertainty inherent in the surveillance data causing the DAA algorithm inputs into ground control station display to be smoother and well-behaved for the UAS pilot. Another change to the portfolio resulted from the meeting to assess the FY16 technical portfolio. The End-to-End Verification and Validation (E2V2) study to exercise the DAA MOPS reference implementation with test procedures from the MOPS was an important activity. This demonstrated the flexibility of the UAS-NAS project processes to allow inputs from key stakeholders to adjust the subprojects technical focus to better support the development of the DAA MOPS.

In early 2015, the SSI Subproject members at Langley worked with SC-228 Leadership to include their Detect and AvoID Alerting Logic for Unmanned Systems (DAIDALUS) DAA algorithm in the DAA MOPS as the reference algorithm. The Langley team also adopted a Program Verification System (PVS) as a formal methodology to verify and validate DAIDALUS. This was a complex process to formally verify the algorithmic logic against functional requirements and validate the algorithmic logics against the MOPS requirements. Completing this process, which included creation of a stand-alone version of the software, established the pedigree of the DAIDALUS code as the reference algorithm to be included in the DAA MOPS for use by UAS designers and manufacturers. This effort demonstrated how the collaborative relationship between the Stakeholder and the UAS-NAS Project could be beneficial to the UAS community.

2.2.1.6 Batch Simulations

The batch simulations, conducted using the Airspace Concept Evaluation System (ACES), had a dual purpose: 1.) Providing the foundational data used to support the development of the HITL simulations and flight test objectives 2.) Providing the ability to evaluate the system through NAS-wide testing. This simulation was used to identify the bounding parameters defining DAA Well Clear (DWC)[†], evaluate surveillance requirements for DAA alerting and guidance, as well as investigate corner case encounters, not easily tested in flight.

Even during SC-203 (the predecessor to SC-228), UAS community stakeholders have been instrumental in support of the batch simulations, starting with the acquisition of the underlying traffic operating under visual flight rules obtained from radar sources within the Air Force's 84th Radar Evaluation Squadron. This data contained the manned VFR

[†] DAA Well Clear is defined as the boundary around the UA defined by time and/or distance intended to be an electronic means of compliance for UAS to provide safety and conform to the rules of the air.

traffic profiles that future UAS systems would be require to detect and avoid to remain well clear, which ultimately, inform the simulation scenarios. During the early stages of the batch simulation development, the ACES software was augmented to support 17 UAS aircraft types, providing a additional simulation capability for evaluating UAS flight profiles. These additions to ACES enhanced its ability to emulate NAS operations.

A key feature of ACES is the NAS-wide simulation capability. Hence using ACES for the batch simulations allows for collecting NAS system level data providing input into identification of the overall Airspace Safety Threshold. The ACES simulations also provided input into verifying DAA/TCAS interoperability requirements. This is critical not only for development of DAA MOPS, but in a general sense for integration of UAS into the NAS. As such, NASA researchers continually worked with FAA stakeholders to determine test conditions, models, and results needed to help develop DAA MOPS.

As with the HITL simulations and flight tests, the NASA researchers worked with the DAA WG through the weekly teleconferences and quarterly meetings, these supported the definition of the simulations that were necessary to inform not just the DAA MOPS, but also other simulations and flight tests. The ability to quickly set-up additional batch simulations and the coordination within the DAA WG provided a constant test and report cycle with the agility to architect the experiment design of the batch simulations to meet the immediate demands of the MOPS data collection efforts.

2.2.2 C2 Working Group

The C2 WG focused on defining the C2 data link as it pertains to the scope outlined in the Phase 1 Terms of Reference (ToR) for the Minimum Operating Performance Standards (MOPS) for Unmanned Aircraft Systems. NASA took a lead role in the C2 WG, collaborating closely with other members from across the UAS community. The C2 MOPs development focused on the control and non-payload communications (CNPC) link system to support the command and control (C2) function of a UAS. The effort focused on the activity to define, establish performance characteristics, and verify and validate the development of requirements for the use of a defined radio frequency (RF) spectrum for primarily command and control function. The C2 membership focused on terrestrial data links for L and C-Band data link and initial analysis of the satellite communications. A secondary interim consideration included the ATC voice communications relay pending implementation of the FAA’s digital voice switch network.

The NASA researchers worked closely with stakeholders within the C2 WG at weekly teleconferences to help define the test objectives and data collection requirements for all lab, ground, and flight tests. These objectives and simulation and test plans were briefed at the SC-228 quarterly meetings to invite further comments from the SC-228 community at large, ensuring a vetted test plan. The sub-sections below provide detail of interactions with our stakeholders to elicit feedback regarding these tests and data collection efforts that were in addition to the standard C2 WG process.

