

DANTi: A Tool for Assistive Detect and Avoid Research

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Abstract—This paper presents DANTi, a research tool that supports the development of Assistive Detect and Avoid (ADAA) for General Aviation. ADAA is a future on-board aircraft technology intended to augment the pilots’ see-and-avoid capabilities by helping them identify and resolve traffic conflicts earlier and more efficiently. DANTi includes a realistic Electronic Flight Bag display, which provides alerts and maneuver guidance using a highly-configurable detect and avoid (DAA) library, and a fast-time simulation environment that can be fully customized to meet different research requirements. As part of NASA research efforts, DANTi is used in the Air Mobility Pathfinders project on future air transportation systems and in a joint NASA/FAA Laboratory Integrated Test Environment (NFLITE) on next-generation airspace operations in urban environments. These efforts investigate ADAA requirements in advanced urban air mobility settings where new aircraft types, new services, and new traffic patterns will be integrated in an overall crowded airspace. This paper describes the design and capabilities of DANTi, as well as use cases demonstrating some of the current research activities enabled by the tool. DANTi is freely available under NASA’s Open Source Agreement.

I. INTRODUCTION

Public records by the US Federal Aviation Administration (FAA) indicate a total of 112 Mid-Air Collisions (MAC) and 3586 Near Mid-Air collisions (NMAC) over a 10-year period.¹ According to the FAA data, most of the MAC and NMAC events occur in traffic patterns and on final approach, with the majority of MAC reported within 5 miles of an airport, 77% of these below 1,000 ft and 49% below 500 ft. Future manned air traffic operations, which are expected to involve higher traffic densities at low altitudes, will pose additional challenges for traffic conflict resolution.

Under visual flight rules (VFR), pilots have the responsibility for not “operating an aircraft so close to another aircraft as to create a collision hazard” [1], [2], “to see and avoid other aircraft” [3], [4], and when complying with the particular rules addressing right-of-way, on-board pilots “may not pass over, under, or ahead [of the right-of-way aircraft] unless well clear” [3], [4]. While see-and-avoid is a fundamental part of aviation safety, its usefulness is limited by human vision, visual restrictions (e.g., weather conditions), and pilot distraction [5]. TCAS is a family of collision avoidance systems for aircraft equipped with operating transponders. TCAS II [6], the second generation of TCAS devices, is mandated in the US for aircraft with passenger capacity greater than 30 seats

or a maximum takeoff weight greater than 33,000 pounds. Although TCAS could also be installed on turbine-powered general aviation aircraft, it is a relatively expensive technology that works only with cooperative traffic and provides traffic alerts but no resolution advisories at low altitudes. When available, Air Traffic Services provide an additional collision avoidance method available to pilots.

Detect and Avoid (DAA) is a relatively new technology for Unmanned Aircraft Systems (UAS) that provides situational awareness and maneuver guidance to UAS operators [7], [8], [9], [10], [11], [12], [13]. DAA aids pilots in control of UAS in avoiding and remaining well clear of other aircraft in the airspace. DAA is currently accepted as an alternate means of compliance with see-and-avoid regulation for remote UAS pilots. The DANTi research effort aims to further evolve DAA and re-purpose it for onboard pilots as a safety augmentation to see-and-avoid. This safety enhanced concept is referred to as Assistive DAA (ADAA). Key research questions associated with the design, use, and adoption of an onboard ADAA technology in manned aviation are:

- Can ADAA be used effectively to augment see-and-avoid for onboard pilots, providing maneuver options for traffic avoidance well before conflicts become collision hazards?
- Can ADAA support or even be necessary for onboard pilots in advanced urban air mobility (UAM) scenarios operating in high traffic densities at low altitudes, relying on see-and-avoid visual separation with limited services in some cases?
- How complex would it be to certify an ADAA technology?
- What procedures should be followed by onboard pilots when using ADAA?

DANTi is an open source research prototype developed by NASA aiming at supporting a rigorous and systematic exploration of these research questions. The original DANTi design concept was introduced in [14]. Flight tests and experiments with preliminary prototypes are described in [15] and [16].

This paper describes a new version of the DANTi tool, which includes an enhanced traffic display, an improved alerting and maneuver guidance logic, and an integrated analysis environment for fast-time simulation of flight scenarios. DANTi is currently used within several NASA efforts includ-

¹<https://www.bts.gov/>.



