Analysis and Preliminary Results of a Concept for Detect and Avoid in the Cockpit

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***Abstract*—Pilots operating under Visual Flight Rules and not receiving Air Traffic Control radar services rely on see and avoid to remain well clear of other aircraft and avoid collisions. The DANTi (Detect and Avoid iN the cockpit) concept developed at the National Aeronautics and Space Administration (NASA) leverages advancements achieved in surveillance and Detect and Avoid technologies for unmanned aircraft systems as a safety enhancing capability for pilots of manned aircraft. The DANTi concept provides traffic awareness as well as maneuvering resolution guidance to the flight crew to remain well clear. Conflict detection and resolution guidance is generated by the DAIDALUS Detect and Avoid algorithm, also developed at NASA. This paper presents the data analysis results of the NASA Langley Research Center flight tests and the results of simulation studies to evaluate DANTi's and DAIDALUS' performance. The results of the data and simulation analysis are presented in terms of severity of encounter. Preliminary results suggest that DANTi could provide substantial risk mitigation benefits and that the DAIDALUS resolution maneuvers significantly reduce the severity of the encounter and risk of collision.**

Keywords—collision, detect and avoid, resolution, well clear, surveillance

I. INTRODUCTION

The 27th Joseph T. Nall General Aviation accident report [1] indicates that there were approximately 23 mid-air collisions in the United States in 2015 of which 9 resulted in fatalities. See-and-avoid alone is not always sufficient to remain well clear of other aircraft and avoid collisions. The limitations of the human vision, obstructions in the cockpit, pilot workload, and other factors restrict the effectiveness of see-and-avoid.

The DANTi (DAA iN The Cockpit) concept developed at the National Aeronautics and Space Administration (NASA) proposes to leverage advancements achieved in Detect and Avoid (DAA) technologies for unmanned aircraft systems (UAS) as a safety enhancing capability for pilots of manned aircraft [2]. While the concept of "well clear" (WC) as defined in Title 14 Code of Federal Regulations (14 CFR), Part 91, relies on the subjective view of the pilot, DAA technologies for unmanned aircraft use a quantified definition of "well clear" based on distance and time parameters, which will be formally presented in Section IV. In addition, a predicted "loss of WC" or "WC violation" between two aircraft constitutes a "conflict".

The DANTi concept provides traffic awareness as well as maneuvering guidance to the flight crew to remain well clear. A DANTi prototype implementation with NASA developed DAA technology was designed to serve as a safety augmentation means to pilots' see-and-avoid capabilities.

II. DANTI CONCEPT

A DANTi prototype has been developed that incorporates a single ADS-B (Automatic Dependent Surveillance-Broadcast) sensor and displays traffic information on an EFB (Electronic Flight Bag). The DANTi prototype receives ownship flight data as well as traffic aircraft states, and uses the DAIDALUS Detect and Avoid algorithm [3] to predict conflicts (i.e., potential loses of "well clear") and present traffic alerts and resolution guidance on the EFB to the pilot in command.

The DAIDALUS algorithm uses a configurable well-clear volume, a look ahead time, and other parameters to detect conflicts and generate guidance that will keep the ownship well clear of traffic aircraft.

Fig.1 shows the EFB display prototype, which provides situational awareness, guidance, and other information. The display shows the ownship blue chevron symbol in the center of the compass rose which in this view is configured to 2.5 nautical miles. A nearby traffic aircraft is shown as a hollow chevron in an amber colored disc indicating that the ownship's current trajectory is in conflict with that traffic aircraft. Traffic aircraft are represented by a white, hollow chevron when they are not in conflict with the ownship.

The display can be configured to show magnetic heading, magnetic track, true heading or true track at the top of the display, as well as "north" or "track" up. An amber band on the compass rose shows the range of headings that will result in a loss of well clear. For the example in Fig 1, the pilot could turn left to a 266-degree heading or turn right to a 302-degree heading to avoid the conflict.

Maneuver guidance is also given for airspeed and rate of climb or descent enabling the pilot to choose the most efficient or safest (single) maneuver to avoid the conflict. Combined maneuvers are not supported in this implementation.

