

National Aeronautics and
Space Administration



Unmanned Aircraft Systems Integration in the National Airspace System Project

PHASE 2 ABSTRACTS—FY2017 TO FY2020

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UNMANNED AIRCRAFT SYSTEMS INTEGRATION IN THE NATIONAL AIRSPACE SYSTEM PROJECT

There is an increasing need to fly Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) to perform missions of vital importance to national security and defense, emergency management, science, and to enable commercial applications. However, routine access by UAS into the NAS remains unrealized. The UAS community needs routine access to the global airspace for all classes of UAS. Based upon that need, the National Aeronautics and Space Administration (NASA) Aeronautics Research Mission Directorate (ARMD) Integrated Aviation Systems Program (IASP) UAS Integration in the NAS Project identified the following goal: To Provide research findings, utilizing simulation and flight tests, to support the development and validation of Detect and Avoid (DAA) and Command and Control (C2) technologies necessary for integrating UAS into the NAS. Because this is such a broad reaching challenge facing the UAS community, the UAS-NAS Project recognizes the importance of working together with others in Industry and Other Government Agencies to overcome the technical, operational, and public perception barriers.

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Title: Urban Air Mobility Command and Control Communication

Conference: American Institute of Aeronautics and Astronautics Aviation Forum

Date: June 2020

Author: Israel Greenfeld–NASA Glenn Research Center

ABSTRACT

Urban Air Mobility (UAM), commonly called Air Taxis, is a commercial application for unmanned aerial vehicles (UAV). Unmanned vehicles require a communications system to provide command and control to insure safe operations. NASA Glenn Research Center (GRC) has been researching the Command and Control (C2) portion of NASA's Integration of Unmanned Aerial Systems in the National Airspace System (UAS in the NAS) since 2011. GRC's UAS C2 research encompasses simulations and analysis, laboratory examination, and test flights of a Control non-Payload Command (CNPC) radio designed specifically for UAS operations. This work is in support of the RTCA Special Committee 228 (SC-228) to develop a UAS C2 Minimum Operational Performance Standard (MOPS). The radio is a joint developmental effort between GRC and Collins Radio. The long term UAM vision is for pilotless, fully autonomous vehicles; in other words, UAVs. However, until the autonomy technologies mature to the level of safe operations, the UAM vehicles will take an evolutionary path to full autonomy. The first step, or phase, is likely to be an expert pilot on-board. As experience with UAM is gained and technology improves, a second phase with a skilled pilot might begin. Here again, as experience and technology improvements occur, a third phase, the one with a Remote Pilot in Command (RPIC) may be initiated. Because GRC's mandate is UAVs, the UAM work has concentrated on the RPIC phase. A Concept of Operations (ConOps) was developed from which a set of C2 seed requirements were deduced and translated into criteria for assessing wireless technologies meanwhile identifying missing regulations. Additionally, UAM C2 simulations are being carried out and lab, ground, and air tests for Long Term Evolution (LTE), 4G wireless, systems are being examined as one possible wireless communications solution in the urban environment. This paper will describe in more detail the various UAM pieces that GRC has been working on.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Generic Resolution Advisor and Conflict Evaluator (GRACE) in Applications to Detect-And-Avoid (DAA) Systems of Unmanned Aircraft

Conference: American Institute of Aeronautics and Astronautics AVIATION 2017

Date: July 2017

Authors: Michael Abramson and Mohamad Refai–Crown Consulting Inc.,

Confesor Santiago–NASA Ames Research Center

ABSTRACT

The paper describes the Generic Resolution Advisor and Conflict Evaluator (GRACE), a novel alerting and guidance algorithm that combines flexibility, robustness, and computational efficiency. GRACE is "generic" in that it makes no assumptions regarding temporal or spatial scales, aircraft performance, or its sensor and communication systems. Accordingly, GRACE is well suited to research applications where alerting and guidance is a central feature and requirements are fluid involving a wide range of aviation technologies. GRACE has been used at NASA in a number of real-time and fast-time experiments supporting evolving requirements of DAA research, including parametric studies, NAS-wide simulations, human-in-the-loop experiments, and live flight tests.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: UAS Well Clear Recovery against Non-Cooperative Intruders using Vertical Maneuvers

Conference: American Institute of Aeronautics and Astronautics AVIATION 2017

Date: July 2017

Authors: Michael Abramson and Mohamad Refai—Crown Consulting Inc.,
Confesor Santiago—NASA Ames Research Center

ABSTRACT

This paper documents a study that drove the development of a mathematical expression in the detect-and-avoid (DAA) minimum operational performance standards (MOPS) for unmanned aircraft systems (UAS). This equation describes the conditions under which vertical maneuver guidance should be provided during recovery of DAA well clear separation with a non-cooperative VFR aircraft. Although the original hypothesis was that vertical maneuvers for DAA well clear recovery should only be offered when sensor vertical rate errors are small, this paper suggests that UAS climb and descent performance should be considered—in addition to sensor errors for vertical position and vertical rate—when determining whether to offer vertical guidance. A fast-time simulation study involving 108,000 encounters between a UAS and a non-cooperative visual-flight-rules aircraft was conducted. Results are presented showing that, when vertical maneuver guidance for DAA well clear recovery was suppressed, the minimum vertical separation increased by roughly 50 feet (or horizontal separation by 500 to 800 feet). However, the percentage of encounters that had a risk of collision when performing vertical well clear recovery maneuvers was reduced as UAS vertical rate performance increased and sensor vertical rate errors decreased. A class of encounter is identified for which vertical-rate error had a large effect on the efficacy of horizontal maneuvers due to the difficulty of making the correct left/right turn decision: crossing conflict with intruder changing altitude. Overall, these results support logic that would allow vertical maneuvers when UAS vertical performance is sufficient to avoid the intruder, based on the intruder's estimated vertical position and vertical rate, as well as the vertical rate error of the UAS' sensor.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: An Alternative Time Metric to Modified Tau for Unmanned Aircraft System Detect and Avoid

