International Civil Aviation Organization

The Fifteenth Meeting of the Regional Airspace Safety Monitoring Advisory Group (RASMAG/15)

Bangkok, Thailand, 01 – 05 August 2011

Agenda Item 3: Reports from Asia/Pacific RMAs and EMAs

SAFETY ASSESSMENT OF THE LONGITUDINAL SEPARATION IN THE OCEANIC AIRSPACE OF FUKUOKA FLIGHT INFORMATION REGION

(Presented by Japan)

SUMMARY

This paper presents the result of safety assessment of the longitudinal separation standard applicable in the oceanic airspace of Fukuoka Flight Information Region (FIR).

This paper relates to –

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

1. INTRODUCTION

1.1 Japan Civil Aviation Bureau (JCAB) has applied 10-minute longitudinal separation minimum <u>without</u> mandatory Mach Number Technique (MNT) to aircraft on all ATS routes in the oceanic airspace of Fukuoka FIR since November 2010. The safety of this minimum has been assessed and discussed through the Informal Pacific ATC Coordination Group (IPACG) meetings for some years.

2. DISCUSSION

2.1 The JCAB Regional Monitoring Agency (RMA) has conducted a safety assessment of the 10-minute longitudinal separation minimum <u>without</u> mandatory MNT in the oceanic airspace of Fukuoka FIR by using the methodologies transferred from the Electronic Navigation Research Institute (ENRI), as detailed in **Attachment 1**.

3. ACTION BY THE MEETING

3.1 The meeting is invited to note the results of the airspace safety oversight presented in this working paper.

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Attachment 1

SAFETY ASSESSMENT OF THE LONGITUDINAL SEPARATION IN THE OCEANIC AIRSPACE OF FUKUOKA FLIGHT INFORMATION REGION

Presented by: JCAB RMA

August 2011

Japan Civil Aviation Bureau (JCAB) has applied more than one longitudinal separation minimum in the oceanic airspace of Fukuoka FIR. The distance-based separations (i.e. RNP10/ADS-C/CPDLC-based 50NM separation and RNP4/ADS-C/CPDLC-based 30NM separation) are applied to the suitably equipped aircraft pairs on a target-of-opportunity basis. The time-based separations (i.e. procedural 15-minute separation, and 10-minute separation with assignment of Mach number), however, are still widely applied to any aircraft in the oceanic airspace. In order to use airspace more efficiently, JCAB has started to apply 10-minute longitudinal separation minimum without mandatory Mach Number Technique (MNT) to aircraft on all ATS routes in the Pacific oceanic airspace of Fukuoka FIR since November 2010. This paper presents the safety assessment of the longitudinal separation applied in the oceanic airspace, which is focused mainly on the 10-minute longitudinal separation minimum without mandatory MNT.

1. Introduction

JCAB introduced RNP10/ADS-C/CPDLC-based 50NM longitudinal separation minimum to the whole Pacific oceanic airspace of Fukuoka FIR in February 2006. Prior to the introduction, JCAB and the Electronic Navigation Research Institute (ENRI) conducted a safety assessment [1].

JCAB introduced RNP4/ADS-C/CPDLC-based 30NM longitudinal separation minimum to the whole Pacific oceanic airspace of Fukuoka FIR in December 2008. Prior to the introduction, JCAB and ENRI conducted a safety assessment [2].

JCAB introduced 10-minute longitudinal separation minimum without mandatory MNT to all ATS routes in the Pacific oceanic airspace of Fukuoka FIR in November 2010. Prior to the introduction, JCAB and ENRI conducted a safety assessment. It concluded that the estimated collision risk was below the regionally agreed Target Level of Safety (i.e. 5.0×10^{-9}) if the separation of position report is 350NM or less for North Pacific (NOPAC) routes, and 370NM or less for other oceanic routes [3].

In order to introduce 10-minute longitudinal separation minimum without mandatory MNT, JCAB upgraded Oceanic Data Processing (ODP) system in July 2010, and the Oceanic Transition Routes (OTR) and NOPAC routes were realigned in November 2010. Accordingly, all oceanic ATS routes in Fukuoka FIR were put in place an environment that will enable 10-minute longitudinal separation minimum without MNT.

Further analysis for reduced time-based separation minimum on oceanic ATS routes was practiced by using the improved software by ENRI, which took into account the differences of speed between the aircraft-pairs [4].

