Assistive Detect and Avoid Technology in Urban Air Mobility Environments

James Chamberlain*, María Consiglio†, César Muñoz†, and Paolo Masci*

†*NASA Langley Research Center*
Hampton VA, USA
**Analytical Mechanics Associates, Inc.*
Hampton *VA, USA*
Email: james.c.chamberlain@ama-inc.com, maria.c.consiglio@NASA.gov, cesar.a.munoz@NASA.gov, paolo.masci@ama-inc.com

Abstract---The use of Assistive Detect and Avoid (Assistive DAA or ADAA) technology in Urban Air Mobility (UAM) environments poses potential benefits as well as challenges. Assistive DAA refers to the leveraged use of DAA technology, originally developed to replace see-and-avoid capabilities for remotely piloted aircraft, in onboard-piloted aircraft to augment (rather than replace) pilots' see-and-avoid abilities and thus enhance the safety and efficiency of visual flight operations. ADAA is anticipated to be especially safety-enhancing in airspace where traffic density is high or traditional air traffic services are limited, such as in future UAM environments. ADAA may also enable higher-tempo UAM operations than with only see-and-avoid capabilities, while still maintaining acceptable levels of safety. UAM concepts under development by the FAA, NASA, and industry focus on operations moving people and cargo in urban and suburban 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 of potential future UAM operations and concepts in both Class C and Class B airspace environments. These simulations have included use of a Langley-developed ADAA research tool called DANTi, which enables configurable ADAA displays to be presented to pilots of simulated eVTOL aircraft participating in higher-density and higher-tempo UAM operations. Experience and observations made during testing of the NASA-developed DANTi ADAA capability in the UAM NFLITE simulation environment will be reported in this paper together with a discussion of airspace integration and regulatory topics.

Keywords—Detect-and-avoid, DAA, UAM, Assistive DAA

I. Introduction

Mid-air collisions (MACs) and near-mid-air collisions (NMACs) between aircraft have been ongoing safety concerns for pilots and the flying public arguably since multiple aircraft began sharing the same airspace more than a century ago. The concern is elevated in areas of high air traffic density and near convergence points such as airports, and while modern airspace design, air traffic control (ATC) services and traffic awareness/collision avoidance systems [1-6] have improved the MAC/NMAC safety record over time, a non-trivial safety hazard still exists, especially for general aviation (GA) operations. An analysis [7] of incident and accident records showed 112 MAC and 3586 NMAC reports over a 10-year period, with the majority of these MAC and NMAC reports occurring in or near an airport environment. A Federal Aviation Administration (FAA) analysis [8] states that the majority of in-flight collisions occur within five miles of an airport with 77% occurring below 1000 feet.

The oldest and primary means of mitigating MAC/NMAC risk in visual flight conditions is pilots' regulatory responsibility to see and avoid other aircraft and to remain "well clear" of them [9]. This see-and-avoid responsibility may be the only means of mitigation in some relatively high collision risk situations such as arrival to or departure from busy non-towered airports (or heliports) where ATC services are unavailable. This regulatory responsibility is also a significant challenge more generally for uncrewed aircraft systems (UAS) because the remote pilot has no means to comply, and has led to extensive development, certification and rulemaking efforts, e.g., [10-18] toward Detect and Avoid (DAA) systems. Such emerging DAA systems are safety-critical technologies for UAS since they are intended for use by their remote UAS pilots to replace an onboard pilots' abilities and regulatory responsibilities to see and avoid other aircraft when in visual meteorological conditions. DAA design, standards development, and certification efforts have been underway for well over a decade, with operational approvals anticipated soon for DAA use by UAS in limited enroute and terminal operations.

The concept of Assistive DAA (or ADAA) refers to the leveraged use of DAA technology in onboard-piloted aircraft to augment (rather than replace) pilots' see-and-avoid abilities and thus enhance the safety and efficiency of visual flight operations. ADAA may be especially safety-enhancing in airspace where traffic density is high and/or traditional air traffic services are limited, such as near busy non-towered general aviation airports or heliports, as previously described. The National Aeronautics and Space Administration (NASA) has developed a prototype version of ADAA known as DANTi (for Detect and Avoid iN The Cockpit) and conducted flight tests [19] and safety analyses [20-22] of it with promising initial results. More recently, and relevant to the subject of this paper, an updated version of DANTi has been developed [23] and incorporated into a medium-fidelity joint NASA/FAA air traffic simulation

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environment, to investigate the efficacy of ADAA in an Urban Air Mobility (UAM) environment.

