Study on Conflict Detection Method with Downlink Aircraft Parameters

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***Abstract*—In order to keep safety of air traffic, ENRI (Electronic Navigation Research Institute) tries to improve CA (Conflict Alert) function by using airborne information via Mode S data-link. CA supports air traffic controller to keep safe separations between aircraft by predicting aircraft positions and detecting potential conflicts. Our purpose of this study is to develop the new DAPs-CDM (Conflict Detection Method using Downlink Aircraft Parameters) and evaluate the impacts of its introduction by computer simulation.**

Firstly, in order to understand the characteristics of the conventional CDM, we calculated horizontal and vertical prediction errors of aircraft position. The conventional CDM uses linear prediction with only radar information on the ground. We also analyzed CA occurrences by the conventional CDM. We found that both horizontal and vertical prediction errors were reduced by using airborne information in addition to radar information. We also found that it was better to smooth vertical speed for prediction and to utilize selected altitude in DAPs-CDM.

Finally, the characteristics of DAPs-CDM were studied and the advantages were demonstrated. The new function of DAPs-CDM is to predict aircraft positions by using aircraft velocity on the airborne side and to determine aircraft flight phases by using roll angle and selected altitude. For the purpose of comparing DAPs-CDM with the conventional CDM, ENRI developed CDES (Conflict Detection Evaluation System). It can simulate both DAPs-CDM and the conventional CDM under air traffic situations and system parameters as almost same as operational ones. As a result of computer simulation with CDES, the determination of vertical flight phases by selected altitude was most effective to reduce the number of unnecessary CA.

Keywords-component; Conflict Alert; Conflict Detection Method; Downlink Aircraft Parameters

I. INTRODUCTION

From the perspective of safety, it is necessary to ensure spacing between aircraft. In Japan, the horizontal separation minimum is 5 NM (1 NM = 1,852 m) under radar control. The vertical separation minimum is 1,000 ft (1 ft = 0.3048 m) where altitude is below 41,000 ft under IFR (Instrument Flight Rules) and RVSM (Reduced Vertical Separation minimum), or 2,000 ft where altitude is above 41,000 ft. [1]

The situation that a proximity distance between aircraft and another cannot be satisfied with both the horizontal and vertical minima is called as a conflict. In order to ensure proper spacing between aircraft, air traffic controller issues some instructions to aircraft as needed, based on the situations of air traffic.

RDP (Radar Data Processing System), which air traffic controller uses for en-route airspace in Japan, has the function of predicting aircraft positions and detecting potential conflicts; called CA (Conflict Alert). This function predicts aircraft positions in 3 minutes future, using current aircraft positions and estimated aircraft velocities by tracking process. When a potential conflict is detected, a warning message for air traffic controller will be displayed on RDP screen. [2]

In the function, aircraft is assumed to fly with constant speed. Therefore, when predicting aircraft positions, prediction error is occurred by estimation differences and fluctuations of aircraft velocity. It is also difficult to predict the changes of aircraft flight phases such as from straight to turn and from climb to cruise due to linear prediction.

Currently, SSR (Secondary Surveillance Radar) Mode S, which is a new radar system for air traffic control, is being introduced. Mode S is able not only to get aircraft positions more accurately, but also to have the function of digital communication to downlink some aircraft parameters such as ground speed, vertical speed, magnetic heading and selected altitude. These airborne parameters available on the ground side are expected to contribute the improvements of air traffic management. In terms of conflict detection, the usage of DAPs (Downlink Aircraft Parameters) will reduce the number of unnecessary CA and workload of air traffic controller. [3]

The purpose of this study is to develop the new DAPs-CDM (Conflict Detection Method using Downlink Aircraft Parameters) and evaluate the effectiveness of its introduction by computer simulation. [4]

First, overviews on CA and CDM (Conflict Detection Method) are introduced in Section 2 and 3 to reinforce research background. Then, in order to understand CDM well, the results of analyzing prediction error on DAPs-CDM are explained in Section 4. More over, for the same purpose, the analyses on the situation that CA occurred are explained in Section 5. Finally, in Section 6, the characteristics of DAPs-

CDM are studied and the results of simulation which verify the effectiveness of its introduction are demonstrated.

