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Investigation of DAA System Effectiveness with a Pilot Decision Model and Realistic Sensor Performance Limits

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***Abstract*—Detect and Avoid (DAA) system is an essential part of Remotely Piloted Aircraft System (RPAS) for the safe operations within civil airspace. This paper investigates the performances of a DAA system in a fast-time simulation environment. A pilot decision model was developed to enable fast-time simulation using the Detect and AvoID Alerting Logic for Unmanned Systems that computes the range of maneuvers that are free of conflicts. In addition, realistic constraints about the DAA sensors are applied. Sensor's limits are set with azimuth angle, vertical angle, and distance as well as update rates. A realistic encounter scenario was generated based on the recorded traffic in a congested terminal area. DAA Sensor performances and update rates as well as alerting criteria were varied to have the total of 24 different configurations. The results revealed that the developed model reasonably resolves conflicts in arrival procedure junctions, but it struggles when the conflict geometry is complicated near a holding pattern. In addition, increasing the update rate was not effective in preventing Loss of Well Clear in these situations.**

***Index Terms*—Detect and Avoid (DAA), Fast-Time Simulation, Pilot Decision Model, Sensor Performance, DAA Well Clear (DWC)**

I. Introduction

Detect and Avoid (DAA) system is an essential component of RPAS to ensure safe operations within civil airspace. The publication of the DO-365, Minimum Operational Performance Standards (MOPS) for Unmanned Aerial Systems [1], enabled various research related to DAA such as generic sensor performance requirements and avoidance algorithms. [2], [3] investigated the requirements for DAA system sensor performances by detecting the alert levels using recorded ADS-B data. Detect and AvoID Alerting Logic for Unmanned Systems (DAIDALUS) [4] developed at NASA Langley Research Center is being widely used as the DAA guidance provided to remote pilots. It is possible to perform Human-in-The-Loop (HiTL) simulations [5].

However, to perform fast-time simulations to process the large number of conflicts to gather statistical insights and to improve the algorithms, an automated model that interprets the DAIDALUS output and maneuvers the aircraft to avoid Loss of Well Clear (LoWC) is required. This model also needs to maneuver the aircraft to the original flight plan paths once all the alerts are cleared. A simple pilot decision model was developed in [6] and verified with a selected set of standard encounter geometries from DO-365.

This study incorporates the pilot decision model of [6] to perform fast time simulations in a congest terminal area near Incheon International Airport (ICN) and Gimpo International Airport (GMP) using a scenario based on [5] that includes 160 aircraft. Three different sets of sensor azimuth, elevation, and range limits, Two different DAA alerting criteria (Phase I or Phase II), two different update rates (1 Hz and 10 Hz), and two different modes of DAA execution (RPA only or all aircraft) resulted in a total of 24 configurations. Fast-time simulation revealed that the proposed system reasonably resolved the conflicts at busy junctions in the terminal area, but not in a complicated holding pattern. In addition, there was no noticeable difference between the update rate of 1 Hz and 10 Hz, which needs further investigation.

Section II describes the pilot decision model that enables the fast-time simulation. The simulation setup and the scenarios are presented in Section III. Section IV shows the results of the fast time simulation for many different configuration. Finally, Section V concludes the paper.

II. Pilot Decision Model

To conduct fast-time simulations, it is necessary to develop a model that takes the DAIDALUS guidance directives as an input and generates actual maneuver commands. For the current study, an updated version of the model developed in [6] is used. This model demonstrated reasonable avoidance behavior when tested against selected encounter geometries specified in DAA MOPS [1]. Fig. 1 shows and example test case from [6]. Two aircraft are on a converging path at around 60 degrees. The ownship that was originally flying at a heading of 360 degrees changes its heading to the left when the Corrective Alert is raised and then returns to its original route.