The display range at the bottom shows that the outer concentric ring is 2.5 nautical miles from the ownship, but it can be configured to much larger ranges.

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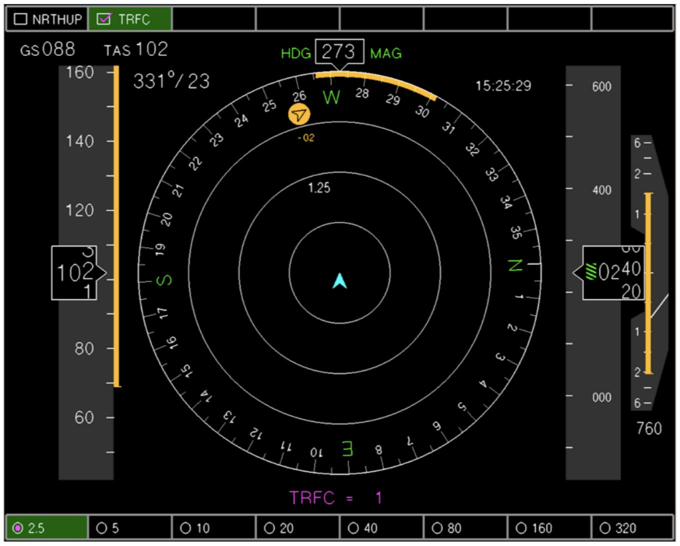


Fig 1.DANTi prototype Electronic Flight Bag display

III. FLIGHT TESTS AND DATA ANALYSIS

The DANTi prototype was installed in NASA Langley Research Center's Cirrus SR22 research aircraft. A series of flight tests were conducted using the Cirrus SR22 as the ownship and NASA Langley's Cessna 206 aircraft as the traffic aircraft. The flight tests in the Cirrus SR22 included a pilot, a safety pilot, and a research crew monitoring the DANTi EFB. The research crew, amongst other duties, instructed the pilot what maneuver to perform per the DANTi guidance.

A. *Well clear volume and parameter sets*

As mentioned before, the well-clear concept defines a volume surrounding traffic aircraft that the ownship should not penetrate. This volume includes a dynamic component. A more precise mathematical definition of well clear is given in Section IV. The set of parameters used in the Detect and Avoid algorithm include horizontal distance, vertical distance, alerting time, and time threshold parameters. Table 1 shows three sets of parameters that were used in the flight tests.

Table.1. PARAMETER THRESHOLD SETS

	Parameter Set		
	1	2	3
Horizontal distance threshold, DTHR	1219 m (4000 ft)	366 m (1200 ft)	366 m (1200 ft)
Vertical distance threshold, ZTHR*	137 m (450 ft)	91 m (300 ft)	91 m (300 ft)
Time threshold, TTHR	35 sec.	15 sec.	0 sec.
Alerting time	40 sec.	40 sec.	40 sec.
* The ZTHR parameter was set to 305 meters (1,000 feet) for all flight tests because encounter runs were flown with a 152 meter (500-foot) vertical offset for safety.			

B. *Flight tests*

Seven flight tests were conducted to evaluate the DANTi concept and prototype. The first two flight tests were conducted in the pattern of Langley Air Force base air field, KLFI and Wakefield municipal airport, KAKQ. The results of these first two flight tests are documented in [2].

The remaining five test flights were conducted near Wakefield municipal airport (KAKQ), Wakefield, Virginia. This airport is a non-towered airport with light general aviation traffic. Several runs were performed for each flight test with the different parameter sets shown in Table 1. There were three encounter geometries used for these flight tests:

- Head on
- Ninety-degree crossing with traffic flying right to left
- Ninety-degree crossing with traffic flying left to right

The aircraft were in straight, level flight during the encounter runs. For safety reasons, encounters were flown with 152 meters (500 feet) vertical offset between the ownship and the traffic aircraft. Therefore, the vertical distance threshold, ZTHR, was set to 305 meters (1,000 feet) to trigger the detection algorithm to detect a conflict and produce guidance. The research crew on-board the ownship aircraft monitored the DANTi EFB and gave the pilot instructions to maneuver to avoid the conflict. In some runs, the guidance produced by DANTi was ignored to observe the progression of the guidance as the two aircraft converged horizontally.