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 urban and suburban areas using innovative technologies, operations, and aircraft, including electric vertical takeoff and landing (eVTOL) aircraft [24]. Many proposed UAM operations, such as airport transfer operations where passengers are shuttled on demand between urban vertiports and one or more primary air transport airports, have many of the higher-risk collision characteristics as were previously described for operations near busy non-towered airports: high traffic densities at lower altitudes to/from busy airports (vertiports) with limited air traffic services. Some of these collision risks will be mitigated by UAM airspace structure, strategic conflict management (SCM), and operating procedures, but there may also be a use for ADAA technology as a part of tactical conflict management (TCM) and overall collision risk reduction. ADAA may also aid in higher-rate UAM operations than practical with only see-and-avoid capabilities, while still maintaining acceptable levels of safety.

This paper reports initial insights and observations of ADAA utility and limitations in a simulated future UAM environment; many of these initial observations inform open UAM and ADAA research questions. The next two sections briefly describe the DANTi ADAA prototype and UAM simulation environment, respectively, followed by a section describing ADAA guidance and observations for various UAM encounter geometries. The next two sections describe the significance of wind effects on ADAA guidance, and the challenges of providing ADAA guidance to rotorcraft at low speeds and/or altitudes such as in the immediate vicinity of vertiports, followed by concluding remarks.

II. DANTi

The DANTi ADAA prototype is described more fully in [23] but is functionally comprised of: 1) one or more onboard traffic sensors along with own aircraft (or "ownship") air data, heading, track and groundspeed inputs, as well as radio altimeter data (for altitude above ground level (AGL)) if available; 2) a logic module that compares ownship and traffic (or "intruder") positions and air velocities to determine any conflicts between ownship and intruders within a defined alerting time; and 3) a display unit to provide ownship pilots with traffic situation awareness and with intruder alerts and maneuver guidance options to resolve any such conflicts. The DANTi ADAA prototype as used for the current UAM simulations assumes ADS-B In as the single traffic sensor, and employs the NASA-developed DAIDALUS software [17] as the logic module to compute traffic conflicts. DAIDALUS is the reference implementation for RTCA's DAA Minimum Operational Performance Standards (MOPS) [10] and uses the concept of a parametrically-defined geometric well clear volume (WCV) around each intruder when computing traffic conflicts. The WCV shape is defined by lateral (DTHR) and vertical (ZTHR) distances from the respective intruder as well as a time-based threshold TTHR in the direction of closure rate between the intruder and ownship. The WCV shape can be complex but can be envisioned as a cylinder of radius DTHR and height ZTHR above and below the intruder, with an elongated extension in the direction of closure with ownship that equals the closing distance that would be covered in TTHR time.

DAIDALUS is state-based and, for a given time and for each intruder, computes whether the ownship and intruder air velocities will result in the ownship penetrating the intruder's WCV within a specified alerting time; if so, the intruder is considered in conflict with the ownship and an alert will be generated for that intruder. DAIDALUS additionally computes whether conflicts would (or would not) exist if the ownship velocity vector's lateral direction (heading), vertical direction (vertical speed), or magnitude (airspeed) were changed to a range of new values at a given parametric rate (e.g., a 10-degree left heading change at a standard 3-degree-per-second turn rate). By doing these additional calculations, DAIDALUS can provide a range of ownship headings, vertical speeds and airspeeds (i.e., maneuver guidance) which will either cause, resolve or avoid conflicts with intruders. DAIDALUS is typically invoked once or twice per second as ownship and intruder state data updates, and thus the maneuver guidance and alert status will also update with time.