DAIDALUS computes directive guidance, which is range of the maneuvers that are free of conflicts for the given look-

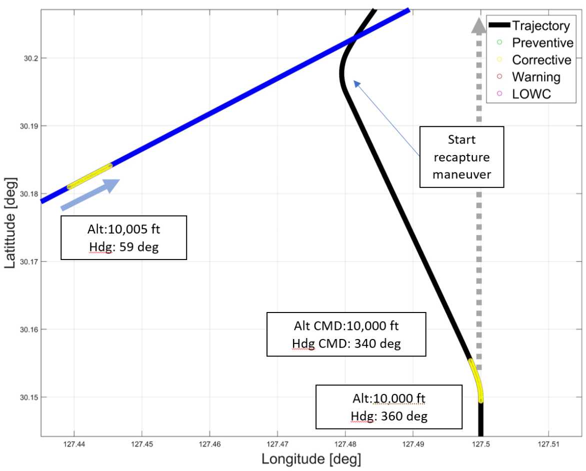

Fig. 1. Avoidance and return maneuver for converging case [6]

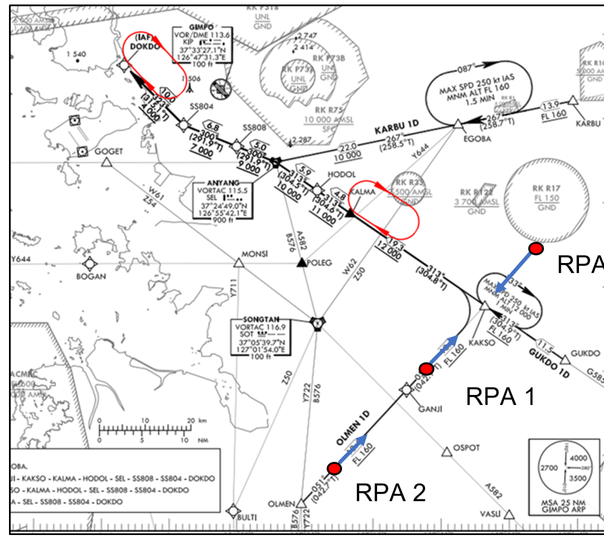

Fig. 2. OLMEN 1D arrival procedure for RPAs [5].

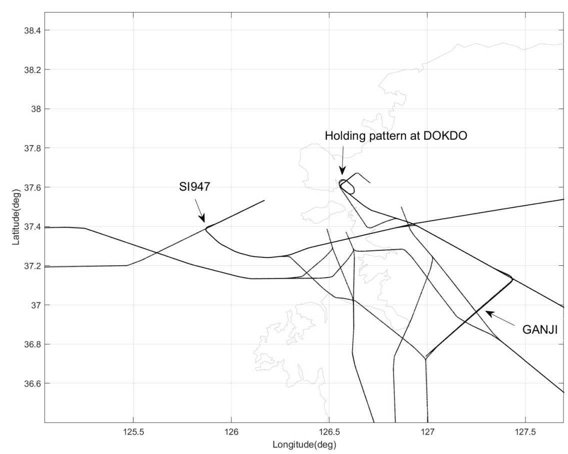

Fig. 3. Flight plan routes for the simulation scenario.

ahead time. The guidance consists of the horizontal direction, horizontal speed, vertical speed, altitude resolutions. When there is an alert above Corrective Alert, the pilot model uses the horizontal direction resolution as a default, and the altitude resolution is used with certain conditions. If the heading difference between the ownship and intruder is larger than 30 degrees, or if no altitude resolution is provided, the ownship follows horizontal direction resolution. In [6], the smallest heading change outside the blocked boundary was selected. For the current study, the preferred turn direction provided the version 2 of the DAIDALUS is used, and the minimum turn angle within the conflict free maneuver range is selected.

Altitude resolution command is given if the heading difference between two aircraft is less than 30 degrees or when no horizontal resolution is available. The pilot model uses the preferred direction, whether to climb or descend, given by DAIDALUS and selects the target altitude rounded to 500 ft step that is within the conflict free maneuver range.

If both the horizontal direction resolution and altitude resolution are not available, the aircraft is set to continue with the current speed, heading, and altitude for five seconds and then return to the original flight plan.

The pilot model for returning to the original flight plan is based on [7]. Maneuvering aircraft maintains the command for a time, t_{CPA}, which is the time to Closest Point of Approach (CPA) provided by DAIDALUS while checking the alert level at the given update rate. If a new higher level alert is raised, the maneuver command and t_{CPA} are updated for the new alert. If no threat is detected after t_{CPA}, the aircraft executes its control logic to return to the original flight plan, which is returning to the route segment that the aircraft was originally flying at the beginning of the DAA maneuver.