C. *Data analysis results*

A total of 41 encounter runs were flown during the five tests near Wakefield. Of the 41 encounter runs, the flight crew did not follow the guidance and did not maneuver in 6 encounter runs. These 6 encounter runs were used for adjustment of the encounter trajectories, as the baseline of the flight tests, and to observe the progression of the guidance when no action by the flight crew was taken. The flight crew followed the guidance and performed an avoidance maneuver in 35 of the encounter runs.

For each of the encounter runs, the time of the initial guidance, the time from when guidance is first shown to the start of the maneuver (also referred to as "pilot delay"), type of maneuver, and horizontal distance at Closest Point of Approach (CPA) were determined. For the purpose of data analysis, the run started when the tracks of the aircraft were plus or minus 5 degrees of the intended track. The run ended when the loss of well clear ended, when the conflict ended, or in the case of no loss of well clear and no conflict, when the aircraft were observed to turn to position themselves for the next run.

Fig. 2 shows the distribution of the "pilot delay" time, for the 35 encounter runs when the pilot implemented the guidance maneuver.

Fig. 3 shows the distribution of horizontal distance at the CPA for the 6 encounter runs where the flight crew did not follow the guidance and did not maneuver.

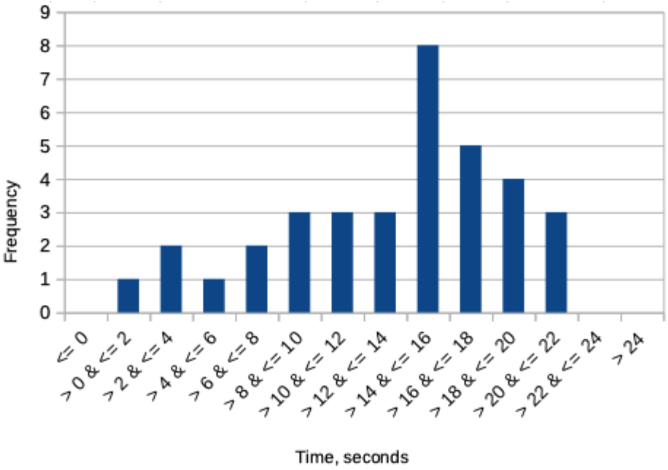


Fig 3.Time delay distribution, guidance to guidance implementation

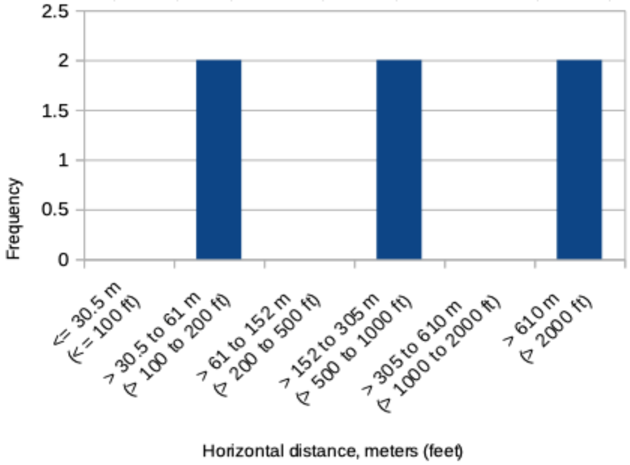


Fig 4.Horizontal distance at CPA, no maneuver

Figures 4 and 5 show the distribution of horizontal distances at CPA for parameter set 1 (1219 meters (4000 ft)) and parameter set 2 (366 meters (1200 ft)), respectively.