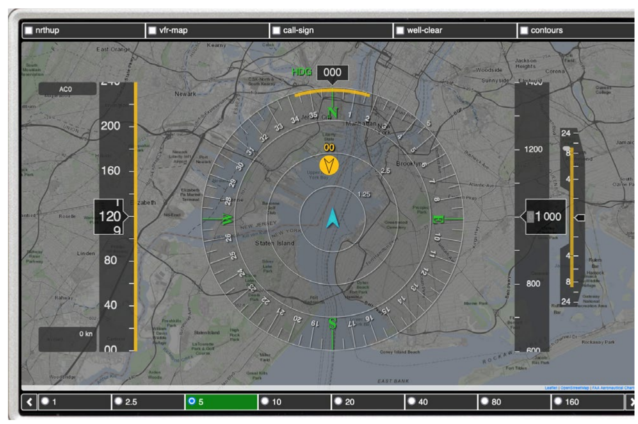

Fig. 1. DANTi display. Opposite direction encounter

Fig. 1 shows an example of a DANTi display with a single co-altitude opposite-direction intruder that has come just close enough to the ownship to cause an alert and maneuver guidance bands. This DANTi implementation uses a standalone display with a heading indicator in the center, airspeed tape on the left, altitude tape on the near-right and vertical speed indicator on the far-right, but other implementations might alternatively display DANTi alerts and guidance on the aircraft's primary flight display (PFD) and navigation display (ND), for example. In this case, the ownship is depicted as the cyan chevron in the center of the heading indicator compass rose at 1000 feet altitude and heading due north at 120 knots, and the intruder is shown as a filled amber (i.e., caution alert) chevron two miles north of the ownship and heading due south on a collision course. Amber maneuver guidance bands are shown on the heading, airspeed, and vertical speed indicators showing a conflict with the intruder for the current ownship velocity vector; these are known as "corrective bands" because the velocity vector must be changed ("corrected") to resolve the conflict. In this case, the ownship heading could be changed at least 18 degrees left or right, to go around the intruder and laterally avoid its WCV, or could climb or descend at least 1500 feet per minute (fpm) to avoid the WCV vertically; there is no airspeed change that will resolve this conflict geometry as shown by the full amber band on the airspeed tape. By providing multiple maneuver guidance options (left/right, up/down), DANTi enables the pilot to resolve the conflict within other constraints outside the scope of DANTi (e.g., terrain, obstacle, airspace or ATC constraints, etc.).

III. UAM Simulation Environment

The UAM simulation environment within which DANTi has been embedded is more fully documented in [25] but is based on the NASA/FAA Laboratory Integrated Test Environment (NFLITE). NFLITE is a collaborative human-in-the-loop (HITL) air traffic simulation capability using networked equipment and personnel at both NASA Langley Research Center (LaRC) and the FAA's William J. Hughes Technology Center (WJHTC). NFLITE includes medium- and high-fidelity aircraft and air traffic simulation capabilities across both NASA and FAA locations, including realistic out-the-window views for both pilot and ATC tower cab participants, multi-frequency voice communications, data communications, realistic ATC equipment such as Standard Terminal Automation Replacement System (STARS), sophisticated target generation facilities, and multiple "pseudo pilot stations" to enable realistic HITL simulations of high-density air traffic scenarios. For UAM simulations the NFLITE was additionally equipped at LaRC with Mission Planner and Vertiport Scheduler stations which can simulate a future multi-UAM-operator medium-tempo collaborative environment, and with pseudo pilot stations and (currently) two "UAM Flyers" (Fig. 2) which can simulate multiple types of piloted eVTOL aircraft flying in the airspace.

Fig. 2. NFLITE UAM Flyer

The DANTi display is shown on the right-side screen of the UAM Flyer. In all UAM simulations to date, the DANTi systems have not been actively used by UAM Flyer pilots to resolve conflicts, but rather have been passively observed by researchers with various adjustments to WCV parameters and alerting times.

NFLITE simulations have been extensively conducted in both Class C and Class B airspaces, beginning with the Atlantic City, New Jersey (ACY) Class C airspace in 2022-2023, and later in 2023 through the current time in the New York City (NYC) area Class B airspace. Fig. 3 shows the ACY Class C airspace area with four potential future vertiports in the downtown area and two vertipad at ACY, with two notional airport transfer routes between the downtown area and ACY.

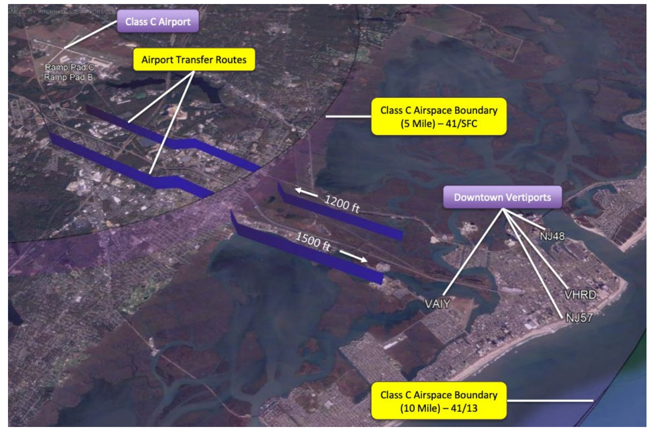

Fig. 3. ACY Class C airspace area (Base image: Google Earth © 2024)