Conference: American Institute of Aeronautics and Astronautics AVIATION 2017

Date: July 2017

Authors: Minghong G. Wu–NASA Ames Research Center,
Vibhor L. Bageshwar and Eric A. Euteneuer–Honeywell International

ABSTRACT

A new horizontal time metric, Time to Protected Zone, is proposed for use in the Detect and Avoid (DAA) Systems equipped by unmanned aircraft systems (UAS). This time metric has three advantages over the currently adopted time metric, modified tau: it corresponds to a physical event, it is linear with time, and it can be directly used to prioritize intruding aircraft. The protected zone defines an area around the UAS that can be a function of each intruding aircraft's surveillance measurement errors. Even with its advantages, the Time to Protected Zone depends explicitly on encounter geometry and may be more sensitive to surveillance sensor errors than modified tau. To quantify its sensitivity, simulation of 972 encounters using realistic sensor models and a proprietary fusion tracker is performed. Two sensitivity metrics, the probability of time reversal and the average absolute time error, are computed for both the Time to Protected Zone and modified tau. Results show that the sensitivity of the Time to Protected Zone is comparable to that of modified tau if the dimensions of the protected zone are adequately defined.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Unmanned Aircraft Systems Detect and Avoid System: End-to-End Verification and Validation Simulation Study of Minimum Operations Performance Standards for Integrating Unmanned Aircraft into the National Airspace System

Conference: American Institute of Aeronautics and Astronautics AVIATION 2017

Date: July 2017

Authors: Rania W. Ghatas–NASA Langley Research Center, Devin P. Jack–Adaptive Aerospace Group Inc., Dimitrios Tsakpinis–Science Applications International Corporation, Michael J. Vincent–NASA Langley Research Center, James L. Sturdy–Stinger Ghaffarian Technologies Inc., Keith D. Hoffler–Adaptive Aerospace Group Inc., Robert R. Myer–Stinger Ghaffarian Technologies Inc., Anna M. Dehaven–Craig Technologies, Inc.

ABSTRACT

As Unmanned Aircraft Systems (UAS) make their way to mainstream aviation operations within the National Airspace System (NAS), research efforts are underway to develop a safe and effective environment for their integration into the NAS. Detect and Avoid (DAA) systems are required to account for the lack of “eyes in the sky” due to having no human on-board the aircraft. The technique, results, and lessons learned from a detailed End-to-End Verification and Validation (E2-V2) simulation study of a DAA system representative of RTCA SC-228’s proposed Phase I DAA Minimum Operational Performance Standards (MOPS), based on specific test vectors and encounter cases, will be presented in this paper.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Mitigating the Impact of Sensor Uncertainty on Unmanned Aircraft Operations

Technical Report prepared for NASA Langley Research Center

Date: July 2017

Authors: Devin P. Jack and Keith D. Hoffler—Adaptive Aerospace Group, Inc.,
James L. Sturdy—Stinger Ghaffarian Technologies Inc.

ABSTRACT

Without a pilot onboard an aircraft, a Detect-and-Avoid (DAA) system, in conjunction with surveillance sensors, must be used to provide the remotely-located Pilot-in-Command sufficient situational awareness in order to keep the Unmanned Aircraft (UA) safely separated from other aircraft. To facilitate safe operations of UA within the U.S.' National Airspace System, the uncertainty associated with surveillance sensors must be accounted for. An approach to mitigating the impact of sensor uncertainty on achievable separation has been developed to support technical requirements for DAA systems.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Unmanned Aircraft Systems Detect and Avoid System: End-to-End Verification and Validation Simulation Study of Minimum Operations Performance Standards for Integrating Unmanned Aircraft into the National Airspace System

Conference: American Institute of Aeronautics and Astronautics AVIATION 2017

Date: July 2017

Authors: Rania W. Ghatas–NASA Langley Research Center, Devin P. Jack–Adaptive Aerospace Group Inc., Dimitrios Tsakpinis–Science Applications International Corporation, Michael J. Vincent–NASA Langley Research Center, James L. Sturdy–Stinger Ghaffarian Technologies Inc., Cesar A. Munoz–NASA Langley Research Center, Keith D. Hoffler–Adaptive Aerospace Group Inc., Aaron M. Duple–NASA Langley Research Center, Robert R. Myer–Stinger Ghaffarian Technologies Inc., Anna M. Dehaven–Craig Technologies, Inc., Elliot T. Lewis and Keith E. Arthur–NASA Langley Research Center