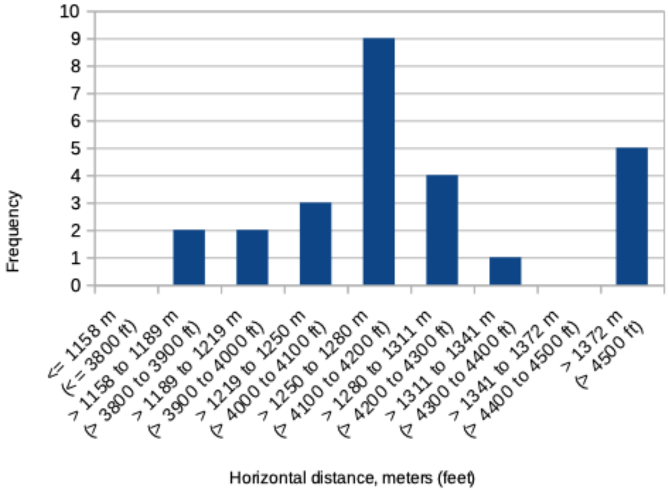


Fig 2.Horizontal distance at CPA, parameter set 1, 1219 meter (4000 ft) thresh-

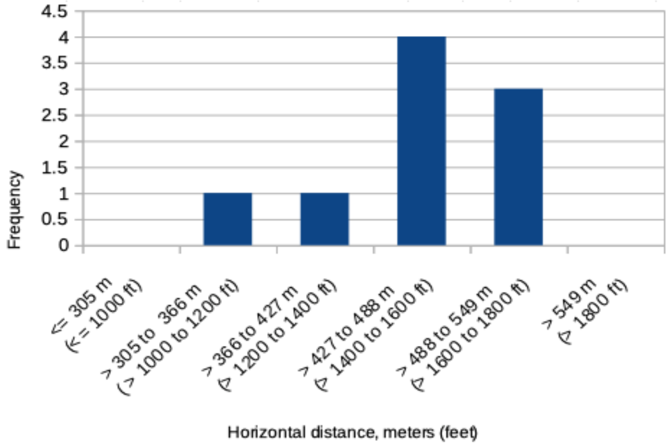


Fig 5.Horizontal distance at CPA, parameter set 2, 366 meter (1200 ft) threshold

The geometry of the scenario, the parameter set, and the promptness with which the guidance is implemented determines the magnitude of the maneuver needed to stay well clear.

Ninety-degree crossing scenarios, with parameter set 1 and implementation within 5 seconds of the initial guidance, will require an 8 to 14 degree turn to remain well clear. Waiting 15 seconds to implement the guidance will require a 12 to 20 degree turn to remain well clear. Head-on scenarios, with parameter set 1 require a 14 to 18 degree turn within 5 seconds and a 17 to 20 degree turn when waiting 15 seconds.

Ninety-degree crossing scenarios, with parameter set 2 and implementation within 5 seconds of the initial guidance, will require a 4 to 8 degree turn to remain well clear. Waiting 15 seconds to implement the guidance will require a 5 to 10 degree turn to remain well clear. Head-on scenarios, with parameter set 2 require a 4 to 6 degree turn within 5 seconds and a 5 to 7 degree turn when waiting 15 seconds.

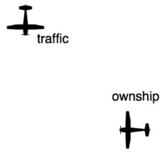
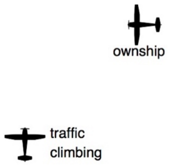
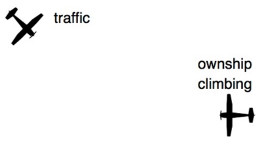
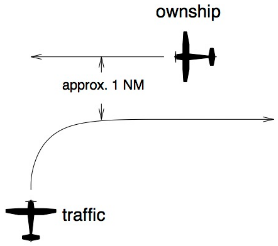
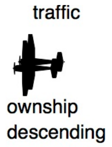
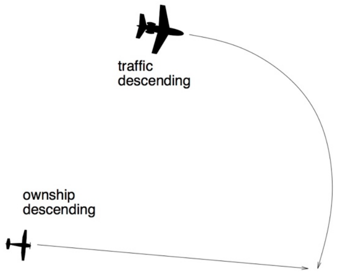
IV. SIMULATIONS

Encounter simulations were performed to evaluate the DAIDALUS Detect and Avoid (DAA) algorithm in a statistical manner and also to expand on the scenarios that were used in flight tests. The simulation consists of a dynamics module that move aircraft along their trajectory, the DAIDALUS algorithm that generates the alerting and guidance, a virtual pilot that implements the guidance, and a module that determines the severity of the encounter.