II. International Trend of CA and Mode S

International trends about STCA (Short Term Conflict Alert) are introduced. The trend of SSR Mode S in the Europe is also introduced.

A. International Trend of STCA

Reference [5], published by ICAO (International Civil Aviation Organization) in 2001, describes the procedures of STCA; e.g., "*A statistical analysis should be made of justified alerts in order to identify possible shortcomings in airspace design and ATC procedures as well as to monitor overall safety levels*".

EUROCONTROL developed the operational requirements of STCA in 1998. [6] For the purpose of improving safety of air traffic, SSAP (The European Strategic Safety Action Plan) was conducted in 2003. After SSAP, ESP (European Safety Programme for ATM) also was conducted in 2006. ESP made the improvement plans of safety in 5 main fields and one of them was to consolidate system safety nets. STCA was considered as a function for safety on the ground systems.

Because the functions and procedures of STCA were not standardized in European countries, the specification and guidance of STCA were made. [7][8] Policy, training, regulation and requirement are described in the specification from the viewpoint of management. The guidance refers to STCA more technically.

Now, the efforts of safety improvement by STCA using enriched surveillance information are being conducted in SESAR Master Plan. [9]

B. Mode S Trend

The international standard of BDS (Comm-B Data Selector) code about SSR Mode S was implemented in [10], published by ICAO in 2002.

In Europe, SSR Mode S ELS (Elementary Surveillance) was implemented. Also, Mode S EHS (Enhanced Surveillance) was implemented in the France, Germany, and England. [11]

- Necessary Capability for ELS

  BDS 1,0; Data Link Capability

  BDS 1,7; Common Usage GICB Capability

  BDS 2,0; Aircraft Identification

- Necessary Capability for EHS

  BDS 4,0; Selected Vertical Intention

  BDS 5,0; Track and Turn

  BDS 6,0; Heading and Speed

In Japan, aircraft which equips the transponder applied to Mode S data-link capability are increasing. [12]

III. Conflict Alert in Japan

This section explains a function overview of CA and CDM in Japan. In 1979, CA was implemented as one of RDP functions. In 2002, CDM with flight plan information was added to CA function. [13][14]

Fig. 1 shows an example of CA display. Triangle symbols stand for aircraft positions and each symbol has one information tag. Information tag displays call sign at the first row, altitude information at the second row and ground speed at the third row. If CA function detects some potential conflicts up to 3 minutes, it displays 'CNF' blinks into information tags of related aircraft and, at the same time, renews a CA status list. In Fig. 1, it list is shown at the upper left corner.

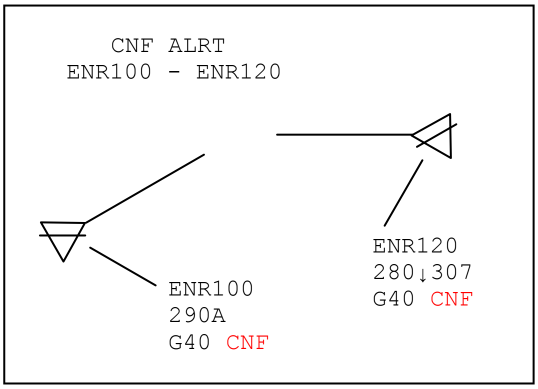

Figure 1. Example of CA Display

This section also describes how CA function detects potential conflicts. The conventional CDM is divided into 2 types; one is LP-CDM (Linear Prediction - Conflict Detection Method) and the other is FP-CDM (Flight Plan - Conflict Detection Method).

A. LP-CDM

Fig. 2 shows a concept of LP-CDM. As LP-CDM assumes that aircraft continue to fly with constant speed, predicted position $\mathbf{p}_i(t)$ is given by

$$\mathbf{p}_i(t) = \mathbf{x}_i(t) + \tau \cdot \mathbf{v}_i(t). \tag{1}$$

$\mathbf{x}_i(t)$ and $\mathbf{v}_i(t)$; Position and velocity of aircraft i

LP-CDM executes the checks of (2) and (3) for all the aircraft combinations (i, j) in time t, where time τ changes in $0 \le \tau \le T_p$. If both (2) and (3) are satisfied, LP-CDM regards the situation as a conflict.