III. Scenario

The arrival scenario from the HiTL simulations of [5] is used. This scenario is based on the actual recorded traffic around the GMP. Two RPAs are added to the scenario of [5] to increase the number of conflict cases that triggers DAA maneuvers. The scenario includes 157 manned aircraft and three RPAs as shown in Fig. 2. RPA 1 and RPA 2 are on the OLMEN 1D Standard Arrival Route (STAR) of GMP. RPA 3 is flying towards the KAKSO fix so that it will cause head on conflicts with the aircraft on the OLMEN 1D procedure. Fig. 3 shows the planned routes for all 160 aircraft in the scenario. As the original scenario was created for Lost C2 Link situation, the two RPAs that are on the OLMEN 1D procedure are pre-programmed to be on the holding pattern at the DOKDO located at the top left corner of the figure. All 160 aircraft are assumed to have flight performances similar to those of Boeing 737 class aircraft.

Three different sensor limits are tested for this study, which are summarized in Table I. In Table I, 'All' refers to an ideal sensor that has 360 degree field of view with a very long detection range. 'MOPS' denotes the recommended sensor performance given by the DAA MOPS [1]. 'Inha' represents one of the recommended sensor performances given by a previous study that analyzed detection rate assuming all aircraft are equipped with identical DAA sensors [3].

Two different update rates of 1 Hz and 10 Hz are applied for the DAA system to investigate the impact of the update rate. Both the en-route criteria [1] and terminal area criteria [8] are tested to examine the validity of the criteria. Finally, two different DAA implementations are compared. In the first case, only RPAs perform DAA maneuvers while manned aircraft fly according to their flight plans. Possible conflicts between manned aircraft are ignored. In the other case, every aircraft including manned aircraft performs DAA maneuver. A total of 24 configurations is simulated and analyzed in the next section.

IV. Fast-Time Simulation Results

Fast-time simulations were performed for the 24 configurations using the pilot decision model described in the previous sections. In Fig. 3, conflicts between manned aircraft occurred near SI947 and GANJI fixes. Conflicts involving RPAs are near the DOKDO fix. Due to the holding pattern, conflict geometries were generally complicated, and in some cases, multiple conflicts occurred between a single conflict pair.

A. Conflicts between Manned Aircraft

Two major conflict area was discovered. One is near the SI947 fix of one of the STARs of ICN as marked in Fig. 3. The other is at the junction of OLMEN 1D arrival procedure of GMP and A582 route near GANJI fix in Fig. 3.

Fig. 4 shows the avoidance trajectories near SI947 fix. The DAA behavior is based on the Phase I criteria, sensor performance 'all', and 1 Hz update rate. All aircraft are assumed to have the same DAA system and execute maneuvers based on the pilot decision model.

Fig. 5 shows the avoidance trajectories near GANJI fix. All the conditions are the same as in Fig. 4. Table II summarizes the number of conflict pairs for all twelve configurations. LoWC occurred only when Phase I criteria is used with 1 Hz update rate. The number of conflicts is not enough to be conclusive, but the results suggest that the ideal sensor will detect and resolve more conflicts. Sensor limits of 'MOPS' or 'Inha' both detected fewer conflicts and resolved all of them without LoWC at 10 Hz update rate, which may be more beneficial for applications for actual operations.

TABLE I
SENSOR LIMITS.

	Azimuth	Elevation	Range
All	±180°	±90°	20 nmi
MOPS	±110°	±15°	6.7 nmi
Inha	±90°	±26.2°	3.6 nmi

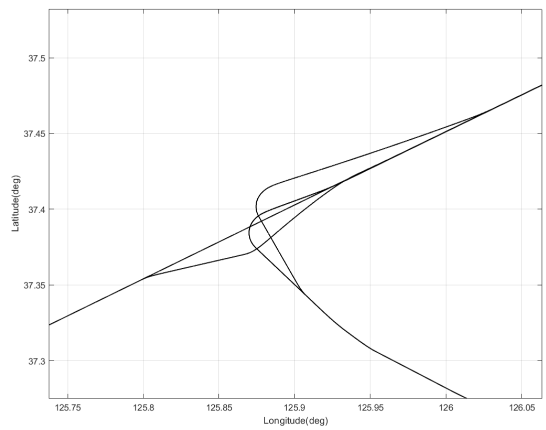

Fig. 4. Conflict area near SI947 fix.