A. Scenarios

Eight scenarios were defined which included the crossing and head-on scenarios of the flight tests, plus in-trail, turning, crossing at different angles, climbing, and descending. Table 2 shows the eight scenarios.

TABLE 2. SCENARIOS WITH NOMINAL GEOMETRIES

Scenario	Description	Geometry
1	Crossing, 90-degree, co-altitude	
2	Crossing, 90-degree traffic climbing	
3	Crossing, 135-degree, ownship climbing	
4	Head-on, co-altitude	
5	Turning from initial crossing, co-altitude	
6	Overtaking with traffic climbing	
7	Horizontally co-located, ownship descending onto traffic	
8a	Faster aircraft turning towards slower aircraft, both descending	
8b	Same as 8a, with ownship and traffic interchanged	

The scenarios were defined with nominal values of initial range, coordinates, horizontal direction, horizontal speed, altitude, and vertical speed. A pseudo-random value was added to each of the initial conditions parameters to make each simulation run a pseudo-random run. The pseudo-random values added were picked from a pseudo-random distribution as shown in Table 3.

TABLE 3. PSEUDO-RANDOM VALUES ADDED TO INITIAL CONDITIONS

Parameter	Pseudo-random variable, mean and standard deviation
Horizontal direction	nominal + X(0 mean, 1 degree s.d.)
Latitude	nom. + X(0 mean, 50 meters s.d.)
Longitude	nom. + X(0 mean, 50 meters s.d.)
Horizontal speed	nom. + X(0 mean, 5 knots s.d.)
Altitude	nom. + X(0 mean, 15 m (50 ft) s.d.)
Vertical speed	nom.+ X(0 mean, 1.27 m/s (25ft/min) s.d.)

The time from the initial conditions to the Closest Point of Approach varied from 111 seconds to 240 seconds for scenarios 1 through 7. The time from initial conditions to CPA for scenario 8 was 30 seconds. Scenario 8 approximates the trajectories of the two aircraft involved in a mid-air collision over Brown field, San Diego, California, on the 16th of August 2015.

B. Well clear

Title 14 Code of Federal Regulations, Part 91, Section 91.113, paragraph b states:

"(b) General. When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear."

The regulations, however, do not define *well clear* in a quantitative or mathematical way. RTCA Special Committee

SC-228 defined a quantified notion of well clear to be able to analyze and evaluate operations of Unmanned Aircraft System and to be used by automation and the UAS remotely located pilots. Two aircraft are defined to be well clear if they are currently 137 meters (450 feet) or more vertically from one another or if they are projected to be more than 1219 meters (4,000 feet) horizontally at all times in their trajectory within the next 35 seconds. Two aircraft are said to have lost well clear when:

$$[0 <= tau_{mod} <= 35 \text{ sec.}] \text{ and } [HMD <= 4{,}000'] \text{ and } [-450' <= d_h <= 450'],$$

where tau_{mod} is the modified tau, defined below, HMD is the projected horizontal missed distance at the closest point of approach, d_h is the vertical distance between the aircraft.

Modified tau is approximately the time to the horizontal closest point of approach and it is defined as follows:

$$tau_{mod} = \begin{cases} \dfrac{DMOD^2 - r^2}{r\dot{r}} & r > DMOD \\ 0 & r \leq DMOD \\ \infty & \dot{r} > 0 \wedge r > DMOD \end{cases} \quad (1)$$

where $DMOD$ is 1219 meters (4,000 feet) (modified horizontal distance threshold),

r is the horizontal distance between the aircraft,

$\dot{r}$ is the rate of change of the horizontal distance (negative for closure).

C. *DAIDALUS guidance*

The DAIDALUS algorithm is invoked with the current states of the aircraft. The DAIDALUS algorithm produces alerting and resolution guidance. Alerting and guidance include horizontal direction, horizontal speed, vertical speed, and altitude. In the simulation presented in this paper, only the horizontal direction and vertical speed are used as guidance. The alerting and guidance produced by DAIDALUS are passed to the virtual pilot part of the simulation to implement the guidance.