The airport transfer routes are designed so that the north route is used for traffic inbound to the primary airport (ACY) and the south route is used for outbound traffic, and both routes are offset by 2500 feet laterally from a major highway below, so that opposite-direction traffic is offset laterally by 5000 feet and vertically by 300 feet. It should be noted that the routes run parallel but have a "dogleg" offset at roughly their midpoint as they track the highway, which has implications for DANTi that are described subsequently. Simulated UAM traffic was run at several rates significantly higher than what would be encountered in today's environment with helicopters, with abbreviated UAM-ATC voice communications, and metered UAM arrivals at transfer route entry points, via a notional ATC-UAM Letter of Agreement (LOA). Legacy fixed-wing and rotorcraft traffic was simulated both at ACY and over downtown. A loitering small UAS was also introduced at lower altitudes over downtown.

Fig. 4 depicts a high-level view of the NFLITE UAM simulations under development in the NYC Class B airspace, specifically for simulating hypothetical future higher-rate UAM passenger airport transfer operations between three existing multipad heliports on Manhattan Island (three upper-left red circles) and three existing/new heliport sites on/near John F. Kennedy International (JFK) (lower-right red oval at JFK plus red circle above it at Jamaica Station intermodal site), as well as three non-passenger staging/charging stations (Hillside, Woodside, and Floyd Bennett Field). These sites are linked largely by existing helicopter routes (white lines on the chart) with the addition of lateral offsets for bidirectional travel. This airspace is much more compact, congested and complex than ACY airspace or even many other Class B airspaces, with three primary Class B airports (JFK, LGA, EWR) in close proximity plus heavy low-altitude traffic subject to 14 CFR Part 93 special flight rules along both shorelines of the Hudson and East Rivers west and east of Manhattan, respectively.

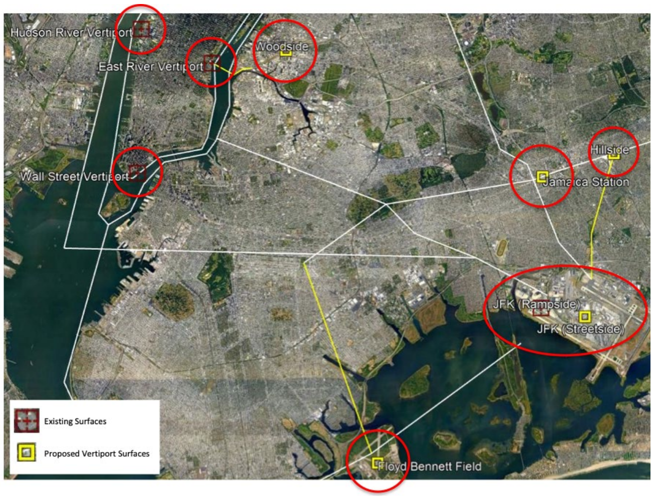

Fig. 4. NYC Class B airspace area (Base image: Google Earth © 2024)

This complexity limits options for altitude separation, among other things, due to overflying legacy traffic and terrain/obstacles below. Additional constraints include noise abatement, limiting flexibility for new routes.

IV. ADAA FOR COMMON UAM ENCOUNTER GEOMETRIES

This section briefly discusses ADAA guidance and observations in UAM simulation environments for three classes of encounters: opposite-direction traffic on bidirectional routes with lateral offsets; overtaking encounters; and crossing encounters.

A. *Bidirectional Routes with Lateral Offsets*

Bidirectional helicopter routes with lateral offsets are relatively common where good continuous ground references are available, such as the highway below the ACY routes or the Hudson and East River shoreline routes in the NYC area. Other

Fig. 5. Bidirectional route, lateral offset

routes are defined only as a series of direct lines between visual points, and lateral offsets on these routes will require assistance from navigational equipment and displays, as well as guidelines for safe minimum offsets when continuous ground references are absent. One guideline is to use the minimum DTHR value of 1500 feet for terminal-area DAA WCV [10] plus a margin of 300 feet for near-full-scale maximum flight technical error for an ILS or RNAV(GPS) approach at the runway threshold [26], yielding a minimum lateral UAM separation of 1800 feet, or 900 feet offset from the route centerline. Fig. 5 shows an example of a DANTi display when encountering opposite-direction traffic on such a bidirectional route, with ownship flying due north and the intruder flying due south with 1800 feet of lateral separation, and a DTHR value of 1500 feet. In this case DANTi displays no alert but a prominent “peripheral” amber heading band, showing that the current north heading is conflict-free but that any left turn beyond about 3 degrees will cause a conflict with the intruder. Such guidance is arguably good protection against excessive flight technical error from either aircraft that is not detected in time visually.