The Air Traffic Control Association Japan (ATCA-J) has received technical transfers from ENRI on behalf of Japan RMA. Last year, ATCA-J received know-how needed to conduct the safety assessment of reduced lateral separation minimum [5]. And this year, ATCA-J received a technical transfer of the risk calculation for the reduced longitudinal separation minimum.

2. Airspace description

2.1 ATS routes and flexible tracks

There are sixteen (16) ATS routes in the Pacific oceanic airspace of Fukuoka FIR (Figure 1). In addition to these fixed ATS routes, operators can fly this oceanic airspace via flexible tracks. One of the flexible tracks is the Pacific Organized Track System (PACOTS) route. PACOTS routes are generated and NOTAMed daily by FAA's Oakland ARTCC and JCAB's Air Traffic Management Center. They are the combination of time/fuel-efficient unidirectional tracks between Japan and North America/Hawaii, and between North America and Southeast Asia. They are calculated and established flexibly by using timely forecast of upper wind condition and severe weather areas. Another flexible track is User Preferred Route (UPR). Operators can file UPRs for individual flights flexibly but complying with the published rules in AIP or NOTAM.

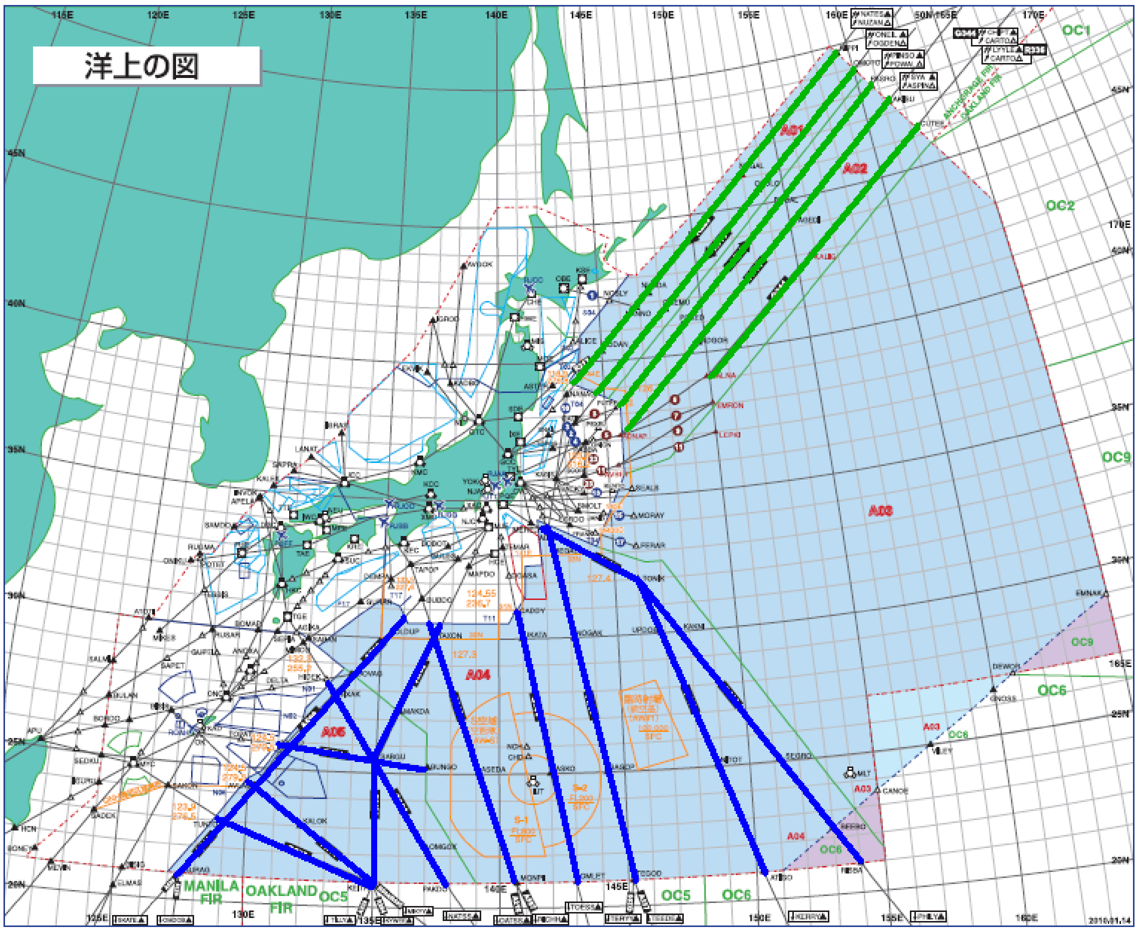


Figure 1: Oceanic ATS routes in Fukuoka FIR

Ten (10) oceanic ATS routes colored in blue (i.e. A590 south of MJE (Miyakejima VOR), R595, R584, A339, G339, A597, B586, A337, B452 and G223) link Japan with Southeast Asia/South Pacific through Oakland/Manila FIRs. Five (5) oceanic ATS routes colored in green are called NOPAC routes (i.e. R220, R580, A590 north of MJE, R591 and G344), which link Japan with Alaska through Anchorage FIR. Each NOPAC route is basically unidirectional (Figure 2).