Fig. 1: DANTi's EFB interface

ing the Air Mobility Pathfinders (AMP²) project on future air transportation systems and a joint NASA/FAA Laboratory Integrated Test Environment (NFLITE³) on next-generation airspace operations in urban environments. The prototype has recently been released as an open source package under the NASA Open Source Agreement. DANTi can be freely downloaded from GitHub⁴ and used by the research community and stakeholders to explore ADAA system designs.

The rest of the paper is organized as follows. Section II discusses the design and functionalities provided by DANTi. Section III describes its architecture. Section IV presents use cases and research activities enabled by the tool. Section V concludes the paper.

II. THE DANTi RESEARCH PROTOTYPE

The DANTi tool includes two main elements: (i) a configurable Electronic Flight Bag (EFB) application providing ADAA capabilities and (ii) an integrated analysis environment for fast-time simulation of DANTi using flight scenarios based on synthetic data or recorded flight data. The ADAA capabilities of the tool build on the DAIDALUS [17] library, which is the DAA reference implementation for UAS in RTCA's DO-365 [18].

DANTi gets as input the current ownship and traffic states. It predicts traffic conflicts and displays traffic alerts and maneuver guidance on an EFB display with a navigation moving map and flight display instruments (see Figure 1).

In the ADAA concept, the EFB is intended to be used by the pilot in command to augment information available on the standard flight displays of the aircraft. DANTi is not a substitute for cockpit equipment required by airworthiness or operating regulations. As such, DANTi can be already used in an aircraft under FAA's Non Required Safety Enhancing Equipment (NORSEE⁵) directive, which addresses avionics equipment that is not required by any federal regulation with the intent to measurably increase aircraft safety.

A. EFB Display

DANTi's EFB display includes a compass rose superimposed over one of several moving map options, with speed, altitude, and vertical speed tape indicators displayed on both sides of the compass rose.

The ownship is shown at the center of the interactive display, as a blue chevron. A moving map is shown in the background and follows the position of the ownship. The map can be in either street mode or VFR chart mode. When in street view mode, the map displays landmarks and city names. When in VFR chart mode, the map shows sectional charts used in aeronautics for navigation under visual flight rules.

Traffic aircraft and traffic alerts are rendered using standard symbols recommended in the RTCA's DO-365 standard for DAA systems [18].

Each traffic aircraft has a numerical label indicating the relative altitude of the traffic aircraft with respect to the ownship in hundreds of feet. For example, "+01" indicates that the aircraft is 100 feet above the ownship. An up/down arrow besides the label indicates that the traffic aircraft is

²<https://www.nasa.gov/directorates/armd/aosp/amp/>

³https://www.faa.gov/about/office_org/headquarters_offices/ang/offices/tc/library/Storyboard/detailedwebpages/nflite.html