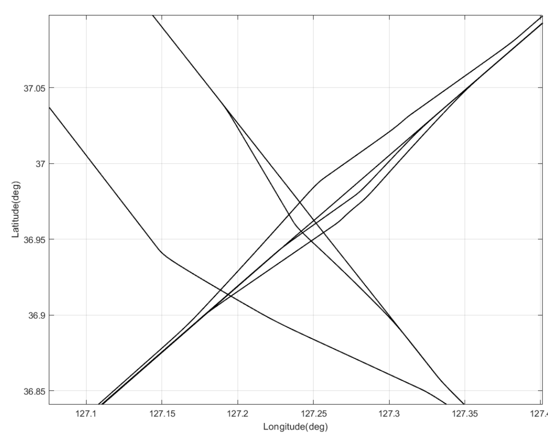

Fig. 5. Conflict area near GANJI fix.

B. Conflicts Involving RPAs

All conflicts involving RPAs occurred near the holding pattern shown in Fig. 3. Fig. 6 shows all the trajectories in this area for one of the configurations. As the RPAs are forced to make two rounds around the holding pattern, maneuvers become very complicated. This is not likely to happen in the real-world scenario but can be a good test case for the algorithm.

Fig. 7 shows one of the simple cases that a manned aircraft is approaching an RPA from behind. In this particular case, both aircraft are supposed to perform DAA maneuvers. As the sensor limits are 'Inha', the RPA that is in front cannot detect the COY2010 from behind. COY2010 executes a horizontal

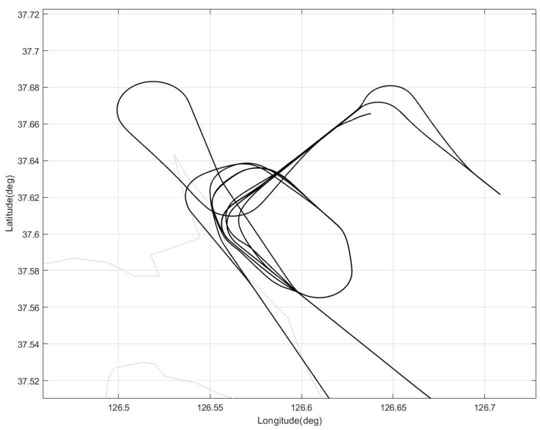

Fig. 6. Major conflict area near DOKDO fix (sensor limits 'All', update rate 1 Hz, alerting criteria Phase I, DAA for all aircraft).

maneuver to the right until the warning alert is cleared. As soon as COY2010 starts the return to flight plan maneuver, a warning alert is raised again, which causes the second horizontal maneuver.

In Fig. 8 (a), only RPA 1 performs DAA maneuvers. Due to the sensor limits, RPA 1 cannot detect the KAL1200 from behind and results in LoWC. In Fig. 8 (b) both the aircraft perform DAA maneuver, which shows a complicated interaction between the two aircraft. However, even though Phase I criteria are used, the two aircraft were able to avoid LoWC.

Table III summarizes the number of conflict pairs that triggered DAA maneuvers, the number of LoWCs, and the percentage of conflict pairs that reached LoWC for twelve configurations when only the RPAs performs DAA.

Table IV summarizes the number of conflict pairs that triggered DAA maneuvers, the number of LoWCs, and the percentage of conflict pairs that reached LoWC for twelve configurations when all aircraft performs DAA.

TABLE II
NUMBER OF CONFLICT PAIRS.

DAA Update Rate			1 Hz		10 Hz	
DWC Alerting Criteria			Phase I	Phase II	Phase I	Phase II
Total Number of Conflict Pairs	Sensor Limits	All	2	1	4	1
		MOPS	2	1	2	1
		Inha	1	1	1	1
Total Number of Pairs with LoWC	Sensor Limits	All	1	0	0	0
		MOPS	1	0	0	0
		Inha	1	0	0	0
% of LoWC	Sensor Limits	All	50.0	0.0	0.0	0.0
		MOPS	50.0	0.0	0.0	0.0
		Inha	100.0	0.0	0.0	0.0

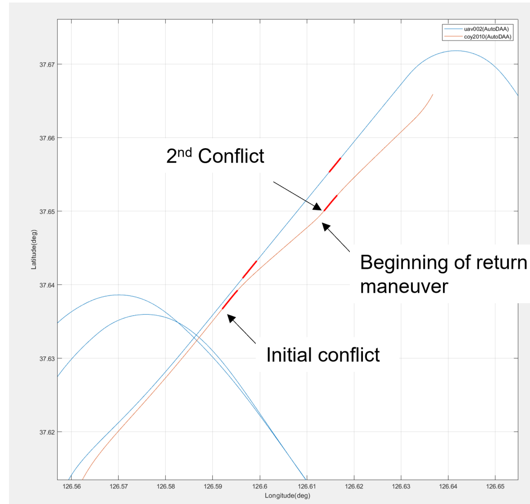

Fig. 7. DAA example (sensor limits 'Inha', update rate 10 Hz, alerting criteria Phase II, DAA for all aircraft).