ABSTRACT

As Unmanned Aircraft Systems (UAS) make their way to mainstream aviation operations within the National Airspace System (NAS), research efforts are underway to develop a safe and effective environment for their integration into the NAS. Detect and Avoid (DAA) systems are required to account for the lack of “eyes in the sky” due to having no human on-board the aircraft. The current NAS relies on pilot’s vigilance and judgement to remain Well Clear (CFR 14 91.113) of other aircraft. RTCA SC-228 has defined DAA Well Clear (DAAWC) to provide a quantified Well Clear volume to allow systems to be designed and measured against. Extended research efforts have been conducted to understand and quantify system requirements needed to support a UAS pilot’s ability to remain well clear of other aircraft. The efforts have included developing and testing sensor, algorithm, alerting, and display requirements. More recently, sensor uncertainty and uncertainty mitigation strategies have been evaluated. This paper discusses results and lessons learned from an End-to-End Verification and Validation (E2-V2) simulation study of a DAA system representative of RTCA SC-228’s proposed Phase I DAA Minimum Operational Performance Standards (MOPS). NASA Langley Research Center (LaRC) was called upon to develop a system that evaluates a specific set of encounters, in a variety of geometries, with end-to-end DAA functionality including the use of sensor and tracker models, a sensor uncertainty mitigation model, DAA algorithmic guidance in both vertical and horizontal maneuvering, and a pilot model which maneuvers the ownship aircraft to remain well clear from intruder aircraft, having received collective input from the previous modules of the system. LaRC developed a functioning batch simulation and added a sensor/tracker model from the Federal Aviation Administration (FAA) William J. Hughes Technical Center, an in-house developed sensor uncertainty mitigation strategy, and implemented a pilot model similar to one from the Massachusetts Institute of Technology’s Lincoln Laboratory (MIT/LL). The resulting simulation provides the following key parameters, among others, to evaluate the effectiveness of the MOPS DAA system: severity of loss of well clear (SLoWC), alert scoring, and number of increasing alerts (alert jitter). The technique, results, and lessons learned from a detailed examination of DAA system performance over specific test vectors and encounter cases during the simulation experiment will be presented in this paper.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: An Interoperability Concept for Detect and Avoid and Collision Avoidance Systems: Results from a Human-In-The-Loop Simulation

Conference: American Institute of Aeronautics and Astronautics AVIATION 2018

Date: June 2018

Authors: Conrad Rorie and Dr. Lisa Fern–NASA Ames Research Center

ABSTRACT

The integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS) poses a variety of technical challenges to UAS developers and aviation regulators. In response to growing demand for access to civil airspace in the United States, the Federal Aviation Administration (FAA) has produced a roadmap identifying key areas requiring further research and development. One such technical challenge is the development of a "detect and avoid" system (DAA) capable of providing a means of compliance with the "see and avoid" requirement in manned aviation. The purpose of the DAA system is to support the pilot, situated at a ground control station (GCS), in maintaining "DAA well clear" of nearby aircraft through the use of GCS displays and alerts. In addition to its primary function of aiding the pilot in maintaining DAA well clear, the DAA system must also safely interoperate with existing NAS systems and operations, such as the airspace management procedures of air traffic controllers (ATC) and Collision Avoidance (CA) systems currently in use by manned aircraft, namely the Traffic Alert and Collision Avoidance System (TCAS II). It is anticipated that many UAS architectures will integrate both a DAA system and a TCAS II. It is therefore necessary to explicitly study the integration of DAA and TCAS II alerting structures and maneuver guidance formats to ensure that pilots understand the appropriate type and urgency of their response to the various alerts. This paper presents a concept of interoperability for the two systems. The concept was developed with the goal of avoiding any negative impact on the performance level of TCAS II while retaining a DAA system that still effectively enables pilots to maintain DAA well clear. The interoperability concept described in the paper focuses primarily on facilitating the transition from a late-stage DAA encounter (where a loss of DAA well clear is imminent) to a TCAS II Corrective Resolution Advisory (RA), which requires pilot compliance within five seconds of its issuance. The interoperability concept was presented to 10 participants (6 active UAS pilots and 4 active commercial pilots) in a medium-fidelity, human-in-the-loop simulation designed to stress different aspects of the DAA and TCAS II systems. Pilots' ability to maintain separation, their rate of compliance and response times using the interoperability concept are reported. Results indicated that pilots exhibited comprehension of, and appropriate prioritization within, the DAA-TCAS II combined alert structure. Pilots demonstrated a high rate of compliance with TCAS II RAs and were also seen to respond to corrective RAs within the five second requirement established for manned aircraft. The DAA system presented under test was also shown to be effective in supporting pilots' ability to maintain DAA well clear in the overwhelming majority of cases in which pilots had sufficient time to respond.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

**Title: Analysis of Influence of UAS Speed Range and Turn Performance on
Detect and Avoid Sensor Requirements**

Conference: American Institute of Aeronautics and Astronautics AVIATION 2018

Date: June 2018

Authors: Devin P. Jack, Jeremy Hardy, and Keith D. Hoffler—Adaptive Aerospace Group, Inc.

ABSTRACT

In support of NASA's Unmanned Aircraft Systems Integration in the National Airspace System project and RTCA Special Committee 228, an analysis has been performed to provide insight in to the trade space between unmanned aircraft speed and turn capability and detect and avoid sensor range requirements. The work was done as an initial part of the effort to understand low size, weight, and power sensor requirements for aircraft that have a limited speed envelope or can limit the envelope for portions of their mission and may be able to turn at higher than "standard rate." Range and timeline reductions coming from limiting speed range and from increasing available turn rate in some speed ranges are shown.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: En Route Detect and Avoid Well Clear in Terminal Area Landing Pattern

Conference: American Institute of Aeronautics and Astronautics AVIATION 2018

Date: June 2018

Authors: Anna C. Trujillo–NASA Langley Research Center, Devin P. Jack–Adaptive Aerospace Group, Inc.,
and Dimitrios Tsakpinis–Science Applications International Corporation