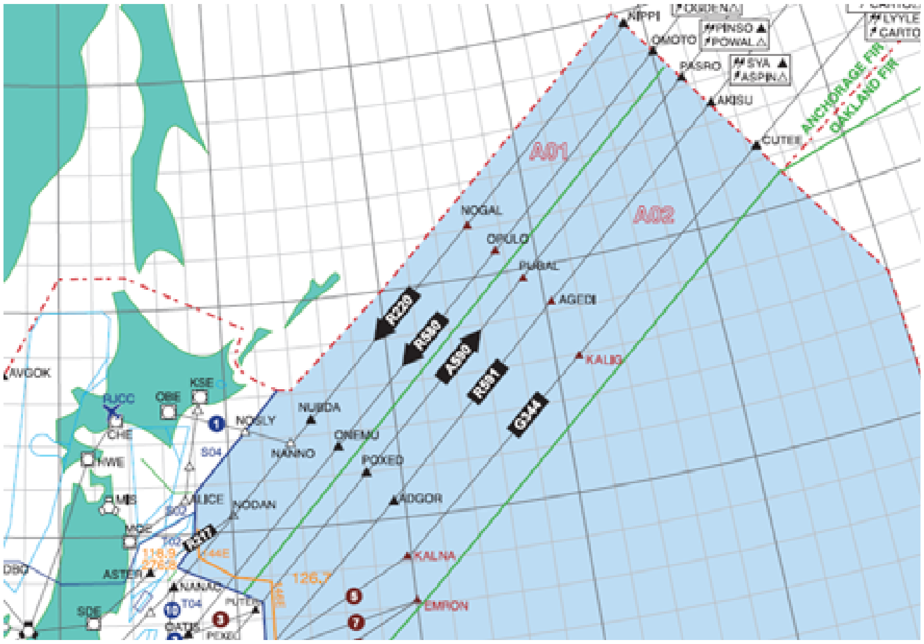


Figure 2: NOPAC routes

Approximately 400 to 500 flights per day operate within the Pacific oceanic airspace of Fukuoka FIR. According to the findings of two weeks survey on 14th-20th December 2010 and 14th-20th May 2011, 51.4% of oceanic flights operated on ATS routes and 48.6% operated on PACOTS or UPR. Among the 51.4% of ATS routes flyers, 57.4% of aircraft operated on NOPAC routes.

The peak hour of oceanic traffic in Fukuoka FIR is from 1500UTC to 1800UTC, and from 0300UTC to 0600UTC.

NOPAC is the busiest oceanic airspace in Fukuoka FIR. It covers less than 15% of the Pacific oceanic airspace where JCAB has responsibility to provide ATM, while NOPAC routes accommodate about 30% of oceanic flights in Fukuoka FIR every day.

2.2 Separation minima

Table 1 shows the longitudinal separation minima applied to aircraft-pairs on oceanic ATS routes in Fukuoka FIR. 10-minute separation minimum is not applied to aircraft on PACOTS/UPR without mandatory MNT.

Longitudinal separation minima			
	RNP4 aircraft (ADS-C/CPDLC)	RNP10 aircraft (ADS-C/CPDLC)	Other aircraft
RNP4 aircraft (ADS-C/CPDLC)	30NM	50NM	10min*
RNP10 aircraft (ADS-C/CPDLC)	50NM	50NM	10min*
Other aircraft	10min*	10min*	10min*

Table 1: Longitudinal separation minima in the oceanic airspace of Fukuoka FIR

* Not applicable on PACOTS/UPR without MNT. Require position reports every 40 minutes.