⁴<https://github.com/nasa/DANTi>

⁵https://www.faa.gov/aircraft/air_cert/design_approvals/norsee

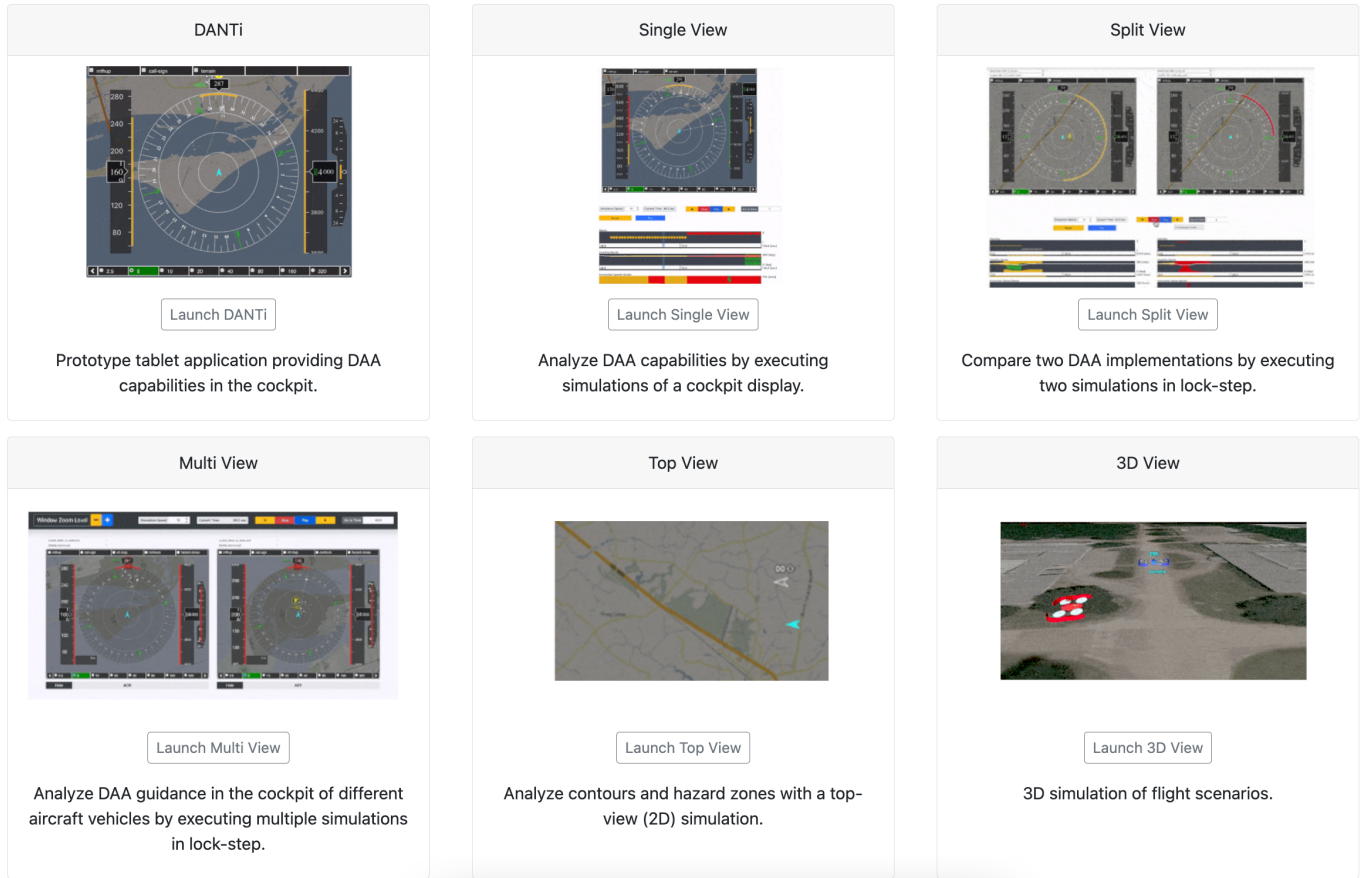


Fig. 2: Simulation views

climbing/descending. If the label does not show an arrow, as in Figure 1, the traffic aircraft is on a level flight. Call sign or tail number can also be displayed as part of the label of each traffic aircraft.

The compass rose shows the heading of the ownship. The compass can be in track-up mode, where the ownship points up and the compass rotates, or in north-up mode, where the compass is fixed and the ownship points to the current direction. Tape indicators on the side of the display indicate ground speed (on the left side of the display), altitude, and vertical speed (on the right of the display).

Maneuver guidance is provided using color-coded bands. Colors correspond to different levels of severity, where yellow indicates a *corrective* alert and red indicates a *warning* alert. Bands displayed on the compass provide information on heading maneuvers to either maintain well clear or recover well clear if it has been lost. For example, in Figure 1, the red band on the compass is called a *peripheral band* since it is slightly to the side of the current heading of the ownship. This band represents heading maneuvers that would result in a warning alert and an imminent loss of well clear. If the band was in front of the current heading, the band would be called a *conflict band* and would indicate that the current heading will lead to a loss of well clear. In this case, a warning alert would

be issued, and the pilot should maneuver the aircraft outside of the band. Similarly, the yellow band on the ground speed tape is a peripheral band and indicates speed changes that would result in a corrective alert and, potentially, a loss of well clear. When the ownship is in loss of well clear with respect to another aircraft, a dashed green band may be displayed. These types of bands are called *recovery bands*, and they indicate maneuvers that the pilot should take to regain well clear in a timely manner.

Other possible ways to present maneuver guidance to the pilot include contours and well-clear volumes. Contours are regions of the airspace that should be avoided to prevent a loss of well clear. Well-clear volumes show the protected area around traffic aircraft that should not be entered by any other aircraft. Contours and well-clear volumes morph over time depending on the relative position and velocity of the ownship and traffic aircraft. Aural annunciations can also be used to enhance alerts and maneuver guidance through programmable text-to-speech synthetic voices. All visual elements and aural annunciations can be fully customized.