2.2.2.1 CNPC Development

NASA partnered with Rockwell Collins through a shared resource cooperative agreement to demonstrate and support the development of an Unmanned Aircraft CNPC System. This work resulted in both ground and airborne prototype CNPC radios to provide a basis for verifying and validating proposed RTCA SC-203 CNPC system performance standards. This work was transitioned into SC-228, after SC-203 was closed.

The development of the prototype CNPC radio system was coordinated with private and public stakeholders through SC-203 and later SC-228, through five versions (Gen 1-5) of the radio. Feedback, based on presentations from NASA and Rockwell Collins on the system trade study, design specifications, and results from flight testing were used to modify the radio design, as it progressed through the five prototype generations.

The Gen-4 prototype radio was used to inform the preliminary C2 Terrestrial MOPS.

2.2.2.2 C2 MOPS Validation (Gen 5 Radio Testing)

The NASA Communications subproject performed all flight test activities used to validate the C2 MOPS. In preparations for verifying and validating the C2 MOPS, the Communications Project Engineer distributed a flight test request form. This form was completed by members of the C2 working group to request flight test data needed for validating C2 MOPS performance requirements. The completed forms were returned to the Project Engineer (PE). In coordination with the C2 Working Group, flight test plans were developed in order to collect the necessary validation data as prioritized by the PE. NASA GRC performed the flight test, and the data was distributed to the appropriate C2 Working Group members for data processing. The results from this data were the validation of C2 MOPS performance requirements.

2.2.2.3 Data Link Security

The NASA Communication subproject teamed with personnel at the FAA Technical Center, in order to develop, test, and validate the security requirements for the C2 MOPS. This work followed established security processes in order to develop risk and vulnerability analysis, develop a risk mitigation plan, develop and implement the recommended risk mitigations, and test the mitigation within the prototype CNPC system. This work was coordinated with the SC-228 C2 Working Group. As a majority of the developed documentation was sensitive, it could not be released to the entire C2 Working Group for comment. Summaries of the security work was presented to the C2 Working Group during the development and testing phases, which received feedback that was incorporated into the security requirements. This work resulted in the security requirements documented in the C2 MOPS.

During the development of the C2 MOPS, questions arose related to the security of the radio frequency (RF) link itself. The NASA Communication subproject performed a trade study related to protecting the physical layer RF of the CNPC link. This document was thoroughly reviewed and commented on by the C2 Working Group, resulting in the final trade study document. The results of this trade study were independently verified by FAA personnel, and used as the basis for justifying C2 MOPS requirements related to the CNPC physical layer.

2.2.3 ITU-R WP5B

2.2.3.1 WRC-12:

The Communication subproject supported the International Telecommunications Union Radiocommunications Sector (ITU-R) Working Party 5B (WP5B). The Communication team provided technical analyses through RTCA-203 and on-site support at the 2012 World Radio Conference to obtain allocation for line-of-sight CNPC Spectrum. As a result of the international efforts, allocations were made for UAS CNPC line-of-sight (terrestrial) spectrum.

The Communication subproject supported the International efforts to obtain a new agenda item for WRC-15 WRC 2012 to consider regulatory actions needed to enable the use of spectrum in the Fixed Satellite Service (FSS) bands for UAS CNPC.

2.2.3.2 WRC-15:

Leading up to WRC-15, The US (FAA, NASA, DoD, UAS Industry), Germany, Satellite Industry (SES, Inmarsat, Intelsat) collaborated in the development of the draft report M. [UAS-FSS]: "Technical and operational characteristics, interference and regulatory environments associated with the use of frequency bands allocated to the fixed-satellite service not subject to Appendices 30, 30A and 30B for the control and non-payload communication of unmanned aircraft systems in non-segregated airspace." This report defined all of the UAS technical characteristics: UAS system characteristics, link performance, impairment/failure mitigation, and sharing studies. The effort included the analysis and advocacy of identification and allocation of civil UAS frequency spectrum.

NASA's specific contribution was to develop sharing studies on the satellite link interference with existing terrestrial systems. (The FAA performed sharing studies on the terrestrial systems interference with the satellite link) The studies received enthusiastic review and comment at the International level, which resulted in several iterations of simulations and analysis performed by NASA leading up to the conclusions of WRC-15. The outcome of WRC-15 was the need to conduct additional analysis, based on flight test data, leading up to WRC-19 & 23.

3 Summary

Stakeholder feedback was a very important component of the UAS-NAS project. This report cited many examples of how the UAS-NAS Project solicited, received, and used feedback from stakeholders. The feedback was primarily applied to modifying various project activities to increase the relevancy of the test environment and the resulting outcomes.

The resulting outcomes of the research and work of the project had a profound impact on the successful completion of the SC-228 MOPs contributing to flying UAS in the NAS.

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[1] National Aeronautics and Space Administration, Integrated Human in the Loop: Test Report, Document No. UAS-ITE.5.0-004.001, September 2014

[2] National Aeronautics and Space Administration, Flight Test Series 3: Test Environment Report, Document No. UAS-ITE.5.1-016-001, 15 April 2016