ABSTRACT

A fast time simulation was conducted to test the detect and avoid Well Clear definition designed for en route use when an unmanned aircraft (UA) is approaching the landing pattern of the terminal area. Measures focused on were loss of well clear and alerts intended to help the pilot avoid loss of well clear. Data indicated warning-level alerts will occur outside the typical Class D airspace which may prevent the UA from normal operations in the terminal airspace. Other aircraft on 450 entry could result in "nuisance" alerts which may also prevent the UA from normal operations in the terminal airspace. However, eliminating horizontal proximity (τ_{mod}) has the potential to increase "nuisance" alerts on the 450 entry and downwind legs. Overall, this suggests that a more stringent definition of Well Clear may be advisable in the landing pattern of the terminal area.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

**Title: Sensitivity Analysis of Detect and Avoid Well Clear Parameter Variations
on UAS DAA Sensor Requirements**

Conference: American Institute of Aeronautics and Astronautics AVIATION 2018

Date: June 2018

Authors: Devin P. Jack, Jeremy Hardy, and Keith D. Hoffler—Adaptive Aerospace Group, Inc.

ABSTRACT

In support of NASA's Unmanned Aircraft Systems Integration in the National Airspace System project and RTCA Special Committee 228, an analysis has been performed to provide insight in to the trade space between detect and avoid (DAA) Well Clear definition threshold variations, which could affect DAA sensor range and alerting requirements.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Encounter-Based Simulation Architecture for Detect-And-Avoid Modeling

Conference: SciTech 2019

Date: January 2019

Authors: Mohamad Refai, Michael Abramson, and Seungman Lee—Crown Consulting Inc.,

M. Gilbert Wu—NASA Ames Research Center

ABSTRACT

This paper presents an encounter-based simulation architecture developed at NASA to facilitate flexible and efficient Detect and Avoid modeling in parametric or tradespace studies on large data sets. The basic premise of this tool is that large-scale input data can be reduced to a set of 'canonical encounters' and that using the reduced data in simulations does not lead to loss of fidelity. A canonical encounter is specified as ownship and intruder flight portions potentially resulting in a loss of well clear along with a set of properties that characterize the encounter. The advantages of using canonical encounters include faster simulations, reduced memory footprint, ability to select encounters based on user-specified criteria, shared encounters across multiple teams, peer-reviewed encounters, and a better understanding of the input data set, to name a few.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

**Title: Detect and Avoid Alerting Performance with Limited Surveillance Volume
for Non-Cooperative Aircraft**

Conference: American Institute of Aeronautics and Astronautics SciTech 2019 Forum

Date: January 2019

Authors: Gilbert Wu and Andrew C. Cone—NASA Ames Research Center,
Seungman Lee—Crown Consulting Inc.

ABSTRACT

This paper investigates effects of limited surveillance volume on the alerting performance of a Detect and Avoid (DAA) system for unmanned aircraft systems (UAS). The surveillance volume accounts for an airborne sensor capable of detecting non-cooperative aircraft. Independent variables include four candidate DAA Well Clear (DWC) definitions and five surveillance volumes. Open-loop alerting performance metrics are computed from the results of running a reference DAA algorithm on a large number of synthesized encounters. The speed range for the UAS traffic considered is between 40 and 100 kts. Results show that, with a 2.5 nmi sensor range, all four candidate DWCs allow at least an average of 25 seconds warning alert times before a loss of DWC. Cumulative distributions of the intruder's bearing and elevation at the first warning alert suggest that $\pm 10^\circ$ and $\pm 140^\circ$, respectively, are sufficient for alerting > 95% of the encounters that lead to losses of DWC.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: A Comparison of Two Terminal Area Detect and Avoid Well Clear Definitions

Conference: American Institute of Aeronautics and Astronautics AVIATION 2019

Date: May 2019

Authors: Conrad Rorie, Kevin J. Monk, and Summer L. Brandt–NASA Ames Research Center,
Zachary Roberts–Flight Research Associates, and Lisa Fern–Honeywell International Inc.

ABSTRACT

Technical requirements are currently under development for a detect and avoid system (DAA) that would support the operation of Unmanned Aircraft Systems (UAS) within the National Airspace System (NAS). Such a system would aid UAS pilots in maintaining sufficient separation, or “well clear”, from other aircraft in their vicinity. The first set of technical standards for a UAS DAA system (referred to as “Phase 1” requirements) was limited to UAS operations transiting through Class D, E, and G airspace to, or from, Class A or special-use airspace. The operation of UAS within terminal airspace was explicitly out of scope of the Phase 1 requirements. The present study tested two different DAA well clear definitions (referred to as “With Tau” and “No Tau”) designed to accommodate standard terminal area operating procedures, such as traffic in the downwind leg of a VFR traffic pattern while the UAS is on final. Participants were tasked with operating a simulated MQ-9 Reaper using the Air Force Research Laboratory’s (AFRL) Vigilant Spirit Control Station (VSCS). Participants flew both the visual and instrument approach procedures into Sonoma County Airport (KSTS) with each of the candidate DAA well clear definitions. Results of the study indicated that both candidate definitions improved pilot and DAA system performance relative to previous research on the Phase 1 system in the terminal area. The With Tau candidate resulted in a higher number of undesirable DAA alerts, as well as a higher proportion of losses of DAA well clear than the No Tau candidate. However, losses of DAA well clear in the With Tau candidate condition tended to be less severe than losses of DAA well clear in the No Tau condition. Finally, the With Tau candidate led to a greater number of maneuvers against terminal area traffic but were not typically disruptive to the airspace. The implications of these findings and recommendations for future research are also provided.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: A Detect and Avoid System in the Context of Multiple-Unmanned Aircraft Systems Operations