B. Integrated Analysis Environment

DANTi is integrated to an interactive analysis tool called DAA-Displays [19]. This tool extends the interactive display with fast-time simulation capabilities and specialized analysis

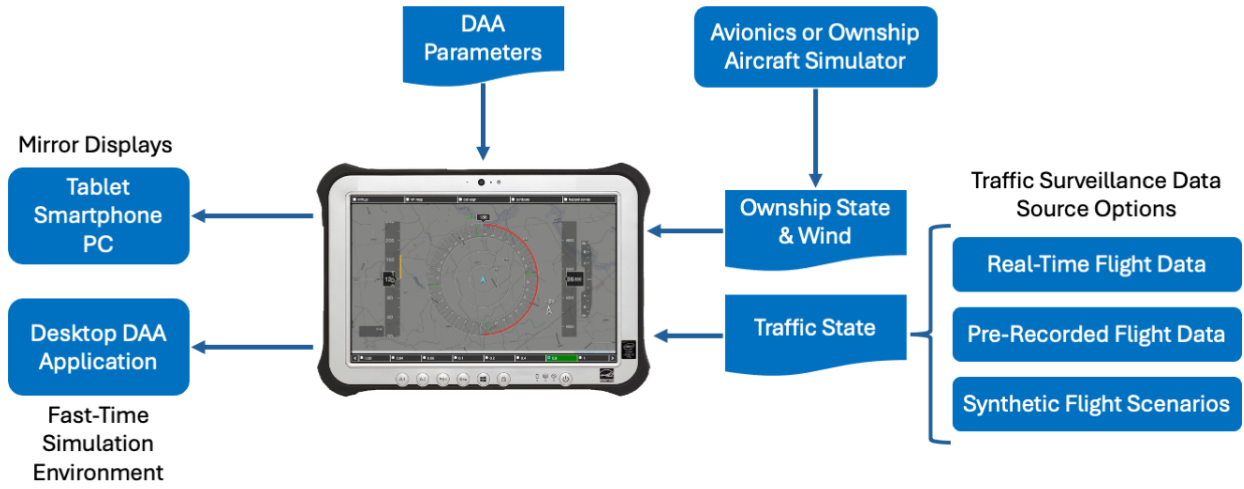


Fig. 3: DANTi connection options

views for the validation of ADAA traffic alerts and maneuver guidance. The simulation environment includes six main views, which are shown in Figure 2 and are now described.

The *DANTi View* connects the DANTi display to a simulation environment providing simulation controls and simulation plots for fast-time analysis of ADAA alerts and guidance in a flight scenario. This is the basic view for the analysis of ADAA alerts and maneuver guidance in a flight scenario. It allows researchers to see what the pilot would see on the DANTi display during the scenario. Additional plot diagrams show the timeline history of maneuver alerts and guidance presented to the pilots as the flight encounter progresses.

The *Single View* extends the DANTi view with a developer panel providing detailed information about the encounter, including ownship and traffic position and velocity. This view also displays several metrics related to DAA such as horizontal and vertical range, time and distance of closest point of approach, time to loss of well clear, horizontal and vertical miss distances, horizontal and vertical closure rate, and time to co-altitude.

The *Split View* allows for the lock-step simulation of a flight scenario using two different ADAA configurations. The view is useful to compare different ADAA configurations and possibly different versions of the ADAA logic. Markers on the plot diagrams highlight when and where alerts and maneuver guidance differ between the two simulations.

The *Multi-Aircraft View* extends the single view by introducing n fast-time simulations executed in lock-step, where n is the number of aircraft involved in the flight scenario. This view shows in a single screen side-by-side the ADAA guidance computed by each aircraft in the flight scenario. It is useful to review the maneuver guidance computed by the ADAA systems of the various aircraft involved in a specified scenario.

The *Top View* shows the flight scenario from the top, using a virtual camera located at a fixed position. The view can be used to assess the ADAA logic on different 2-D geometries

such as head-on, crossing, and overtake.

The *3D View* provides a 3-dimensional view of the flight scenario, using a virtual tracking camera that follows the ownship from a fixed distance. The view can be used to visualize different features of the ADAA logic on 3-D geometries such as those involving vertical maneuvers, take off, and landing.

