International Civil Aviation Organization

The Sixteenth Meeting of the Regional Airspace Safety Monitoring Advisory Group (RASMAG/16)

Bangkok, Thailand, 20 – 24 February 2012

Agenda Item 5: Airspace Safety Monitoring Activities/Requirements in the Asia/Pacific Region

Refined Calculation Method for Risk Analysis of Longitudinal Time Separation

(Presented by Japan)

SUMMARY

This paper presents a new calculation method to estimate the risk of collision for longitudinal time separation in order to reduce the overestimation of the uncertainty.

This paper relates to –

Strategic Objectives:
*A: **Safety** – Enhance global civil aviation safety*

1. INTRODUCTION

1.1 10 minutes longitudinal time separation without Mach Number Technique (MNT) is planned to be introduced on all routes in the Pacific Oceanic airspace of Fukuoka FIR. However, the safety of this separation has been verified only on the condition that position reports are obtained at least every 40 minutes[1]. There are some routes which do not meet the requirement, e.g. Pacific Organized Track System (PACOTS) routes, which are flexible routes between Japan (or East Asia) and North America (or Hawaii).

1.2 In order to evaluate the separation safety, the estimated risk of collision must be calculated and meet the target level of safety (TLS). The risk of collision for time-based separation is usually calculated by a gain-loss distribution model. However, the conventional gain-loss distribution model is based on many assumptions, and some of them lead to over-estimation. In this report, the gain-loss distribution method is refined to avoid over-estimation by considering the relative speed of two aircraft.

2. DISCUSSION

2.1 In the conventional gain-loss distribution method, the distribution of the loss time (loss distribution) is obtained as uncertainty. The loss time is defined as the change of the separation of two aircraft between two waypoints, as shown in Fig. 1. However, the loss distribution does not consider the relative speed of the two aircraft. If the relative speed of a pair of aircraft is obtained, the uncertainty associated with it can be eliminated from the loss distribution. Considering the speed effect, the remained uncertainty is expected to decrease, which leads to decrease the risk of collision. The details of the calculation can be found in the attached Appendix A or Reference 2.

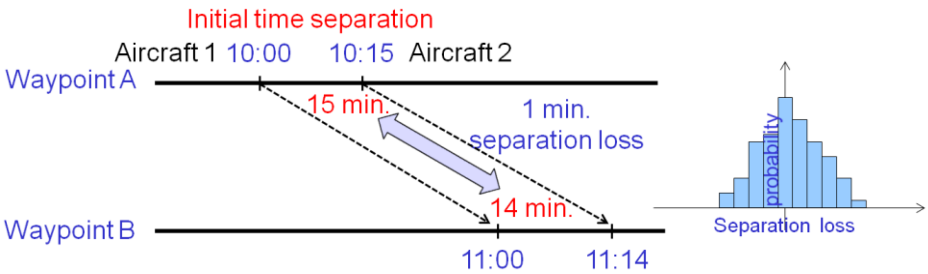

Fig. 1 Calculation of loss time

2.2 In order to show the effectiveness of the proposed method, the risk of collision is calculated. Data is obtained for 7 months, between May 2011 and November 2011. Since the data available on PACOTS routes is insufficient, the proposed refined method is verified with data of North Pacific (NOPAC) A590 route between POXED and PUGAL in Fukuoka FIR (shown in Fig. 2) is on target. This route is allowed to be flown east bound only. The length of the segment is 330 NM, and the average flight time of the segment is 37.6 minutes. Flight data processing system (FDPS) data is used to extract aircraft flying A590 route, and ADS message and ATO (Actual Time Over Fix) data are used to obtain the actual time at each waypoint. Altogether 12,287 flights are observed. Among them, 4,855 pairs of aircraft applied time-based separation. 1,719 pairs of aircraft applied the initial time separation within 1 hour. In order to consider the relative speed, the data of true air speed (TAS) recorded in the FDPS data are used.