Conference: American Institute of Aeronautics and Astronautics AVIATION 2019

Date: May 2019

Authors: Kevin J. Monk, Conrad Rorie, and Summer L. Brandt–NASA Ames Research Center, Garrett G. Sadler–San José State University Research Foundation, Zachary S. Roberts–Flight Research Associates

ABSTRACT

NASA's Unmanned Aircraft Systems Integration into the National Airspace System (UAS in the NAS) project examines the technical barriers associated with the operation of UAS in civil airspace. For UAS, the removal of the pilot from onboard the aircraft has eliminated the ability of the ground-based pilot in command (PIC) to use out-the-window visual information to make judgements about a potential threat of a loss of well clear with another aircraft. NASA's Phase 1 research supported the development of a Detect and Avoid (DAA) system that supports the ground-based pilot's ability to detect potential traffic conflicts and determine a resolution maneuver, but existing display/alerting requirements did not account for multiple UAS control (1:N). Demands for increased scalability of UAS in the NAS operations are expected to create a need for simultaneous control of UAs, and thus, a new DAA HMI design will likely be necessary. Previous research, however, has found performance degradations as the number of vehicles under operator control has increased. The purpose of the current human-in-the-loop (HITL) simulation was to examine the viability of 1:N operations with the Phase 1 DAA alerting and guidance. Sixteen UAS pilots flew three scenarios with varying number of UAs under their control (1:1, 1:3, 1:5). In addition to their supervisory and sensor mission responsibilities, pilots were to utilize the DAA system to remain DAA well clear (DWC) during scripted conflicts of mixed severity. Measured response times, separation performance, mission task data, and subjective feedback were collected to assess how the multi-UAS control configuration impacted pilots' ability to maintain DAA well clear and perform the mission tasks. Overall, the DAA system proved surprisingly adaptive to multi-UAS control for preventing losses of DAA well clear (LoDWC). The findings suggest that, while multi-UAS operators are able to maintain safe separation (DWC) from other traffic, their ability to efficiently perform missions drastically decreases with their number of controlled vehicles. Pilot feedback indicated that, for this context, the use of automation support tools for completing and managing mission tasks would be appropriate and desired, especially for ensuring efficient use of assets. Finally, human-machine interface (HMI) design considerations for multi-UAS operations are discussed.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Defining Well Clear Separation for Unmanned Aircraft Systems Operating with Noncooperative Aircraft

Conference: American Institute of Aeronautics and Astronautics AVIATION 2019

Date: May 2019

Authors: Christine Chen, Bilal Gill, and Matthew W. Edwards—Lincoln Laboratory, Massachusetts Institute of Technology, Samantha Smearcheck, Tony Adami, and Sean Calhoun—CAL Analytics, M. Gilbert Wu and Andrew C. Cone—NASA Ames Research Center, Seungman Lee—Crown Consulting Inc.

ABSTRACT

Detect-and-Avoid (DAA) systems are essential to the safe operations of Unmanned Aircraft Systems, and have the objectives of mitigating collisions with and remaining Well Clear of manned aircraft. This paper analyzes four candidate DAA Well Clear definitions for non-cooperative aircraft using mitigated performance metrics of DAA systems. These DAA Well Clear definitions were proposed in previous work based on their unmitigated collision risk and maneuver initiation range. In this work they are evaluated using safety and operational suitability metrics computed from a large number of representative encounters. Results suggest that although the four candidate DAA Well Clear definitions provide comparable safety, the alerting characteristics give preference for the DAA Well Clear definition without a temporal parameter.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Terminal Area Considerations for UAS Detect and Avoid

Conference: 2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC)

Date: September 2019

Authors: Keith D. Hoffler and Devin P. Jack—Adaptive Aerospace Group
Tod Lewis—NASA Langley Research Center

ABSTRACT

Unmanned Aircraft Systems need to be able to comply with manned aviation 'see and avoid' separation requirements. A Detect and Avoid (DAA) System includes sensors, a tracker, and alerting and guidance algorithms that assist a remote pilot in maintaining separation from airborne traffic. To date, DAA system requirements development has focused on operations transiting to and from Class A or special use airspace. Current efforts are defining DAA system requirements for operations in and around terminal airspace. As a contribution to the current efforts, this paper highlights results from a Human in the Loop (HiTL) experiment comparing methods of changing from the transit-specific alerting and guidance criteria to proposed terminal-specific alerting and guidance criteria. It discusses operational considerations that are beyond the HiTL.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Impact of Frequencies of Lost Links on Air Traffic Controller Performance and Acceptability Ratings

Conference: Human Factors and Ergonomics Society Annual Meeting

Date: November 2019

Authors: Kim-Phuong L. Vu, Jillian Keeler, Natassia Mattoon, and Thomas Z. Strybel—California State University Long Beach, Lisa Fern—Honeywell International Inc., Conrad Rorie, Vernol Battiste, and Robert J. Shively—NASA Ames Research Center

ABSTRACT

A human-in-the-loop simulation was conducted to determine the effect of the frequency of loss link declarations on air traffic controllers' sector performance and their acceptability ratings of Unmanned Aircraft System (UAS) operations. We used a short versus long transaction expiration time (TET) to derive the number of lost links in a condition, with the shorter TET resulting in twice as many lost link declarations compared to the long TET. We found that long TET conditions led to better performance than the short TET conditions. Moreover, controllers preferred the long TETs compared to the short ones.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Detect-and-Avoid: Flight Test 6 Scripted Encounters Data Analysis Technical Memorandum