C. Connection Options

Different connection options are supported by the DANTi tool to enable both interactive human-in-the-loop experiments and fast-time simulations in batch mode (see Figure 3).

The DANTi application interfaces with flight data from different traffic surveillance sources. Currently, DANTi supports ADS-B reports from GDL-90 compatible devices, prerecorded flight data from flight tests, and synthetic data generated by a computer program or streamed live from an aircraft flight simulator.

DANTi can be used to send ADAA information to other software applications such as computer programs simulating human operators that automatically react to alerts and maneuver guidance. Furthermore, the fast-time simulation capabilities of DANTi can be enhanced by connecting the prototype to external software modules and tools such as dynamic aircraft models and 3D simulators that provide realistic scenery and out-the-window rendering (e.g., see Figure 4).

III. ARCHITECTURE

DANTi's modular architecture is depicted in Figure 5. The main software components are described in the remainder of this section.

A. DANTi-Display

This component is responsible for rendering the visual elements of the display. This module uses the DAA-Displays [19] toolkit for rendering the display elements. Different symbols can be used to provide visual feedback about traffic alerts such as a white chevron for nearby traffic, circled yellow chevron for preventive alert, full yellow circle with inner chevron for



Fig. 4: DANTi prototype integrated with a realistic 3D scenery simulator in NASA's Design Integrity Lab

corrective alert, and red chevron within a red square framing for warning alerts. Color-coded bands are used for suggestive guidance and indicator bugs are used for directive guidance.

B. DANTi-Logic

This component interfaces with DAIDALUS [17], a DAA library that provides the following functions:

- Conflict Detection: Determines the pairwise well clear status between the ownship and every traffic aircraft.
- Traffic Alerting: Determines the pairwise alert level between the ownship and every traffic aircraft.
- Maneuver Guidance: Computes suggestive and directive maneuver guidance for the ownship to maintain or regain a well clear status.

DAIDALUS is a NASA-developed reference implementation of the detect and avoid functional requirements described in RTCA DO-365 [18]. DAIDALUS supports several configuration options that are used to tailor the ADAA logic to ownship's performance and specific well-clear parameters such as time and distance thresholds.

C. DANTi-Gateway

This component is responsible for dispatching events and managing the connection with external software modules and tools. This module provides the following functions:

- Dispatch events and data between internal software components.
- Provide a generic communication API for exchanging events and data with external data sources, simulators,

and analysis tools. The generic API includes functions for sending DAA configuration parameters, updating ownship and traffic information, triggering the computation of alerts and maneuver guidance, and sending rendering requests that trigger a refresh of the display elements.

D. DANTi-Adapters

This component tailors the generic communication API provided by the DANTi Gateway to the specific communication protocol needed to exchange data and events with external software modules and tools. Adapters bundled with the DANTi prototype include an X-Plane adapter for exchanging simulation data with the X-Plane flight simulator, a GDL-90 adapter for receiving traffic data from ADS-B equipment supporting the open standard GDL-90, and a TCP/IP adapter for receiving traffic data and avionics data from external simulation environments using the TCP/IP protocol.

E. Interactions between components

The sequence of interactions between the data source and DANTi are depicted in Figure 6 using a sequence diagram. Boxes at the top of the sequence diagram represent components. Lines extending downwards are called *lifelines* and represent passage of time. White boxes on lifelines are called *activation boxes* and represent tasks performed by the components. Horizontal arrows between activation boxes represent messages exchanged between components (dashed lines represent messages returned by a component).