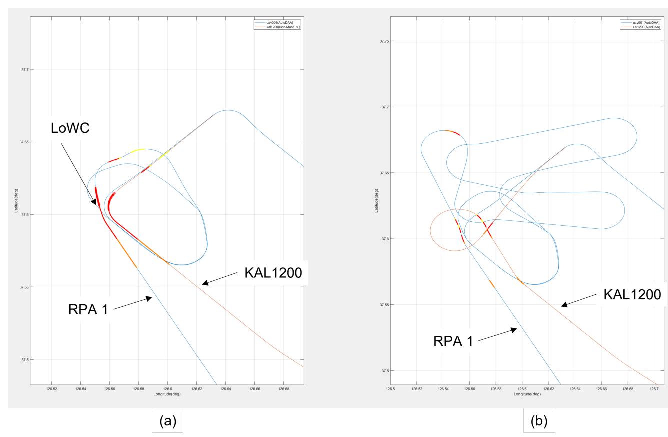

Fig. 8. DAA example (sensor limits 'Inha', update rate 10 Hz, alerting criteria Phase I).

As can be expected, Phase II criteria resulted in a smaller number of conflict pairs with a smaller percentage of LoWC for all configurations. Unlike the conflict between manned aircraft, better sensor performance showed a smaller LoWC percentage, which suggests that sensor performance is important when the encounter geometry becomes complicated. Table IV shows generally smaller percentage of LoWC because unless the sensor limits are 'All', the RPAs cannot detect an intruder from behind to execute avoidance maneuvers. One unexpected result is that the LoWC percentage is not smaller, in some cases, rather larger for the higher update rate of 10 Hz. Further investigation is necessary to find the impact of the update rate.

V. Conclusions

A fully automated DAA capability in fast-time simulation environment incorporating DAIDALUS was developed and tested with realistic traffic scenarios in a congested terminal area. The results revealed that the current system reasonably resolves the conflicts in busy junctions. However, when the

TABLE III

NUMBER OF CONFLICT PAIRS WHEN ONLY RPAS PERFORM DAA.

DAA Update Rate			1 Hz		10 Hz	
DWC Alerting Criteria			Phase I	Phase II	Phase I	Phase II
Total Number of Conflict Pairs	Sensor Limits	All	7	4	8	4
		MOPS	7	4	6	3
		Inha	6	4	6	3
Total Number of Pairs with LoWC	Sensor Limits	All	1	0	1	1
		MOPS	2	1	2	1
		Inha	4	1	4	1
% of LoWC	Sensor Limits	All	14.3	0.0	12.5	25.0
		MOPS	28.6	25.0	33.3	33.3
		Inha	66.7	25.0	66.7	33.3

TABLE IV

NUMBER OF CONFLICT PAIRS WHEN ALL AIRCRAFT PERFORMS DAA.

DAA Update Rate			1 Hz		10 Hz	
DWC Alerting Criteria			Phase I	Phase II	Phase I	Phase II
Total Number of Conflict Pairs	Sensor Limits	All	7	4	8	3
		MOPS	5	4	8	3
		Inha	9	4	9	3
Total Number of Pairs with LoWC	Sensor Limits	All	1	0	1	0
		MOPS	0	0	2	1
		Inha	5	0	5	1
% of LoWC	Sensor Limits	All	14.3	0.0	12.5	0.0
		MOPS	0.0	0.0	25.0	33.3
		Inha	55.6	0.0	55.6	33.3

encounter geometry is complicated due to a forced holding pattern for RPAs, the system resulted in an unacceptable LoWC occurrence rate. Other than the variation due to alerting criteria or sensor performances that resulted in the expected trend, the two different update rates did not display the noticeable difference in terms of LoWC occurrence rate.

A followup study is required to refine the pilot decision model with increased traffic volume to investigate significantly more conflict cases. Finally, a more thorough investigation of the impact of the update rate is necessary.

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