Paper: Technical Memorandum

Date: February 2020

Authors: Wei-Ching Wang—Bay Systems Consulting Inc., M. Gilbert Wu—NASA Ames Research Center

ABSTRACT

The Unmanned Aircraft System (UAS) in the National Airspace System (NAS) project conducted Flight Test 6 (FT6) in 2019. The ultimate goal of this flight test was to produce data to inform RTCA SC-228's Phase II Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) and Low Size, Weight, and Power Sensors. This report documents the analysis of scripted encounters' data. Scripted encounters flown were analyzed and categorized based on the outcome of alert, maneuver guidance, and effectiveness of pilots' maneuver in resolving conflicts. Results indicate that UAS pilots' decisions as well as intruder maneuvers are leading factors that contribute to ineffective DAA maneuvers. Results also show that adding buffers to the DAA's suggested minimum turn angle improves effectiveness of the DAA maneuvers.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: An Examination of Two Non-Cooperative Detect and Avoid Well Clear Definitions

Conference: American Institute of Aeronautics and Astronautics 2020

Date: June 2020

Authors: Kevin J. Monk and Conrad Rorie—NASA Ames Research Center, Jillian Keeler—California State University Long Beach, Garrett G. Sadler—San José State University Research Foundation

ABSTRACT

NASA's Unmanned Aircraft Systems Integration into the National Airspace System (UAS in the NAS) project examines the technical barriers associated with the operation of UAS in civil airspace. The present study explored the differential effects of two candidate non-cooperative Detect-and-Avoid Well Clear (DWC) definitions on pilot and system performance in a human-in-the-loop simulation. Active-duty UAS pilots were recruited to maintain DWC against representative Class 4 encounter types with a low size, weight, and power (SWaP) radar declaration range of 3.5 nautical miles (nmi). Objective performance indicated that pilots could consistently maintain DWC against non-cooperative intruders with either DWC candidate, with negligible differences in response times and separation performance against caution and warning-level threats. While losses of DWC were avoided at rates comparable to Phase 1 findings, pilots uploaded their responses to caution-level alerts over 5 seconds faster in the current setup relative to Phase 1. Encounters with faster closure rates were susceptible to shortened caution-level alert durations, especially when employing the DWC criterion with the additional 'Tau' (temporal) component. Consequently, caution-level threats frequently elevated to warning-level status (nearly twice as often with the Tau candidate). The variable caution alert durations appeared to impact pilots' coordination with air traffic control (ATC), as ATC approval rates were lower with the 'Tau' and 'Disc' candidates relative to Phase 1 research. Ultimately, the increased alerting time enabled by the Disc candidate deemed it more suitable for any reductions to the assumed radar declaration range requirement, which was re-evaluated in a follow-on study. Findings from this study will inform Phase 2 Minimum Operational Performance Standards (MOPS) development for UAS with alternative surveillance equipment and performance capabilities.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Impact of Airborne Radar Uncertainties on Detect-and-Avoid Systems' Performance

Conference: NASA Technical Reports Server (NTRS)

Date: February 2020

Authors: M. Gilbert Wu and Seungman Lee—NASA Ames Research Center

ABSTRACT

Impact of sensor uncertainty on Detect-and-Avoid (DAA) systems' performance is investigated. Key metrics analyzed are the loss of DAA well clear ratio, the near-mid-air-collision risk ratio, the alert ratio, and the number of maneuvers per loss of DAA well clear. Sensitivity of these metrics to the magnitude of sensor uncertainty, pilots' selection of maneuver, and surveillance range is investigated. Benefits of a dynamic buffer around the DAA well clear separation boundary, computed based on track accuracies, are also analyzed. These metrics are computed from open- and closed-loop simulations of a large number of representative encounters between an unmanned aircraft system and a manned aircraft. Results show that sensor uncertainty degrades safety metrics considerably but has only a minor effect on the number of maneuvers per loss of DAA well clear. The number of maneuvers, nonetheless, can be reduced by a 5° buffer away from the edge of the range of conflict-resulting heading in pilots' selection of maneuver.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Display and Automation Considerations for the Airborne Collision Avoidance System Xu

Conference: American Institute of Aeronautics and Astronautics 2020

Date: June 2020

Authors: Garrett G. Sadler—San José State University Research Foundation, Conrad Rorie, Casey L. Smith, and Kevin J. Monk—NASA Ames Research Center, Jillian Keeler—California State University Long Beach