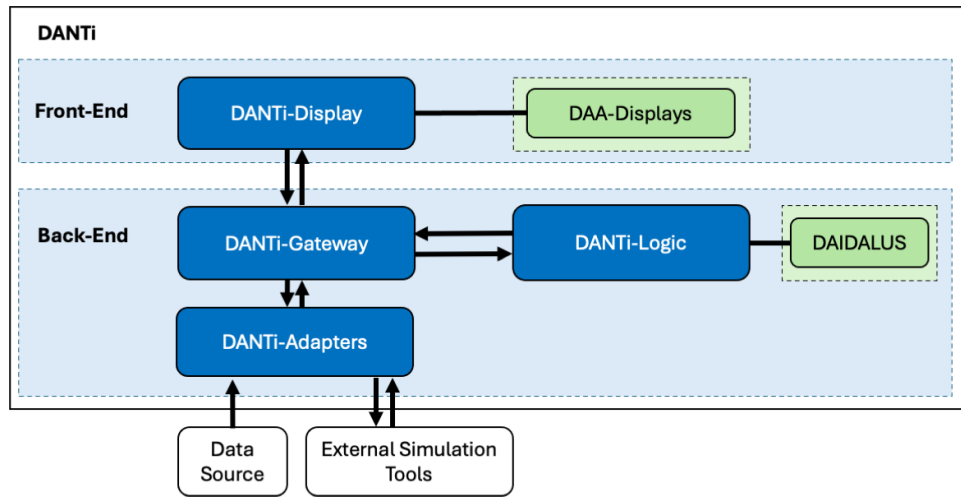


Fig. 5: DANTi architecture

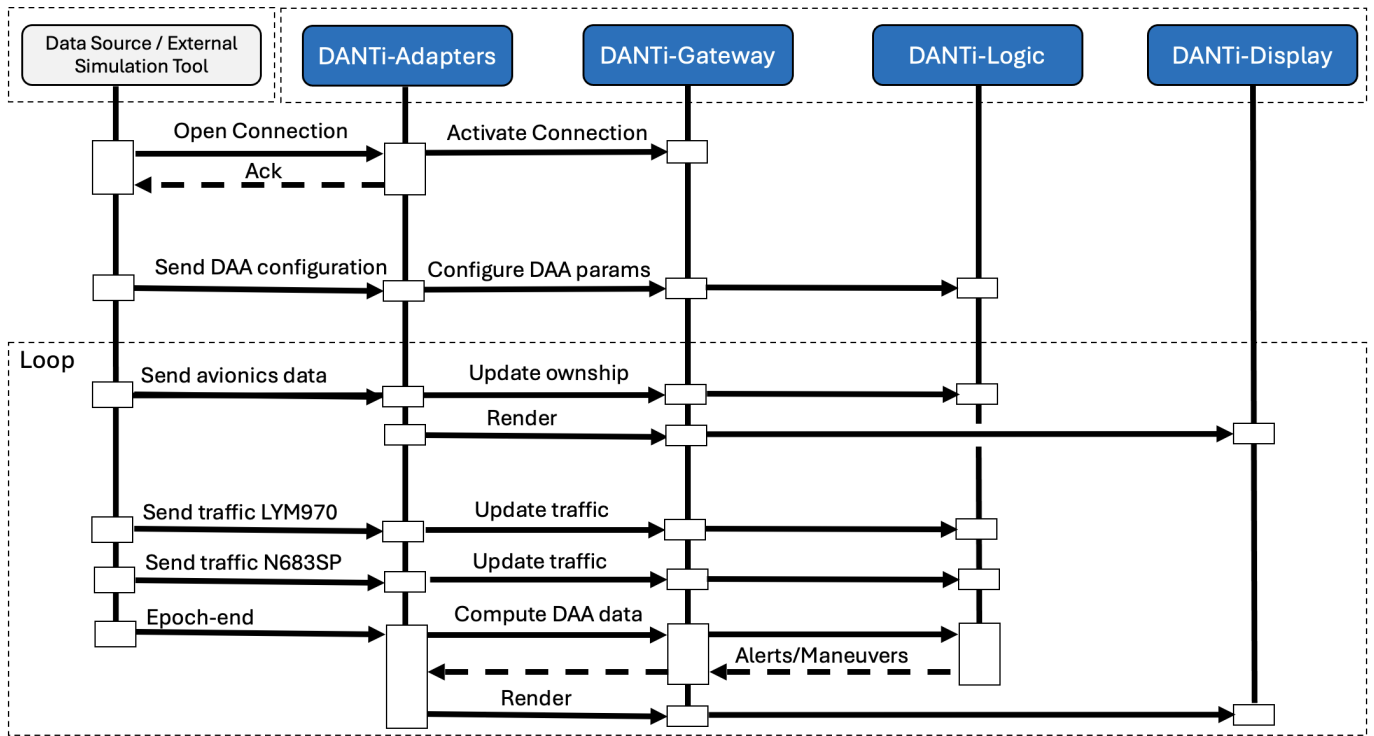


Fig. 6: Sequence diagram representing the interactions between software components in the DANTi architecture.