$$\sqrt{(p_{xi}(t) - p_{xj}(t))^2 + (p_{yi}(t) - p_{yj}(t))^2} \le R_h \tag{2}$$

$$|p_{zi}(t) - p_{zj}(t)| \le R_v \tag{3}$$

$$\mathbf{p}_i(t) = \left(p_{xi}(t), p_{yi}(t), p_{zi}(t)\right) \tag{4}$$

In terms of LP-CDM on RDP, observed position of aircraft is used as $\mathbf{x}_i(t)$ and estimated velocity of aircraft by tracking observed positions with alpha-beta filter is used as $\mathbf{v}_i(t)$. [15] Prediction time T_p is 3 minutes, horizontal detection threshold R_h is 5 NM, and vertical detection threshold R_v is 700 ft if altitude is below 41,000 ft and 1,600 ft if altitude is above 41,000 ft.

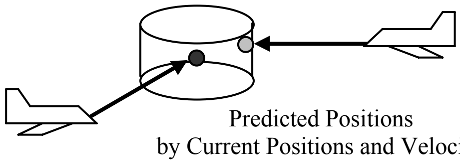

Figure 2. LP-CDM Concept

B. FP-CDM

Fig. 3 shows a concept of FP-CDM. In comparison with LP-CDM, FP-CDM uses flight plan information. Flight plan is submitted to ATS (Air Traffic Service) provider before departure. The route where aircraft is going to fly is included in flight plan information. FP-CDM checks whether or not aircraft are flying on the planned route. If aircraft is flying on the route, FP-CDM extends the prediction course along the route. When the route bends, the prediction course bends at waypoints. On the other hand, if the aircraft isn't flying on the route, FP-CDM is equal to LP-CDM.

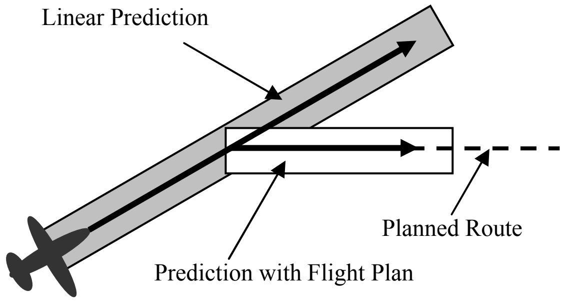

Figure 3. FP-CDM Concept

IV. Analysis on Prediction Error of Position

In order to understand CDM well, prediction error of aircraft position on (1) using flight recorded data were compared with that using radar data. In this section, we discussed horizontal and vertical prediction errors separately.

A. Horizontal Prediction Error

Observed positions of aircraft and estimated velocities of aircraft by tracking observed positions on the ground side are recorded in radar data. Update rate of them for en route surveillance in Japan is 10 seconds.

Aircraft positions and velocities (ground speed and true track angle) measured by airborne sensors are recorded in flight recorded data. Update rate of them is continuously 1 second in case of new aircraft types.

Fig. 4 shows the tracks of aircraft flying from Haneda airport to Fukuoka airport in Japan. The map is plane-projected centering Tokyo Area Control Center. In Fig. 4, aircraft fly to turn around airports. Far from airports, aircraft almost fly straightly. The horizontal aircraft profile was analyzed.

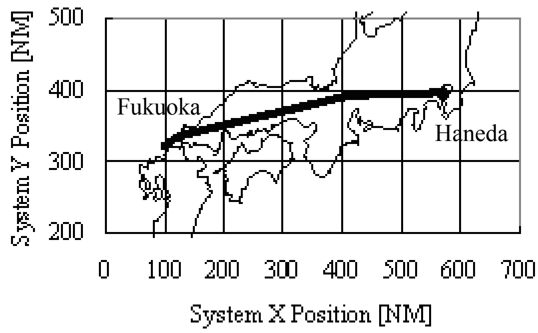

Figure 4. Aircraft Tracks

Horizontal prediction error of position is defined as

$$E_h = \sqrt{\left(X_{xi}(t+T_p) - p_{xi}(t)\right)^2 + \left(X_{yi}(t+T_p) - p_{yi}(t)\right)^2}\ . \tag{5}$$

$X_{xi}(t+T_p)$ and $X_{yi}(t+T_p)$ are horizontal components of aircraft position $\mathbf{X}_i(t+T_p)$ in flight recorded data. $p_{xi}(t)$ and $p_{yi}(t)$ are horizontal components of predicted position $\mathbf{p}_i(t)$ where $\tau = T_p = 3$ minutes.