D. *Virtual pilot*

The virtual pilot receives the alerting and guidance generated by the DAIDALUS algorithm and implements the guidance. The virtual pilot can be configured with the following parameters:

Resolution type [*none, horizontal, vertical, both*]

Horizontal direction [s*mallest, turn right, turn left*]

Vertical speed [*smallest change, increase, decrease, smallest absolute*]

Horizontal direction changes are implemented at a 3 degrees per second turn rate. Vertical speed changes are implemented within one second and are limited to the aircraft's maximum climb rate. The maximum climb rate used for the simulations presented in this paper are based on a Lancair LC40-550FG at maximum gross takeoff weight of 3,400 lbs., sea level pressure altitude, and International Standard Atmosphere (ISO). The corresponding maximum climb rate is 1,225 feet per minute. A maximum descent rate of -1,225 feet per minute is also used.

The virtual pilot implements the guidance after a pseudo-random delay defined by a random variable with a Rayleigh distribution. The probability density function of a Rayleigh distribution is given by,

$$f(x|\sigma) = \frac{xe^{\left(\frac{-x^2}{2\sigma^2}\right)}}{\sigma^2} \quad (2)$$

Fig. 6 shows a graph of the virtual pilot's delay distribution (10,000 samples) when the average delay is 15 seconds.

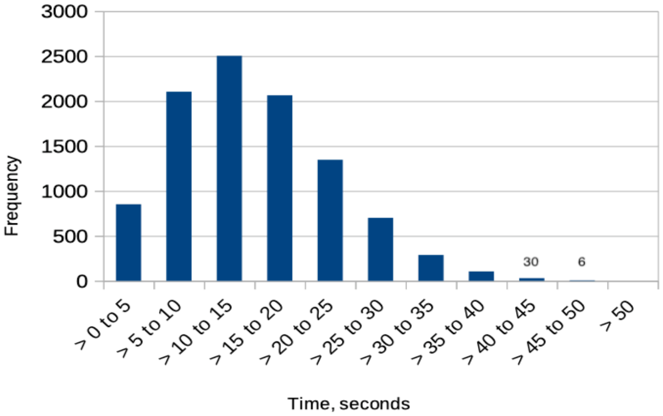


Fig 6: Virtual pilot's time delay distribution for 15 seconds average

E. *Dynamics*

The dynamics part of the simulation takes the states of the aircraft and computes new states. The new states are calculated in one second intervals using the current location of the aircraft, horizontal direction, horizontal speed, altitude, and vertical speed.

F. *Severity*

Severity is defined using two methods:

- The Federal Aviation Administration, Air Traffic Organization, Safety Management System (SMS) manual [4]
- RTCA Special Committee SC-228 [5]

The Safety Management System classification of severity is abbreviated and summarized in Table 4.

TABLE 4. SMS ABBREVIATED HAZARD SEVERITY CLASSIFICATION

	Hazard Severity Classification				
Applies to	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1

Flight Crew	Pilot is aware of traffic. Compliance greater than or equal to 66 percent	Aircraft is in close enough proximity to require specific action. Low risk Analysis Event*	In close enough proximity on a course of potential collision. Medium risk Analysis Event*	Near mid-air collision. Proximity of less than 152 meters (500 feet).	Mid-air collision

* Analysis Event is defined in the SMS manual and includes proximity, rate of closure, ATC mitigation and pilot mitigation.

The RTCA Special Committee SC-228 defines severity using three components:

1. Horizontal Proximity (Tau MOD)
2. Horizontal Miss-Distance projection (HMD)
3. Vertical distance

These 3 components are combined using the norm operator defined as,

$$x \oplus y = \sqrt{x^2 + y^2 - x^2 y^2} \tag{3}$$

The severity is defined as a percentage with 0 percent being the least severe and 100 percent the most severe. Severity of Loss of Well Clear is given by the equation,

$$SLoWC = MAX(SLoWC_i) \forall i, \tag{4}$$

where

$$SLoWC_i = (1 - RangePen_i \oplus HMDPen_i \oplus VertPen_i) \times 100\% \tag{5}$$

A conservative approach is used to map the SC-228 definition of Severity of Loss of Well Clear (SLoWC) to the Safety Management System (SMS) severity. The conservative approach is to use the higher severity of the SMS manual when a percentage of SLoWC could map to more than one severity. Table 5 shows the mapping.