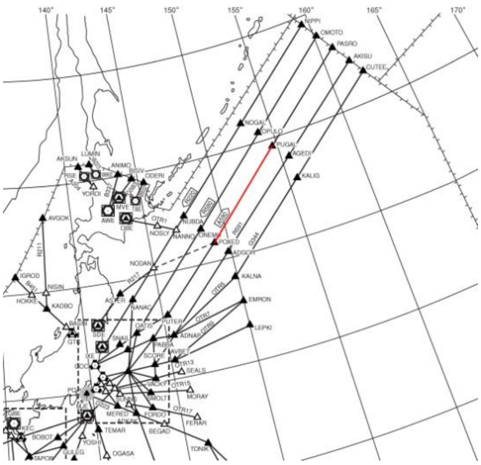
Fig. 2 NOPAC route. (A590 POXED-PUGAL is red colored.)

2.3 Fig. 3 shows the relationship between relative TAS and separation loss. Positive relative TAS indicates that two aircraft are getting closer. According to the figure, there is a correlation between the two parameters. About 23 kt difference corresponds to 1 minute loss time. The expected uncertainty can be decreased when the loss distribution is kept around the correlation axis. To account for the discrepancy between the actual speed and the TAS data recorded in FDPS, the difference of TAS in FDPS and actual TAS is included in the loss distribution as uncertainty.

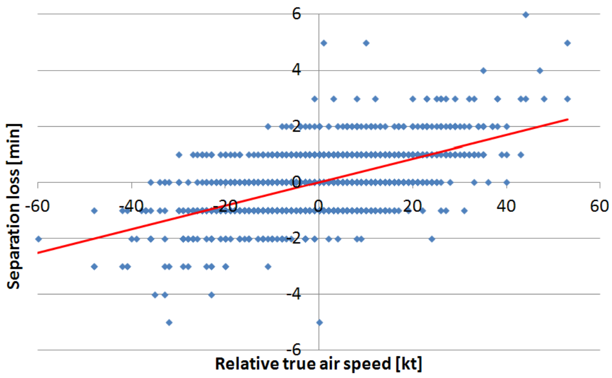

Fig. 3 Relationship between relative TAS and separation loss.

2.4 Fig. 4 shows the obtained loss distribution around the correlation axis and the fitted model, while Fig. 5 shows the result of conventional loss distribution. The distribution around the correlation axis is narrower than the conventional distribution. This means that the uncertainty is decreased by considering the relative speed.

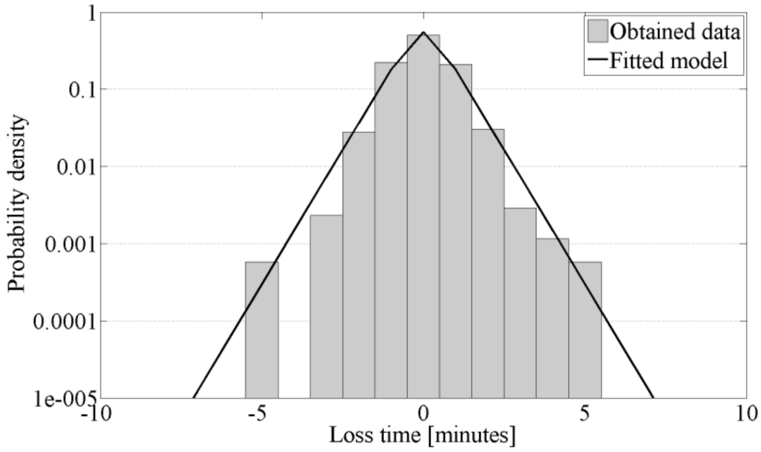

Fig. 4 Loss distribution around correlation axis.

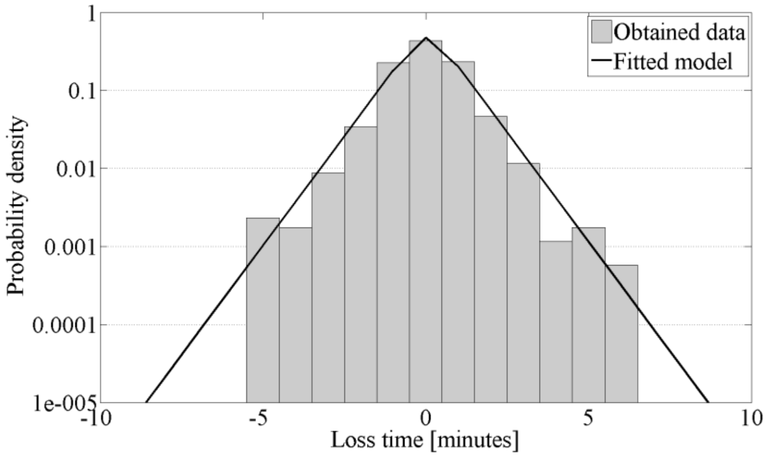

Fig. 5 Loss distribution by conventional method.