Ground speed indicates the absolute value of horizontal aircraft velocity and its unit is knot (1 knot = 1,852/3,600 m/s). Aircraft flight phases based on ground speed are classified into acceleration, constant speed and deceleration phases. True track angle indicates the argument value of horizontal aircraft velocity and its unit is degree. True North is 0 degree and positive rotation is clockwise. Aircraft flight phases based on true track angle are classified into straight and turn phases. Horizontal components of velocity $\left(v_{xi}(t), v_{yi}(t)\right)$ are combined with ground speed $GS_i(t)$ and true track angle $TTA_i(t)$ by

$$\begin{pmatrix} v_{xi}(t) \\ v_{yi}(t) \end{pmatrix} = \begin{pmatrix} GS_i(t) \cdot Cos\left(\dfrac{\pi}{2} - \dfrac{\pi}{180} \cdot TTA_i(t)\right) \\ GS_i(t) \cdot Sin\left(\dfrac{\pi}{2} - \dfrac{\pi}{180} \cdot TTA_i(t)\right) \end{pmatrix}. \tag{6}$$

Fig. 5 shows horizontal prediction errors of position using radar data and flight recorded data. Calculation timing is 10 seconds according as update rate of radar data. Horizontal prediction error of position using flight recorded data is reduced in comparison with that using radar data. In straight phase, it is reduced by 37 % on average (from 1.43 NM to 0.92 NM). In turn phase, it is reduced by 28 % on average (from 6.51 NM to 4.67 NM).

When predicting horizontal aircraft positions, it is important to use airborne velocity (ground speed and true track angle) and to determine adequately whether aircraft flight phase is in straight or turn.

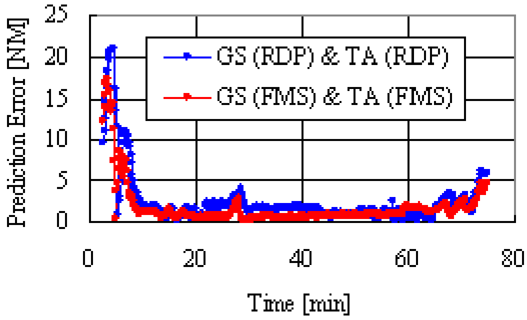

Figure 5. Horizontal Prediction Error

B. Vertical Prediction Error

Observed altitude of aircraft and estimated vertical rates of aircraft by tracking observed altitude on the ground side are recorded in radar data. Update rate of them for en route surveillance in Japan is 10 seconds.

Aircraft altitude and vertical rates measured by airborne sensors are recorded in flight recorded data. Update rate of them is continuously 1 second in case of new aircraft types.

Fig. 6 shows the altitude from climb through cruise to descend. The vertical aircraft profile was analyzed.

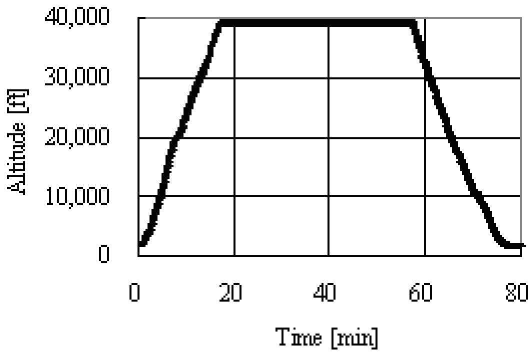

Figure 6. Aircraft Altitude

Fig. 7 shows the vertical rate of altitude. Vertical rate in cruise phase is constantly 0 ft/min, and vertical rate in climb and descend phases has some fluctuations. In Fig. 7, optimized vertical rate by alpha-beta filter in climb and descend phases are shown. Filter gain α is 0.05 (β = 0.001282), initial values are 3,000 ft/min in climb phase and -3,000 ft/min in descend phase. Optimized vertical rate in climb and descend phase is smoothed for prediction.