The applicable longitudinal separation can vary depending on receiving ATC facilities. For aircraft-pairs entering Anchorage/Oakland FIRs, the applicable longitudinal separation at the FIR boundary is 50NM for RNP10or4/ADS-C/CPDLC-based aircraft or 10 minutes with MNT. For aircraft-pairs entering Manila FIR, the applicable longitudinal separation at the FIR boundary is 10 minutes with MNT.

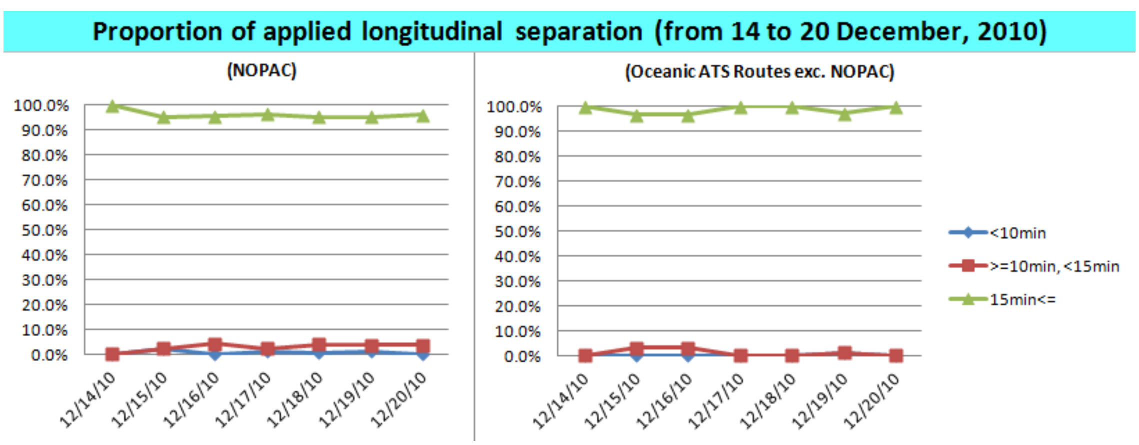
Approximately 27% flights operating in the oceanic airspace of Fukuoka FIR are RNP4 aircraft as of April 2011. The proportion of RNP4 flights hovers at between 26% and 28% for the last one year.

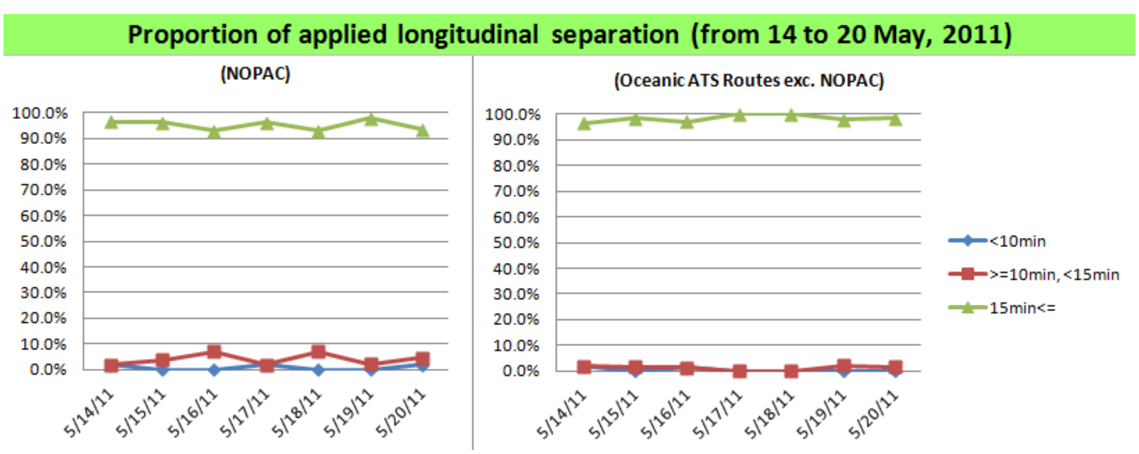
3. Safety assessment of time-based longitudinal separation minimum