Several false-alert challenges arise when using DANTi guidance on routes with lateral offsets, the first of which is turn points on the routes. This was initially noticed for opposite-direction flights on the ACY airport transfer routes near the turn points closest to ACY (Fig. 3), where an outbound intruder on the “dogleg” bend route segment can induce a corrective DANTi alert for an inbound ownship on the parallel segment between bends. This alert happens because DANTi has no knowledge of route structure or aircraft intent, and so correctly calculates that the ownship will penetrate the intruder’s WCV without a course change by one or both aircraft. The corrective alert goes away once the intruder turns onto the parallel portion of the outbound route. The research team was able to eliminate the false alert in this case (and some others) by shrinking the WCV and alerting times to those comparable to a TCAS Traffic Alert (TA), but false alert suppression is not possible in all cases. For example, the East River opposite-direction shoreline routes in the NYC area are separated by less than 1000 feet in some places, with many turn points, and while operational safety is maintained by pilot vigilance and strong, continuous visual shoreline cues, there is no practical way to prevent state-based DANTi alerts (or TCAS TAs) in the general case. Our current mitigations include silencing the aural portion of the caution alert and training/notifying pilots of the false-alert behavior, but this remains an open research topic.

B. *Overtaking Encounters*

Overtaking UAM encounters may benefit from DANTi guidance, particularly since FAA studies show that most MACs occur in overtake encounter geometries [8]. Fig. 6 shows a DANTi display example for a same-route overtaking encounter immediately after an alert is issued with corrective guidance for the slower intruder ahead. In this case the ownship and intruder airspeeds are 120 and 80 knots, respectively, and the maneuver guidance shows that the ownship can resolve the conflict by slowing to 80 knots, or alternatively by turning left or right to go around the intruder, or climbing/descending to go over/under.

Fig. 6. Overtake encounter

C. Crossing Encounters

Fig. 7 shows a DANTi alert and corrective maneuver guidance for a 90-degree crossing encounter. In this case the ownship is flying due north and the intruder due west, both co-altitude at 120 knots and on a collision course. The WCV in this case is cylindrical and symmetric (i.e., TTHR = 0), and the maneuver guidance shows that the conflict can be resolved with a left or right turn of approximately 24 degrees, or by climbing/descending above/below the intruder, or slowing to approximately 70 knots. While the pilot might choose, for various reasons, to go right and behind the intruder rather than left and in front, either choice, in the absence of wind, will keep the ownship out of the intruder's WCV with an equal heading deviation. The next section will describe the importance of wind information for heading maneuver guidance.

Fig. 7. Crossing encounter

V. EFFECT OF WIND ON ADAA HEADING GUIDANCE

Consistent with DAA standards [10], DANTi uses heading and airspeed data to determine ownship air velocity, GPS data to determine ground velocity (track direction and groundspeed), vector arithmetic of air and ground velocities to determine wind velocity at ownship's position, and then makes the approximation that this same wind velocity exists for proximate intruders when deriving their respective air velocities. This use of air velocities enables the DAIDALUS logic to evaluate conflict geometries in an inertial reference frame fixed to the moving airmass in which the aircraft are immersed, rather than to the ground over which they are moving, and results in several important outcomes. First, maneuver guidance for direction and speed is provided to pilots as heading and airspeed bands, respectively (rather than as track/groundspeed bands), which matches what is presented on primary flight instrumentation and what pilots directly control when flying. Intruder locations are also presented relative to ownship heading (rather than track), which more closely matches the out-the-window view of their location. Most importantly, the use of air velocities yields more accurate and stable maneuver guidance; DAIDALUS logic assumes that if ownship direction is changed as part of a conflict resolution, then speed will be held constant, and vice versa. This assumption holds true for heading and airspeed in an airmass-based reference frame, but does not hold true for track/groundspeed in a ground-based reference frame if wind is present.