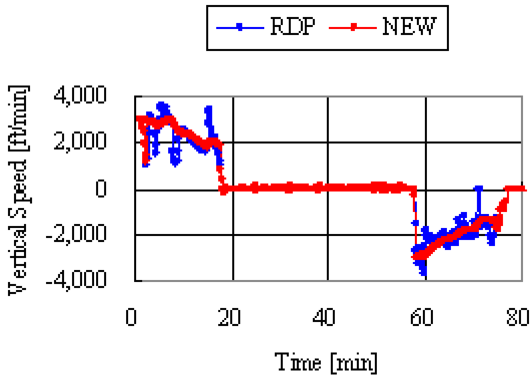

Figure 7. Altitude Vertical Rate

Vertical prediction error of position is defined as

$$E_v(t)=\left|X_{zi}(t+T_p)-p_{zi}(t)\right|. \quad (7)$$

$X_{zi}(t+T_p)$ is vertical component of aircraft position $\mathbf{X}_i(t+T_p)$ in flight recorded data. $p_{zi}(t)$ are vertical components of predicted position $\mathbf{p}_i(t)$ where $\tau = T_p = 3$ minutes.

Fig. 8 shows the vertical prediction errors of position using vertical rate of radar data and optimized vertical rate. Calculation timing is 10 seconds according as update rate of radar data. Vertical prediction errors of position using optimized vertical rate in climb and descend phases is reduced in comparison with that using raw vertical rate. Standard deviation of vertical prediction error is reduced by 23 % (from 1,500 ft to 1,150 ft).

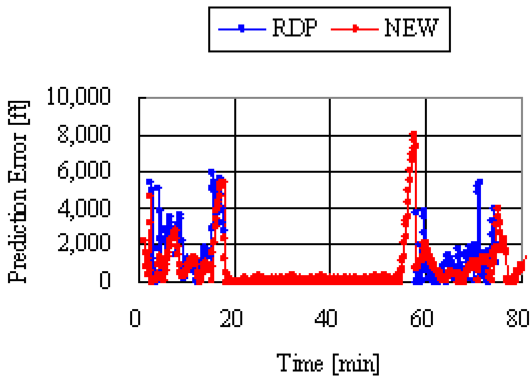

Figure 8. Vertical Prediction Error

In Fig. 8, there are large vertical prediction errors at the changes of aircraft flight phase such as from climb to cruise in case of both using raw and optimized vertical rate. This means that it is impossible to predict the change of aircraft flight phases by only LP-CDM. To reduce this vertical prediction error, it is necessary to use selected altitude built into LP-CDM.

V. Analysis on CA Occurrence

In this section, we mention how CA occurrences were analyzed to understand CDM well. [16]

A. *Simulation Conditions*

We simulated CA occurrences in the current operational environment. Air traffic scenario was made from radar data and flight plan data of Tokyo Area Control Center. Air traffic volume consisted of 1 hour on the peak of air traffic. The number of total aircraft was 409.

The conditions of conflict detection were also decided with reference to operational system parameters. Horizontal threshold R_h was set as 5 NM. Vertical threshold R_v was basically set as 700 ft and as 1,600 ft in case that altitude was over 41,000 ft.

B. *Results*

TABLE I shows the number of CA occurrence by simulation. The number of CA occurrence by LP-CDM and FP-CDM were 135 and 109 respectively. This number included the plural times caused by the same aircraft pair. 84 and 77 pairs of aircraft made all CA occurrences by LP-CDM and FP-CDM. 30 and 21 pairs of all made more than 2 times of CA occurrence.

TABLE I. Number of CA Occurrence

		All	Only 1 Time	More than 2 Times
LP-CDM	Occurrences	135	54	81 (60 %)
	Pairs	84	54	30 (36 %)
FP-CDM	Occurrences	109	56	53 (49 %)
	Pairs	77	56	21 (27 %)

Fig. 9 shows that the frequencies of CA durations by LP-CDM and FP-CDM are the same trends as both 75 % of CA occurrences by LP-CDM and FP-CDM persisted for 0-20 seconds. Fig. 10 shows that the frequencies of CA intervals by LP-CDM and FP-CDM also are the same trends as 71 % and 59 % of CA occurrences by LP-CDM and FP-CDM respectively repeated every 0-20 seconds, in terms of more than 2 times of CA occurrences. Considering the results of Fig. 9 and Fig. 10, intermittent CA might often occur in the conventional CDM.