ABSTRACT

In this paper we examine several display and automation considerations of a collision avoidance system that is currently under development: the Airborne Collision Avoidance System (ACAS) Xu. This study builds on previous work conducted as part of NASA's Unmanned Aircraft Systems (UAS) Integration into the National Airspace System (NAS) project. ACAS Xu represents the next-generation successor to the Traffic Alert and Collision Avoidance System (TCAS II), wherein the Xu variant is intended for next generation UAS applications. Whereas TCAS II exclusively issues RAs in the vertical dimension, a major distinction between ACAS Xu and previous collision avoidance (CA) systems is the introduction of horizontal and "blended" RAs (i.e., RAs with both horizontal and vertical components). This present work was conducted as an engineering analysis involving two parts. In Part 1, a two-by-two, within-subjects study was performed that manipulated how RAs were presented to a pilot situated at a UAS ground control station. Five participants experienced four experimental trials in which text and aural alerting characteristics were manipulated. In Part 2, another five participants experienced four trials in which the levels of automation were manipulated with regard to the CA and return-to-course (RTC) tasks. The results for Part 1 found no effect of display or alerting configuration on pilot performance. However, it was discovered that pilot response time to RAs greatly depended on the RA type. In particular, pilots were quicker to respond to vertical RAs ($M = 4.52$ seconds) than horizontal ($M = 7.42$ seconds) and blended ($M = 9.68$ seconds) RAs in which both dimensions were issued simultaneously. For Part 2 of the study, pilots found both auto-CA and auto-RTC functions equally useful. Most pilots were comfortable with the automation, however responses were mixed. Three of five participants indicated high levels of comfort with the auto-CA function, while two rated their comfort as low. Pilots' comfort for the auto-RTC functionality was slightly higher: four out of five pilots gave high ratings, while one pilot gave a low rating. Overall, pilots ordinaly ranked their preference for automated functions as auto-CA together with auto-RTC (when an aural alert announces a change between CA and RTC states), auto-CA, and auto-CA and RTC (without the aural state-change announcement).

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Applying Sensor Uncertainty Mitigation Schemes to Detect-and-Avoid Systems

Conference: American Institute of Aeronautics and Astronautics 2020

Date: June 2020

Authors: Michael Abramson and Mohamad Refai–Crown Consulting Inc.,
M. Gilbert Wu and Seungman Lee–NASA Ames Research Center

ABSTRACT

Impact of sensor noise on the performance of Detect-And-Avoid (DAA) systems can be reduced by implementing various mitigation schemes. This paper evaluates the Sensor Uncertainty Mitigation (SUM) method, implemented in the Detect and Avoid Alerting Logic for Unmanned Systems (DAIDALUS) algorithm, a reference implementation in the DAA minimum operational performance standards. DAIDALUS SUM performance is evaluated using a few safety and operational suitability metrics and compared with more traditional approaches using static safety buffers. A large number of encounters representative of low-speed unmanned aircraft against non-cooperative manned aircraft are simulated and evaluated. An air-to-air radar model produces representative sensor noise for the DAA system. Results show that increasing the tunable parameters for horizontal and vertical uncertainty in DAIDALUS SUM improves the safety metric at the cost of increasing the number of system alerts leading to increased workload. A range of SUM parameters is recommended as suitable values for the type of operations considered for this work. General trends and optimal SUM configurations were found to be nearly the same for two large and very different encounter data sets.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Human Factors Contributions to the Development of Standards for Displays of Unmanned Aircraft Systems in Support of Detect-and-Avoid

Conference: Human Factors and Ergonomics Society

Date: June 2020

Authors: Kim-Phuong L. Vu—California State University Long Beach,

R.Conrad Rorie and Robert Jay Shively—NASA Ames Research Center, Lisa Fern—The Boeing Company

ABSTRACT

The aim is to provide a high-level synthesis of human factors research that contributed to the development of detect-and-avoid display requirements for unmanned aircraft systems (UAS). Background: The integration of UAS into the U.S. National Airspace System is a priority under the Federal Aviation Administration's Modernization and Reform Act. For UAS to have routine access to the National Airspace System, UAS must have detect-and-avoid capabilities. One human factors challenge is to determine how to display information effectively to remote pilots for performing detect-and-avoid tasks. Method: A high-level review of research informing the display requirements for UAS detect-and-avoid is provided. In addition, description of the contributions of human factors researchers in the writing of the requirements is highlighted. Results: Findings from human-in-the-loop simulations are used to illustrate how evidence-based guidelines and requirements were established for the display of information to assist pilots in performing detect-and-avoid. Implications for human factors are discussed. Conclusion: Human factors researchers and engineers made many contributions to generate the data used to justify the detect-and-avoid display requirements. Human factors researchers must continue to be involved in the development of standards to ensure that requirements are evidence-based and take into account human operator performance and human factors principles and guidelines. Application: The research presented in this paper is relevant to the design of UAS, the writing of standards and requirements, and the work in human-systems integration.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: Detect-and-Avoid Closed-Loop Evaluation of Noncooperative Well Clear Definitions

Conference: The Journal of Air Transportation

Date: July 2020

Authors: M. Gilbert Wu and Seungman Lee—NASA Ames Research Center, Christine C. Serres, Bilal Gill, and
Matthew W. M. Edwards—Lincoln Laboratory, Massachusetts Institute of Technology,
Samantha Smearcheck, Tony Adami, and Sean Calhoun—CAL Analytics

ABSTRACT

Four candidate detect-and-avoid well clear definitions for unmanned aircraft systems encountering noncooperative aircraft are evaluated using safety and operational suitability metrics. These candidates were proposed in previous research based on unmitigated collision risk, maneuver initiation ranges, and other considerations. Noncooperative aircraft refer to aircraft without a functioning transponder. One million encounters representative of the assumed operational environment for the detect-and-avoid system are simulated using a benchmark alerting and guidance algorithm as well as a pilot response model. Results demonstrate sensitivity of the safety metrics to the unmanned aircraft's speed and the detect-and-avoid system's surveillance volume. The only candidate without a horizontal time threshold, named modified tau, outperforms the other three candidates in avoiding losses of detect and avoid well clear. Furthermore, this candidate's alerting timeline lowers the required surveillance range. This can help reduce the barrier of enabling unmanned aircraft systems' operations with low size, weight, and power sensors.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: UAS-NAS NASA 870 Ikhana UAS No Chase COA (NCC) Flights, Flight Test Report

Paper Type: Test Report

Date: August 2018

Authors: Mike Marston, Steffi Valkov, and Alex Flock–Jacobs Engineering Group, Inc.