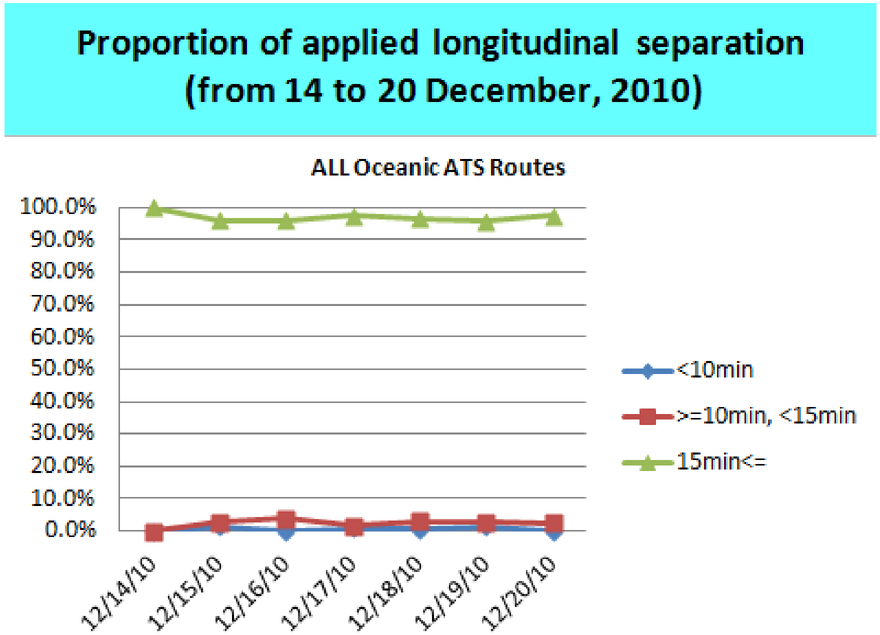
The longitudinal separation had long meant time-based separation in the oceanic airspace of Fukuoka FIR. Only about a decade ago, distance-based separation was introduced to shorten the longitudinal separation for the RNP10/RNP4 aircraft flying in the oceanic airspace. At present the minimum longitudinal separation of 30NM is applicable when both aircraft are suitably equipped RNP4/ADS-C/CPDLC aircraft. As long as aircraft has ADS-C system equipped, it automatically sends information about current position at a specific time interval (e.g. 27 minutes), which is used by air traffic controllers to secure the longitudinal separation. It is very important to get the accurate aircraft position update within a certain time interval. That is the reason why oceanic route fixes were reviewed to satisfy the position report intervals. The increase in number of aircraft with RNAV/RNP capabilities would conduce to more application of reduced distance-based longitudinal separation. However, time-based separation is still widely used to secure the longitudinal separation. The procedural 15-minute separation can be reduced to 10 minutes by applying MNT, which is a little cumbersome. The 10-minute separation without MNT was introduced in October 2010 within Fukuoka FIR except NOPAC routes. For NOPAC routes, 10-minute separation without MNT became available in November 2010 after the compulsory reporting points were realigned to fulfill the minimum reporting interval requirement. The risk calculation for the time-based longitudinal separation minimum without MNT is described in section 4.

3.1 Analysis of application of separation minimum

Figure 3 and Table 2 show the proportion of applied longitudinal separation in minutes to the aircraft-pairs on oceanic ATS routes in Fukuoka FIR. The separation is classified into three groups (i.e. shorter than 10 minutes, 10 minutes or longer but shorter than 15 minutes, and 15 minutes or longer).