Fig. 11 shows the classification of vertical situations at the time of CA occurrence. Vertical axis represents the number of aircraft pair. '0-' stands for altitude differences between 0 ft and 5,000 ft. '50-' stands for altitude differences between 5,000 ft and 10,000 ft. '100-' stands for altitude differences above 10,000 ft. 3 left-hand bars are made from LP-CDM and 3 right-hand others are made from FP-CDM. Depending on vertical flight phases of aircraft at the time of CA occurrence, vertical situations are classified into 6 patterns; the combinations of climb '↑', descend '↓' and cruise '→'.

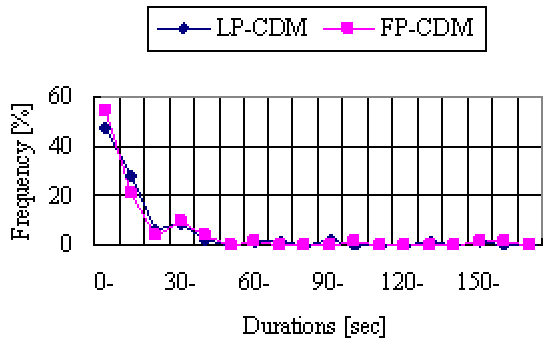

Figure 9. Frequency of CA Durations

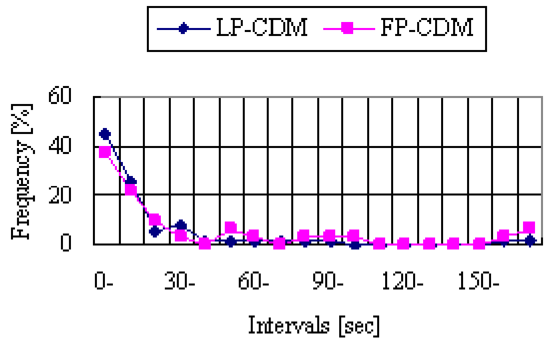

Figure 10. Frequency of CA Intervals

In Fig. 11, pattern '↑↓' is strongly dominant at altitude differences '100-'. Conversely, at altitude differences '0-', 3 patterns '↑↑', '↓↓' and '→→' are the majorities. In addition, pattern '→→' rarely occurs.

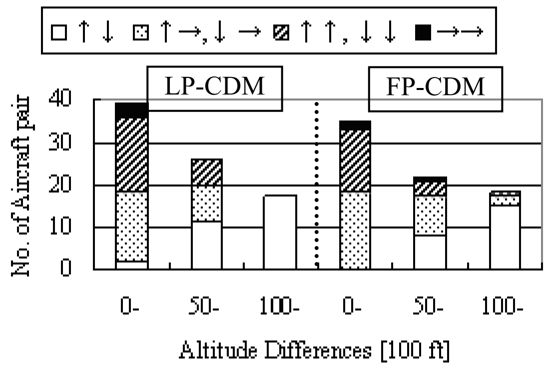

Figure 11. Classification of Vertical Situations

We counted the number of vertical maneuvers by checking the tracks of aircraft pairs at the time of CA occurrence. Vertical maneuver doesn't stand for that air traffic controller issued any instructions and vertical maneuver was planned in advance. The result is summarized in TABLE II. The numbers are categorized by altitude differences at the time of CA occurrence. Percentages stand for the numbers divided by the number of aircraft pair which is 84 by LP-CDM or 77 by FP-

CDM. TABLE II indicates that vertical maneuver rarely occurs at altitude differences '100-' in case of both LP-CDM and FP-CDM. The majorities of vertical maneuver are considerably connected with the 3 patterns including cruise phase '→'.