2.5 Fig. 6 shows the frequency of the relative speed in each range of the initial time separation. When the initial time separation is 60 minutes or less, the maximum relative TAS is 53 kt. However, when the initial time separation is 20 minutes or less, big relative TAS is observed less often and the maximum relative TAS is 32 kt. This infers that ATC tries not to apply big relative TAS when the initial time separation is small. This effect is also to be considered in the calculation, which leads to a more accurate result.

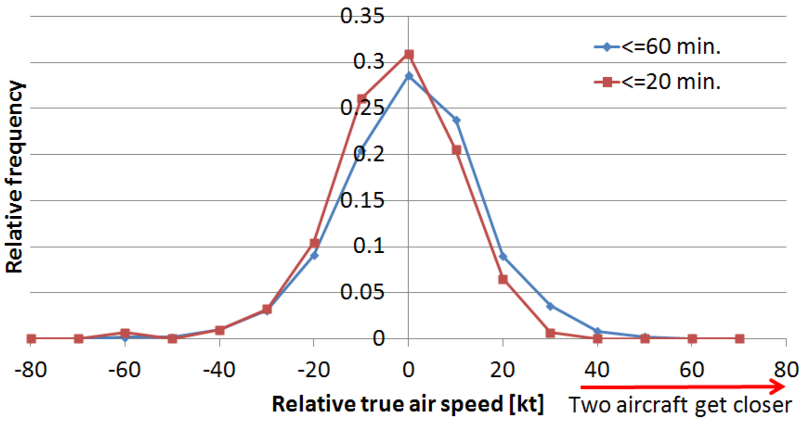

Fig. 6 Relative frequency of the relative true air speed in each range of the initial time separation.

2.6 Finally, the risk of collision is calculated on A590 route, and the result is shown in Table 1. Although the risk of collision calculated by both methods satisfies the TLS, the risk by the refined method is more than 10 times lower than that by the conventional method. This improvement has occurred because unnecessary speed uncertainty has been avoided.

Table 1 The risk of collision on A590 route.

	Risk of collision
Conventional method	5.04×10^{-10}
Refined method	1.78×10^{-11}
TLS	5.0×10^{-9}

2.7 In this report, a refined method for estimating the risk of collision was introduced. The result showed that this refined method could estimate more accurate risk of collision. Using the proposed method, the risk of collision will be calculated on PACOTS routes assuming 10 minutes separation. If the calculated risk of collision meets the requirement of the TLS, 10 minutes time separation without MNT will be introduced on PACOTS routes.

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) note the information contained in this paper; and

b) discuss any relevant matters as appropriate.

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References

[1] "Application of 10 min separation minimum without MNT within Fukuoka FIR," IP/16, IPACG/32, Honolulu, Hawaii, USA, 10-14 May, 2010.
[2] R. Mori, "Safety Assessment for Reduced Time-Based Separation Minima on Oceanic Routes", Journal of Mechanical Systems for Transportation and Logistics, Vol. 4, No. 1 (2011), pp.39-49.

Appendix A

This appendix provides a detailed description of the refined calculation method for longitudinal time separation.
The basic calculation concept is the same as the one in EMA handbook. The expression for the longitudinal collision risk model used in assessing the safety of operations is:

$$N_{ax} = P_y(0)P_z(0)\frac{2\lambda_x}{\overline{|\dot{x}|}T}\left[\frac{\overline{|\dot{x}|}}{2\lambda_x} + \frac{\overline{|\dot{y}(0)|}}{2\lambda_y} + \frac{\overline{|\dot{z}(0)|}}{2\lambda_z}\right]\sum E_x(t)P_x(t) \quad (1)$$

The parameters are summarized in Table A-1. Three parameters must be set.

Table A-1 Parameters in the calculation of the collision risk.