The diagram in Figure 6 describes the interaction between an external component (data source or simulation tool) with DANTi. The interaction starts with an *open connection* request to DANTi. The connection request, as well as any subsequent message originated from the external source, is handled by the DANTi Adapter that implements the specific protocol needed for the connection (e.g., TCP/IP). After opening the connection, the external component sends the DAA configuration to DANTi. Internally, the DANTi Adapter translates the request into a message that is decoded by the DANTi Gateway and will be dispatched to the DANTi Logic. Then, the external

component periodically sends *avionics data* and *traffic data*. Every time avionics data is sent, the DANTi Adapter generates two messages, one for updating the ownship state in the DANTi Logic, and one for triggering a refresh of the display. Similarly, every time traffic data is sent, the DANTi Adapter generates a message for updating the traffic state in the DANTi Logic. When all traffic data is sent, the external source sends an *epoch end* message, which triggers the computation of alerts and guidance. When alerts and guidance are computed, the display is refreshed with the computed results.

IV. USE CASES

This section describes use cases that illustrate on-going and future research activities enabled by DANTi.

A. Design Integrity Lab

The Design Integrity Lab managed by the Safety Critical Avionics System Branch at NASA Langley Research Center has been equipped with two flight simulators, each one connected to a DANTi EFB. These flight simulators use X-Plane for the out-the-window view. These simulators can be used to replay flight scenarios, including real-world accidents and near misses, and synthetic scenarios on different DAA configurations. The Design Integrity Lab will be used in human-in-the-loop experiments to conduct research on tactical separation management for urban air mobility operations.

B. Advanced Research on Urban Air Mobility

UAM is a fundamental part of the Advanced Air Mobility (AAM) concept under development by the FAA, NASA, and industry, and focuses on operations moving people and cargo in metropolitan and urban areas using innovative technologies, operations, and aircraft, including electric vertical takeoff and landing (eVTOL) aircraft. Researchers at NASA Langley Research Center, in collaboration with FAA researchers at the William J. Hughes Technical Center in Atlantic City, NJ, have conducted a series of medium-fidelity, human-in-the-loop research simulations in a joint NASA/FAA Laboratory Integrated Test Environment (NFLITE) of potential future UAM operations and concepts, in both Class C (Atlantic City area) and Class B (New York City area) airspace environments. These simulations have included the use of DANTi, which enabled configurable ADAA displays to be presented to pilots of simulated eVTOL aircraft participating in higher-density and higher-tempo UAM operations. The use of DANTi in the NFLITE UAM simulations has yielded several initial insights and observations on ADAA utility and limitations, which are reported in [20].

C. Cockpit of a Research Aircraft

DANTi is being integrated in the cockpit of a research aircraft. This work is carried out with external stakeholders as part of NASA's Space Act Agreement focused on the UAM Grand Challenge. It involved integrating DANTi with a commercial off-the-shelf ADS-B receiver using the GDL-90 communication standard.

V. CONCLUSION

This paper presented the current version of DANTi, a prototype tool that enables research on the use of assistive detect and avoid for advanced air mobility concepts such as UAM. DANTi was originally introduced in [14]. The current version includes several enhancements with respect to the previous version. First, the software package is now freely available on GitHub under NASA's Open Source Agreement. Next, its architecture has been refactored with a generic gateway and a suite of specific adapters. These new modules support

the integration of DANTi's capabilities into different types of software and hardware systems. A fast-time simulation environment has been integrated with DANTi, allowing researchers to assess the behavior of DANTi in flight scenarios generated using computer programs or based on real flight data. Finally, DANTi incorporates the latest version of the DAIDALUS DAA library, which includes a new guidance logic for low airspeed flight phases, e.g., eVTOL aircraft during landing and take-off. DANTi has been successfully used over the past few years to explore alert and maneuver guidance, and ADAA parameter values in simulated future air mobility traffic scenarios. On-going and future research work includes integration of the DANTi EFB display on a real-world research aircraft and human-in-the-loop experiments where pilots fly relevant traffic conflict scenarios with DANTi guidance in a flight simulation environment. The use of ADAA technology, such as DANTi, in UAM operations would raise operational, regulatory, and technical challenges. These challenges are out of the scope of this paper, but they are discussed in a companion paper [20].