TABLE II. NUMBER OF VERTICAL MANEUVER

		0-	50-	100-
LP-CDM	Vertical Maneuvers	16 (19 %)	8 (10 %)	0 (0 %)
	↑→, ↓→, →→	10 (12 %)	5 (6 %)	0 (0 %)
FP-CDM	Vertical Maneuvers	15 (19 %)	9 (12 %)	1 (1 %)
	↑→, ↓→, →→	13 (17 %)	5 (6 %)	1 (1 %)

Considering the results of Fig. 11 and TABLE II, when there is such a large altitude difference as more than 10,000 ft, vertical maneuvers are rarely observed. Therefore, CA occurred in such situation are regarded as to be unnecessary and should be suppressed.

VI. EVALUATION OF DAPS-CDM

This section discusses the characteristics of the new DAPs-CDM and describe that the results of simulation verify the effectiveness of DAPs-CDM introduction.

A. *Characteristics of DAPs-CDM*

The characteristics of DAPs-CDM are explained below by comparing with the characteristics of the conventional CDM. They are to predict aircraft positions by using aircraft velocity of DAPs and to determine aircraft flight phases by using roll angle and selected altitude of DAPs. TABLE III summarizes the characteristics of DAPs-CDM.

TABLE III. THE CHARACTERISTICS OF DAPS-CDM

	LP-CDM	DAPs-CDM	Remarks
Position $\mathbf{x}_i(t)$	Observed Position by Radar		No Difference
Velocity $\mathbf{v}_i(t)$	Estimated Velocity	$GS_i(t)$, $TTA_i(t)$, Vertical Speed	Possible to be Optimized for Prediction
Horizontal Flight Phase Determination	Variation of Velocity	Roll Angle	Straight or Turn
Vertical Flight Phase Determination	Assigned Altitude	Selected Altitude	Climb/Descend or Cruise on Prediction Line

In DAPs-CDM, Predicted position is calculated by (1) as LP-CDM and prediction course of aircraft tracks is bended by depending on flight plan information as FP-CDM. The different point of DAPs-CDM from the conventional CDM is to use aircraft velocity (ground speed, true track angle, vertical rate) of DAPs instead of velocity of radar data. This aircraft velocity can be optimized for prediction by smoothing.

When determining aircraft flight phases, the absolute value of roll angle on the airborne side is newly used in the horizontal detection. Selected altitude on the airborne side instead of assigned altitude on the ground side is also used in the vertical detection. Roll angle is sometimes called as bank angle because of standing for the amount of aircraft bank. Selected altitude stands for the control target of altitude.

DAPs can reflect the latest and more accurate state and intent of aircraft. Therefore, DAPs-CDM could reduce prediction error of position caused by fluctuations of aircraft velocity. In addition, it could predict the change of aircraft flight phases earlier and aircraft positions more close to actual aircraft trajectories.

B. *Evaluation of DAPs-CDM Introduction*

For the purpose of comparing DAPs-CDM with the conventional CDM, ENRI developed CDES (Conflict Detection Evaluation System). It can simulate both DAPs-CDM and the conventional CDM under air traffic situations and system parameters as almost same as operational ones.

We evaluated the effectiveness of DAPs-CDM introduction by computer simulation. To simulate the environment where aircraft parameters can be downlinked, flight recorded data including all necessary DAPs were used. Air traffic volume consisted of 2 hours on the peak of air traffic. The number of total aircraft was 575 and 22 aircraft of them had DAPs capability. Calculation timing is 10 seconds according as update rate of radar data. Horizontal threshold R_h was set as 5 NM. Vertical threshold R_v was basically set as 700 ft and as 1,600 ft in case that altitude was over 41,000 ft.

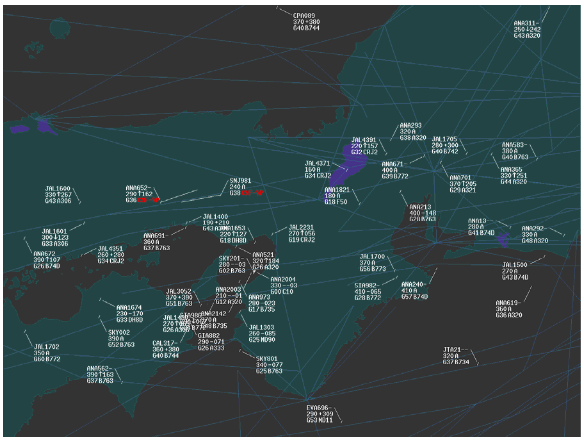

Figure 12. Snapshot Example when Simulation Executed

As a result, when comparing the number of CA occurrence using DAPs-CDM with that using the conventional CDM, there were the difference in 10 occurrences of CA. In all cases of them, the situation was that one aircraft had DAPs capability and another didn't. Additionally, the usage of selected altitude made large differences of CA occurrence.