	Explanation	**Value used**	**Source of the values**
$P_y(0)$	Lateral overlap probability	0.2	EMA handbook [1]
$P_z(0)$	Vertical overlap probability	0.5380	ICAO SASP safety assessment [2]
λ_x	Length of a typical aircraft	0.040 NM	B777-300ER
λ_y	Wingspan of a typical aircraft	0.035 NM	B777-300ER
λ_z	Height of a typical aircraft	0.010 NM	B777-300ER
$\overline{\lvert\dot{x}\rvert}$	Average relative velocity between two aircraft necessary to infringe the planned longitudinal spacing	100 kt	EMA handbook [1]
$\overline{\lvert\dot{y}(0)\rvert}$	Average relative velocity between two aircraft, across track	1 kt	EMA handbook [1]
$\overline{\lvert\dot{z}(0)\rvert}$	Average relative velocity between two aircraft, vertically	1.5 kt	ICAO SASP safety assessment [2]
T	Average time to fly the segment	Estimated by data	
$E_x(t)$	Proportion of aircraft pairs with initial separation *t*	Estimated by data	
$P_x(t)$	Probability of the loss of longitudinal separation for *t* minutes or more	Estimated by data	

In order to estimate the parameters, a pair of aircraft is extracted based on the following conditions.

- The pair flies on the same flight level and the same route segment, and does not change the flight level during the segment.
- The pair does not apply distance-based separation nor mach number technique.
- The initial time separation is at least 10 minutes.

T and $E_x(t)$ are easily calculated from the obtained pairs of aircraft. The obtained $E_x(t)$ is shown in Fig. A-1. The larger the initial time separation is, the less risk of collision is. Therefore, aircraft pairs with more than 30 minutes initial time separation are not included in the distribution. The ratio of pairs of aircraft which have more than 30 minutes initial time separation is 84.8 %, where the risk of collision is assumed to be zero.

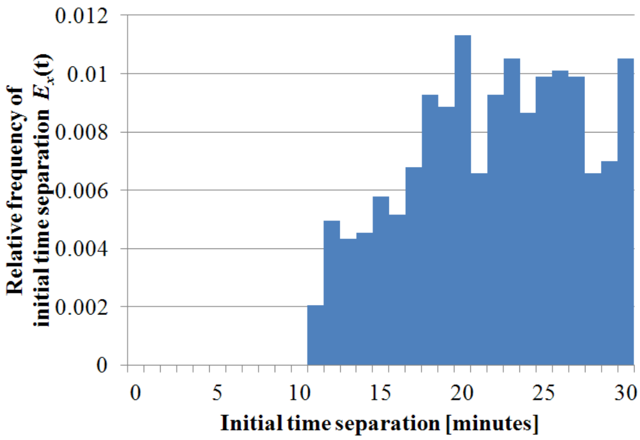

Fig. A-1 $E_x(t)$ vs. initial time separation.

Next, the relationship between the relative TAS and the separation loss time is verified. Note that the relationship tends to be weak when the initial time separation is big. Below, only the data when the initial time separation is 60 minutes or less is used, and the number of the data sets is defined as *n*. If there is plenty of data, the data within 30 minutes initial time separation can be used, which leads to more accurate result. *i* th aircraft loss time l_i and the relative TAS ΔV_i are assumed to have the following linear relationship.

$$l_i = a\Delta V_i + b + \varepsilon \tag{2}$$

a and *b* are the regression parameters and ε is the error term. These two parameters are optimized to minimize the error by least mean square method.

$$\sum_{i=1}^{n}(l_i - (a\Delta V_i + b))^2 \tag{3}$$

When the parameters are optimized, the remaining error is obtained, which is defined as the refined loss time (l_i^{new}) which excludes the effect of the relative TAS.

$$l_i^{new} = l_i - (a\Delta V_i + b) \tag{4}$$

The refined loss time is obtained as shown in Fig. A-2. Note that the refined loss time is discretized by 1 minute. The refined loss time is fitted by double exponential distribution function defined as follows:

$$D(t;\, \mu,\, \lambda) = \frac{1}{2\lambda}\exp\left(\frac{-|t-\mu|}{\lambda}\right) \tag{5}$$

where μ and λ are the parameters of the model. These two parameters are set by the maximum likelihood estimation method, i.e. to maximize the following equation.