TABLE 5. SEVERITY MAPPING FROM SC-228 TO SMS

SC-228 Severity Levels	SMS Severity Classification
0%-17%	5
17%-33%	4
33%-47%	3
47%-94%	2
94%-100%	1

IV. SIMULATION RESULTS

Simulations were run for the eight scenarios shown in Section IV. Scenario 8 was run interchanging the ownship and traffic aircraft as scenarios 8a and 8b. For each scenario, 10,000 simulations runs were performed for each of the following conditions:

- No resolution
- Horizontal resolution (smallest direction change)
- Vertical resolution (smallest absolute)
- Five second average virtual pilot's delay
- Fifteen seconds average virtual pilot's delay

This resulted in a total of 430,000 simulation runs. Table 6 shows the severity of the encounter for the horizontal resolution. The severity is shown when there is no implementation of the resolution guidance (No res), 5 second average implementation delay, and 15 seconds average implementation delay. The severity ranges from No Loss of Well Clear (No LoWC) to catastrophic (1), representing a mid-air collision.

TABLE 6. SEVERITY OF ENCOUNTER, HORIZONTAL RESOLUTION

Scenario		Severity, SMS					
	Delay mean	No LoWC	5	4	3	2	1
1	No res	0.04%	0.31%	2.26%	8.16%	86.4%	2.79%
	15 sec.	21.5%	62.2%	14.0%	2.01%	0.28%	0
	5 sec.	54.0%	46.0%	0	0	0	0
2	No res	0.01%	0.35%	2.17%	7.15%	87.2%	3.09%
	15 sec.	41.3%	54.7%	3.49%	0.48%	0.09%	0
	5 sec.	76.4%	23.6%	0	0	0	0
3	No res	0	0.03%	0.78%	3.68%	91.8%	3.74%
	15 sec.	37.1%	58.3%	4.00%	0.46%	0.10%	0
	5 sec.	83.2%	16.8%	0	0	0	0
4	No res	0	0	0.37%	2.88%	92.7%	4.05%
	15 sec.	23.6%	58.7%	14.7%	2.64%	0.29%	0
	5 sec.	83.6%	16.4%	0	0	0	0
5	No res	0	1.72%	44.6%	49.2%	4.48%	0
	15 sec.	4.13%	32.1%	55.3%	4.86%	3.53%	0
	5 sec.	9.47%	31.8%	56.8%	0.99%	0.92%	0
6	No res	0.08%	1.08%	4.54%	11.7%	80.2%	2.37%
	15 sec.	15.4%	82.8%	1.67%	0.07%	0.01%	0
	5 sec.	43.9%	56.1%	0	0	0	0
7	No res	9.73%	36.9%	17.8%	12.6%	22.6%	0.31%
	15 sec.	41.9%	57.3%	0.72%	0.04%	0	0
	5 sec.	92.3%	7.7%	0	0	0	0
8a	No res	0	0	0	0.11%	87.1%	12.8%
	15 sec.	0	0.01%	0.44%	4.12%	93.7%	1.72%

	5 sec.	0	0.01%	0.98%	8.39%	90.6%	0
8b	No res	0	0	0	0.11%	87.1%	12.8%
	15 sec.	0	18.7%	14.9%	11.9%	52.9%	1.62%
	5 sec.	0	79.9%	16.6%	2.72%	0.79%	0

Table 7 shows the severity of the encounter for the vertical resolution.