REFERENCES

- [1] International Civil Aviation Organization (ICAO), "Annex 2 to the Convention on International Civil Aviation," July 2005.
- [2] US Code of Federal Regulations, "Title 14 Aeronautics and Space; Part 91 General operating and flight rules," 1967.
- [3] International Civil Aviation Organization (ICAO), "Annex 2 to the Convention on International Civil Aviation," July 2005.
- [4] US Code of Federal Regulations, "Title 14 Aeronautics and Space; Part 91 General operating and flight rules," 1967.
- [5] R. Mogford and W. Johnson, "The viability of see-and-avoid for urban air mobility operations," in *International Symposium on Aviation Psychology*. Corescholar, 2023.
- [6] RTCA SC-147, "RTCA-DO-185B, Minimum operational performance standards for traffic alert and collision avoidance system II (TCAS II)," July 2009.
- [7] S. P. Cook, D. Brooks, R. Cole, D. Hackenberg, and V. Raska, "Defining well clear for unmanned aircraft systems," in *Proceedings of the 2015 AIAA Infotech @ Aerospace Conference*, no. AIAA-2015-0481, Kissimmee, Florida, January 2015.
- [8] E. Crück and J. Lygeros, "Sense and avoid system for a MALE UAV," in *Proceedings of the 2007 AIAA Conference on Guidance, Navigation and Control*, Hilton Head, SC, August 2007.
- [9] D. Coulter, "UAS integration into the national airspace system: modeling the sense and avoid challenge," in *Proceedings of the 2009 AIAA Infotech at Aerospace Conference*, no. AIAA 2009-1926, Seattle, Washington, April 2009.
- [10] F. Tomasello and D. Haddon, "Detect and avoid for unmanned aircraft systems in the total system approach," in *Proceedings of the 2011 Tyrrhenian International Workshop on Digital Communications-Enhanced Surveillance of Aircraft and Vehicles (TIWDC/ESAV)*. Capri, Italy: IEEE, September 2011, pp. 47–52.
- [11] R. E. Weibel, M. W. Edwards, and C. S. Fernandes, "Establishing a risk-based separation standard for unmanned aircraft self separation," in *Proceedings of the Ninth USA/Europe Air Traffic Management Research & Development Seminar*, Berlin, Germany, 2011.
- [12] E. Theunissen, B. Suarez, and M. Uijt de Haag, "The impact of a quantitative specification of a well clear boundary on pilot displays for self separation," in *Proceedings of the 2014 Integrated Communications, Navigation and Surveillance Conference (ICNS)*. IEEE, 2014, pp. F2–1 – F2–11.
- [13] M. Consiglio, J. Chamberlain, C. Muñoz, and K. Höffler, "Concept of integration for UAS operations in the NAS," in *Proceedings of 28th International Congress of the Aeronautical Sciences, ICAS 2012*, Brisbane, Australia, 2012.
- [14] J. P. Chamberlain, M. C. Consiglio, and C. A. Muñoz, "DANTi: Detect and Avoid in The Cockpit," in *17th AIAA Aviation Technology, Integration, and Operations Conference*, 2017.

- [15] V. Carreño, "Evaluation, analysis and results of the DANTi flight test data, the DAIDALUS detect and avoid algorithm, and the DANTi concept for detect and avoid in the cockpit," NASA, Langley Research Center, Hampton VA 23681-2199, USA, Contractor Report NASA/CR-20205004594, August 2020.
- [16] V. Carreño, M. Consiglio, and C. Muñoz, "Analysis and preliminary results of a concept for detect and avoid in the cockpit," in *Proceedings of the 38th Digital Avionics Systems Conference (DASC 2019)*, San Diego, CA, US, September 2019.
- [17] C. Muñoz, A. Narkawicz, G. Hagen, J. Upchurch, A. Dutle, M. Consiglio, and J. Chamberlain, "DAIDALUS: detect and avoid alerting logic for unmanned systems," in *2015 IEEE/AIAA 34th Digital Avionics Systems Conference (DASC)*. IEEE, 2015, pp. 5A1–1.
- [18] RTCA SC-228, "RTCA-DO-365, Minimum operational performance standards for detect and avoid (DAA) systems," July.
- [19] P. Masci and C. A. Muñoz, "A Graphical Toolkit for the Validation of Requirements for Detect and Avoid Systems," in *Tests and Proofs*, W. Ahrendt and H. Wehrheim, Eds. Cham: Springer International Publishing, 2020, pp. 155–166.
- [20] M. Consiglio, J. Chamberlain, C. Muñoz, and P. Masci, "Assistive detect and avoid technology in urban air mobility environments," in *2024 IEEE/AIAA 43rd Digital Avionics Systems Conference (DASC)*. IEEE, 2024.