$$L = \prod_{i=1}^{n} D(l_i^{new};\, \mu,\, \lambda) \tag{6}$$

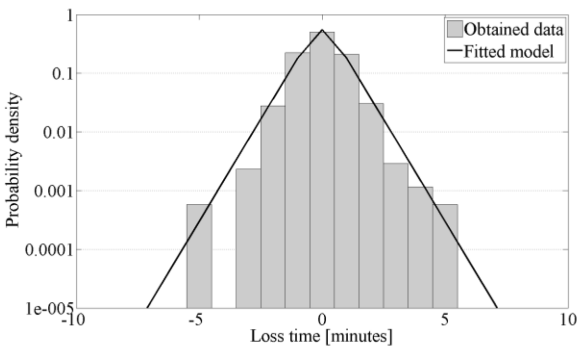

Fig. A-2 Refined loss distribution and fitted model.

The obtained fitted model is defined as $D_{fit}(t)$.

In order to calculate the risk of collision, not only the refined loss time but also the relative TAS must be considered. Therefore, the relative frequency of the relative TAS is also required. According to our pre-testing, the distribution of the relative TAS is affected by the initial time separation. Therefore, two relative frequency functions of the relative TAS ($p_{\le 20}(\Delta V)$ and $p_{\le 60}(\Delta V)$) are considered as shown in Fig. A-3. Although the distributions are discretized by 10 kt in the figure, they actually have 1 kt resolution.

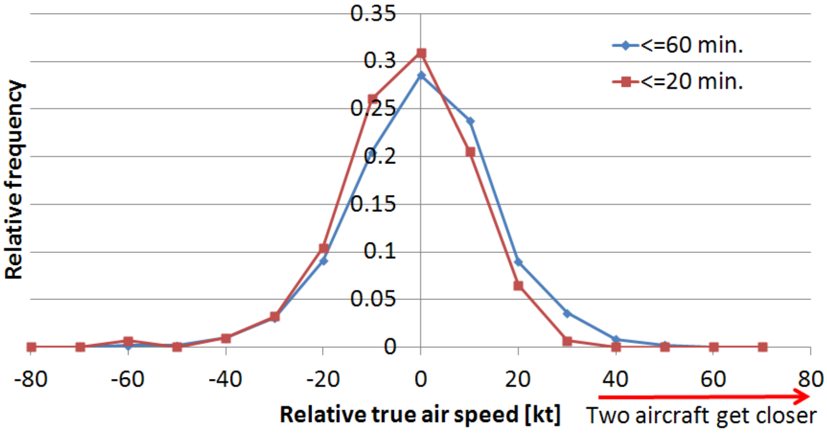

Fig. A-3 Relative frequency of the relative TAS in each range of the initial time separation.

Finally, $P_x(t)$ considering the relative TAS is calculated based on the following equation.

$$P_x(t) = \begin{cases} \sum_j p_{\le 20}(\Delta V_j) \int_{t-0.5}^{t+0.5} ds \int_s^{\infty} d\tau D_{fit}(\tau - (a\Delta V_j + b)) & (t \le 20) \\ \sum_j p_{\le 60}(\Delta V_j) \int_{t-0.5}^{t+0.5} ds \int_s^{\infty} d\tau D_{fit}(\tau - (a\Delta V_j + b)) & (t > 20) \end{cases} \quad (7)$$

$P_x(t)$ is the probability that the separation loss is greater than *t*. However, the initial time separation *t* is discretized by 1 minute, so it is assumed that the initial time separation of *t* is a uniform distribution between $t-0.5$ and $t+0.5$.

Reference

[1] Asia/Pacific Region En-route Monitoring Agency (EMA) Handbook, International Civil Aviation Organization Asia and Pacific Office. (online), available from < http://www.bangkok.icao.int/edocs/EMA_handbook_ver2.pdf >, (accessed 2012-1-16).
[2] Fujita, M., Nagaoka, S., and Amai, O., Safety Assessment prior to Implementation of 50 NM Longitudinal Separation Minimum in R220 and R580, ICAO SASP-WG/WHL/9 WP/14, (2006).