TABLE 7. SEVERITY OF ENCOUNTER, VERTICAL RESOLUTION

Scenario		Severity, SMS					
	Delay mean	No LoWC	5	4	3	2	1
1	No res	0.04%	0.31%	2.26%	8.16%	86.4%	2.79%
	15 sec.	0.04%	70.0%	26.5%	3.18%	0.28%	0
	5 sec.	0.04%	99.95	0.01%	0	0	0
2	No res	0.01%	0.35%	2.17%	7.15%	87.2%	3.09%
	15 sec.	48.4%	47.9%	3.08%	0.49%	0.08%	0
	5 sec.	83.5%	16.5%	0	0	0	0
3	No res	0	0.03%	0.78%	3.68%	91.8%	3.74%
	15 sec.	42.8%	52.7%	3.77%	0.51%	0.14%	0
	5 sec.	78.6%	21.4%	0	0	0	0
4	No res	0	0	0.37%	2.88%	92.7%	4.05%
	15 sec.	0	66.0%	29.3%	4.22%	0.41%	0
	5 sec.	0	99.97%	0.03%	0	0	0
5	No res	0	1.72%	44.6%	49.2%	4.48%	0
	15 sec.	0	58.2%	34.1%	6.97%	0.70%	0
	5 sec.	0	98.5%	0.50%	0.76%	0.21%	0
6	No res	0.08%	1.08%	4.54%	11.7%	80.2%	2.37%
	15 sec.	94.8%	4.96%	0.22%	0.01%	0	0
	5 sec.	99.4%	0.58%	0	0	0	0
7	No res	9.73%	36.9%	17.8%	12.6%	22.6%	0.31%
	15 sec.	96.0%	3.89%	0.13%	0	0	0
	5 sec.	100%	0	0	0	0	0
8a	No res	0	0	0	0.11%	87.1%	12.8%
	15 sec.	0.54%	5.24%	12.2%	16.8%	63.0%	2.23%
	5 sec.	2.44%	23.1%	33.9%	24.6%	15.9%	0
8b	No res	0	0	0	0.11%	87.1%	12.8%
	15 sec.	2.66%	17.7%	17.6%	14.4%	44.0%	3.59%
	5 sec.	13.2%	66.5%	16.6%	2.73%	0.97%	0

When the virtual pilot's delay in implementing the resolution guidance averages 5 seconds, the resolution avoids collisions (severity 1) for all scenarios. Implementing the guidance with 5 seconds average delay also eliminates all encounters of severity 2, Hazardous and severity 3, Major for scenarios 1 through 4 and scenarios 6 and 7.

When the virtual pilot's delay averages 15 seconds, the resolution avoids collisions for scenarios 1 through 7. Note that when the average delay is 15 seconds, there are 429 encounter runs where the delay is larger than 30 seconds (fig. 6). Because the time from initial conditions to CPA for scenario 8 is 30 seconds, any delay larger than 30 seconds is equivalent to not maneuvering and hence not being able to avoid the potential collision.

Scenarios where the traffic aircraft is turning, scenarios 5 and 8, represent the more challenging situation for the Detect and Avoid algorithm. In those turning scenarios, the vertical guidance does better than the horizontal guidance when the average delay is 5 second, and slightly worse when the average delay is 15 seconds.

V. SUMMARY AND CONCLUSION

A concept for the use of DAA technology to support pilots in the cockpit during visual operations has been developed and a prototype implemented. Flight tests were performed and a simulation program and virtual pilot were developed to evaluate the DANTi concept and DAIDALUS conflict detection, alerting, and resolution algorithms. Eight scenarios were defined and 10,000 simulation runs were performed for each scenario.

The simulation runs were randomized by adding a random variable to the initial location of the aircraft, the initial horizontal direction, horizontal speed, vertical speed, altitude, and using a random distribution for the delay with which the virtual pilot implements the resolution.

The implementation of the guidance significantly reduces the probability of a collision and the severity of the encounters, even when the virtual pilot delays the implementation of the resolution by an average of 15 seconds. For example, for scenario 1, there are 86.44% encounters of severity 2 (hazardous, near mid-air collision) when no resolution is implemented and this is reduced to 0.28% encounters of severity 2 with a 15 seconds average pilot delay, or a reduction of a factor of more than 300.

More simulations and analysis are being performed to evaluate the DANTi concept and DAIDALUS DAA algorithm under different conditions and additional scenarios. The system configuration parameters and user interface are also being tested and analyzed. However, results so far seem to indicate that the DANTi technology may increase safety and pilots traffic awareness during operations in which "see and avoid" regulations apply.

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