Fig. 13 and Fig. 14 show the effectiveness of DAPs-CDM especially in using selected altitude to determine vertical flight phases. Fig. 13 shows the CA occurrence not using DAPs-CDM and Fig. 14 shows that using DAPs-CDM. Red and blue lines represent altitude. Only aircraft colored by red has DAPs capability and its selected altitude is represented by green line. The time when CA was detected was plotted by circle points on the lines.

In Fig. 14, CA occurrences around 01:45 and 01:50 are not detected by using DAPs-CDM. Maybe, safety separations had already been set before 01:45 and 01:50. Because selected altitude reflects the latest and more accurate aircraft intent, it is very effective to leverage it proactively; e.g. when checking the agreement with assigned altitude on the ground side.

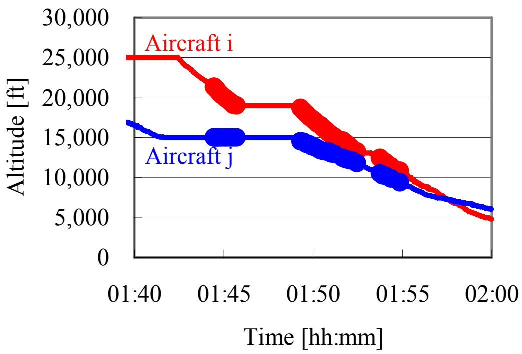

Figure 13. CA Occurrence not to Use Selected Altitude

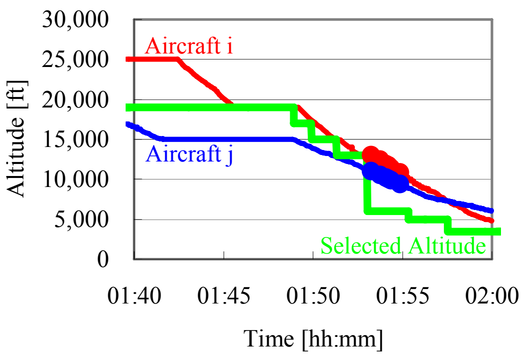

Figure 14. CA Occerrence to Use Selected Altitude

VII. CONCLUSION

The purpose of this study is to develop the new DAPs-CDM and evaluate the effectiveness of its introduction by computer simulation.

First, in order to understand the characteristics of the conventional CDM, we calculated horizontal and vertical prediction errors of aircraft position. Both horizontal and vertical prediction errors using flight recorded data were reduced in comparison with that using radar data. Horizontal prediction error was reduced by 37 % on average in straight phase and reduced by 28 % on average in turn phase. Standard deviation of vertical prediction error is reduced by 23 %. It was found better to smooth vertical speed for prediction and to utilize selected altitude in DAPs-CDM.

Then, we analyzed CA occurrences by the conventional CDM. Intermittent CA might often occur in the conventional CDM. When there was such a large altitude difference as more than 10,000 ft, vertical maneuvers were rarely observed. Therefore, CA occurred in such situation were regarded as to be unnecessary and should be suppressed.

Finally, the characteristics of DAPs-CDM were studied and the results of simulation which verify the effectiveness of its introduction were demonstrated. The characteristics of DAPs-CDM are to predict aircraft positions by using aircraft velocity of DAPs and to determine aircraft flight phases by using roll angle and selected altitude of DAPs. As a result, when comparing the number of CA occurrence using DAPs-CDM with that using the conventional CDM, there were the difference in 10 occurrences of CA. We found that the usage of selected altitude made large differences of CA occurrence.

ACKNOWLEDGMENT

We make an address of grateful thanks to all the concerned people with this study.

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