Fig. 8 Crossing encounter with wind

A comparison of Fig. 7 and Fig. 8 illustrates the effect of wind on DANTi heading guidance. The groundspeeds (GS) and tracks are identical in both figures – that is, the ownship is tracking due north and the intruder due west co-altitude on a collision course, both with GS of 120 knots – but the wind is absent in Fig. 7 and 40 knots from due west in Fig. 8, leading to different airspeeds, headings and maneuver guidance. Specifically, in the no-wind condition of Fig. 7 the GS and true airspeed (TAS) values are the same, as are track and heading values, but in Fig. 8 the intruder's airspeed is much faster (160 knots TAS into a 40-knot headwind) than the ownship's, and the heading bands show that a left turn option in front of the faster intruder is effectively foreclosed. Fig. 8 also shows the ownship's significant wind correction angle of 18 degrees left of its due-north track and the influence that has on the relative bearing of the approaching intruder as it would appear out the window.

VI. ADAA GUIDANCE CONSIDERATIONS FOR ROTORCRAFT

UAM operations are anticipated to use rotorcraft such as eVTOL aircraft to land and depart from vertipads (helipads) at heliports or airports, and such operations pose unique challenges for ADAA applications such as DANTi. DAA standards and algorithms were originally developed for fixed-wing UAS, and while some of the underlying DAA assumptions also hold for rotorcraft, some do not. Specifically, DAA algorithms assume that the ownship's heading and air velocity direction are aligned throughout the flight envelope, with only minor, temporary misalignment of a few degrees immediately prior to a crosswind landing, or during an emergency such as single engine failure of a multiengine aircraft. This assumption allows the wind field and air velocity calculations described in the previous section, but more generally it informs the ADAA guidance provided to the pilot. The sole option for effecting a directional change is to change heading. This assumption breaks down for rotorcraft at low speeds; a hovering rotorcraft in a tailwind, or one that is (briefly) backing out of a one-way vertipad, has an air velocity vector pointing in the opposite direction to its heading. At low speeds, heading and air velocity direction are independent for rotorcraft, airspeed becomes unmeasurable with a pitot system, and ADAA heading and airspeed maneuver guidance loses its meaning.

An additional DAA assumption is that (fixed-wing) aircraft will not normally operate airborne within the WCV of an intruder, but this assumption also breaks down for rotorcraft in the vicinity of heliports with multiple helipads, where rotorcraft often operate visually in extreme proximity to each other. A typical example is the West 30th Street Heliport (JRA) on the Hudson River in NYC, which has six helipads in a row on 75-foot centers along the Manhattan shoreline, with one-way access from only the river side due to urban high-rise buildup on the other side. Appropriate ADAA guidance in these situations is an ongoing research topic, but after significant study the research team is currently inhibiting ADAA guidance below a threshold airspeed of 30 knots and/or an altitude AGL of 300 feet, while keeping the (aural-muted) caution alerts for conflicting traffic. The research team has also incorporated very small traffic display scale options, compatible with operation near such heliports.

VII. CONCLUSION

ADAA tools such as DANTi show potential as a safety and possible efficiency enhancement in future high-density UAM traffic environments by augmenting pilots' see-and-avoid capabilities, based on initial observations in NFLITE simulations of future UAM environments in representative Class C and Class B airspaces. DANTi was introduced and its guidance observed in numerous pilot/controller HITL simulations of the ACY Class C and NYC Class B airspace environments under various traffic rates and route configurations, including bi-directional routes with lateral offsets for opposite-direction traffic, overtaking traffic on the same routes, and crossing traffic both outside of controlled airspace and within controlled airspace under potential future modified air traffic management rules. DANTi appears to be a useful safety augmentation for new closely-spaced bidirectional offset routes without continuous ground references defining the route, although the issue of proper handling of false alerts at route turn points remains an open research area. DANTi guidance also shows promise for overtaking encounters by indicating the degree of airspeed adjustment necessary to resolve the overtake conflict. The effect of wind on ADAA heading guidance has been observed, which may be of particular importance for slower-moving UAM aircraft where wind speed may be a relatively larger fraction of airspeed. Finally, some underlying DAA assumptions that are valid for fixed-wing aircraft, and for rotorcraft at cruising speeds, have been shown to break down at very low speeds such as hovering or vertiport landing/takeoff phases, leading to an initial decision to inhibit ADAA guidance in such situations, pending further research.

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