

National Aeronautics and
Space Administration



Unmanned Aircraft Systems Integration in the National Airspace System Project

PHASE 2 ABSTRACTS – FY2017 TO FY2019

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

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: 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>



UAS INTEGRATION IN THE NAS PROJECT

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