ABSTRACT

This document is a flight test report from the operational perspective for the No Chase Certificate of Waiver or Authorization (COA) flights, or NCC flights, a major milestone of the Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) project. Discussions of a demonstration event began as early as 2014 and the actual flight of the Ikhana UAS into the NAS without a safety chase vehicle in Class A, E, and D airspace was accomplished on 12 June, 2018. The major goal of this flight was to demonstrate an alternate means of compliance to the see and avoid regulations for a UAS using Detect and Avoid (DAA) technology. Participants in this flight activity and planning included the National Aeronautics and Space Administration (NASA) Ames Research Center, NASA Armstrong Flight Research Center, General Atomics Aeronautical Systems, Inc. (GA-ASI), Honeywell International, Inc., and the Federal Aviation Administration (FAA).

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: UAS Integration in the NAS Project: Overview of Flight Test 6 Series Technical Memorandum

Paper: Technical Memorandum

Date: July 2020

Authors: Michael Marston and Sam K. Kim—NASA Armstrong Flight Research Center, Alexander D. Flock—Millennium Engineering and Integration, Victor M. Loera—American Systems, Michael J. Vincent—NASA Langley Research Center, M. Gilbert Wu and Conrad Rorie—NASA Ames Research Center, Wayne W. Bridges—Flight Research Associates, Inc., Wei-Ching Wang—Universities Space Research Association

ABSTRACT

The National Aeronautics and Space Administration (NASA) Unmanned Aircraft Systems Integration in the National Airspace System (UAS-NAS) Project has conducted a series of flight test campaigns intended to support the reduction of barriers that prevent unmanned aircraft from flying without the required waivers from the Federal Aviation Administration (FAA). The 2019 Flight Test Series 6 (FT6) campaign furthered this path and supported three test configurations: 1) Radar Characterization, 2) Scripted Encounters and 3) Full Mission. Radar Characterization assessed the performance of Honeywell's low size, weight, and power (low SWaP) radar system; Scripted Encounters investigated the timing of Detect and Avoid (DAA) alerting thresholds using a Department of Defense (DoD) Group 3 unmanned aircraft system (UAS) equipped with low SWaP sensors and three different live intruder aircraft flown at varying encounter geometries; and Full Mission validated human-in-the-loop simulations by collecting pilot performance data from a ground control station while controlling a live unmanned aircraft on a mission in both virtual and live air traffic controlled airspace. The subject pilot observed a research display that presented DAA advisories to maintain separation from live and virtual aircraft. The test was conducted over a twenty-week period within the R-2508 special use airspace located near Edwards Air Force Base (EAFB), CA. Over 240 encounters were flown during the test series and FT6 proved to be invaluable for the purposes of planning, managing, and executing this type of integrated flight test in both live and virtual environments. Data collected from FT6 was provided to the RTCA Special Committee 228 (SC-228) to help inform the Phase 2 Minimum Operational Performance Standards (MOPS). FT6 was the final test series for the UAS-NAS project that began in 2012. This paper provides an overview of FT6 and its success can be directly attributed to the diligent work of the men and women who supported this effort.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>

Title: UAS Concept of Operations and Vehicle Technologies Demonstrations

Conference: 2019 Integrated Communications, Navigation and Surveillance Conference (ICNS)

Date: April 2019

Authors: Kurt Swieringa–NASA Langley Research Center, Raymond Young–Northeast UAS Airspace Research, Robert Vivona–Aurora Flight Sciences, Mike Hague–Modern Technology Solutions Inc

ABSTRACT

In 2017 and 2018, under National Aeronautics and Space Administration (NASA) sponsorship, the New York Unmanned Aircraft Systems (UAS) Test Site and Northeast UAS Airspace integration Research (NUAIR) Alliance conducted a year-long research project that culminated in a UAS technology flight demonstration. The research project included the creation of a concept of operations, and development and demonstration of UAS technologies. The concept of operations was focused on an unmanned aircraft transiting from cruise through Class E airspace into a high-density urban terminal environment. The terminal environment in which the test was conducted was Griffiss International Airport, under Syracuse Air Traffic Control (ATC) approach control and Griffiss control tower. Employing an Aurora Centaur optionally piloted aircraft (OPA), this project explored six scenarios aimed at advancing UAS integration into the National Airspace System (NAS) under both nominal and off-nominal conditions. Off nominal conditions were defined to include complete loss of the communications link between the remote pilot's control station on the ground and the aircraft. The off-nominal scenarios that were investigated included lost-link conditions with and without link recovery, an automated ATC initiated go-around, autonomous rerouting around a dynamic airspace obstruction (in this case simulated weather), and autonomous taxi operations to clear the runway.

To read the full paper please visit <https://www.nasa.gov/aeroresearch/programs/iasp/uas/abstracts>



UAS INTEGRATION IN THE NAS PROJECT

Participating NASA Centers

Ames Research Center (ARC)

Moffett Field, CA 94035

Armstrong Flight Research Center (AFRC)

Edwards, CA 93523

Glenn Research Center (GRC)

Cleveland, OH 44135

Headquarters

Washington, DC 20546

Langley Research Center (LaRC)

Hampton, VA 23681

For UAS Integration in the NAS Project information
please visit us at <https://www.nasa.gov/aeroresearch/programs/iasp/uas>
or e-mail afrc-uas-nas@mail.nasa.gov.