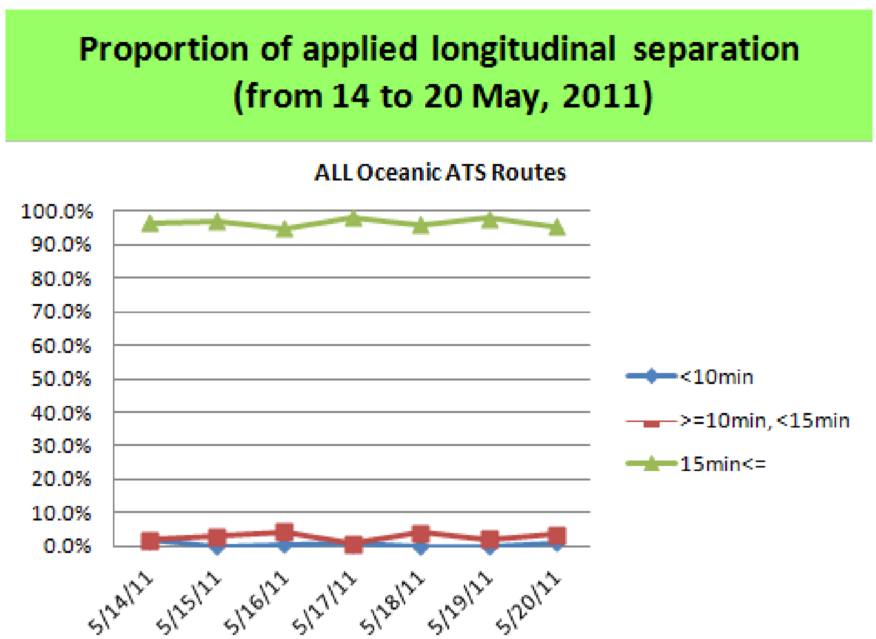


Figure 3: Proportion of applied longitudinal separation on the Oceanic ATS Routes

Proportion of applied longitudinal separation on
NOPAC
Number of pairs = 1,325 (14-20 December 2010, 14-20 May 2011)

< 10 minutes	>= 10 minutes, < 15 minutes	15 minutes <=
0.7%	3.6%	95.7%

Proportion of applied longitudinal separation on
Oceanic ATS Routes except NOPAC
Number of pairs = 750 (14-20 December 2010, 14-20 May 2011)

< 10 minutes	>= 10 minutes, < 15 minutes	15 minutes <=
0.4%	1.1%	98.5%

Total proportion of applied longitudinal separation on **ALL Oceanic ATS Routes** **Number of pairs = 2,075** (14-20 December 2010, 14-20 May 2011)		
< 10 minutes	>= 10 minutes, < 15 minutes	15 minutes <=
0.6%	2.7%	96.7%

Table 2: Proportion of applied longitudinal separation on the Oceanic ATS Routes

In Figure 3 and Table 2, "shorter than 10 minutes" is assumed to be the aircraft-pairs which 50NM/30NM longitudinal separations were applied. The group of "10 minutes or longer but shorter than 15 minutes" is assumed to include the 10-minutes longitudinal separation minimum without MNT.

4. Risk Calculation

Risk calculations used in this safety assessment is developed by ENRI. The detailed explanation of the methodology is published in the academic paper titled "Safety Assessment for Reduced Time-based Separation Minima on Oceanic Routes" [4].

4.1 Loss and Gain

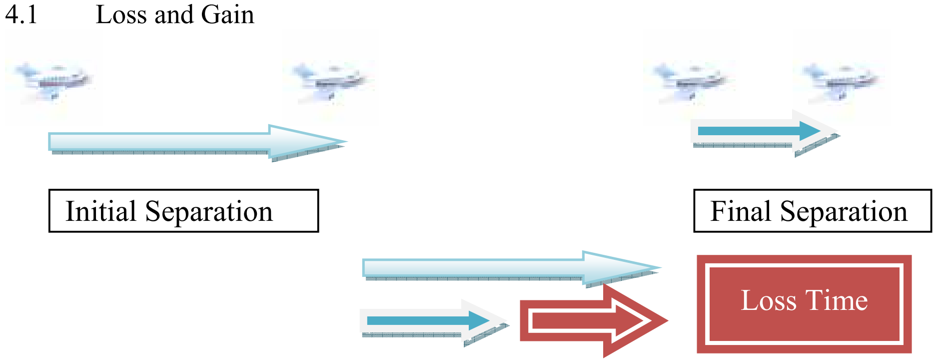


Figure 4: Loss time definition

When time-based separation is applied, the aircraft reports over each fix along the routes. However during the flight between the fixes, no information about the position of the aircraft is available. In rare cases, theoretically, there might be a possibility that the succeeding aircraft bumps into the preceding aircraft flying on the same segment. To estimate magnitude of such a collision risk, the idea of time loss distribution has been applied. Consider a pair of aircraft entering the same segment at the same flight level with a certain time separation. This separation is defined as the initial time separation. In the same manner the time difference between the pair at the segment exit fix is defined as final time separation. Here, the loss time is defined as final time separation minus initial time separation. The relative frequency of loss time is collected from the journal data of Flight Data Processing System (FDPS). By analyzing this data the empirical probabilistic distribution of loss time *l(t)* can be acquired. Based on probability density function the loss time will be estimated. In this theoretical function the bigger variation (λ) indicates the wider loss values. To satisfy TLS, big loss time should remain with very low probability.

The case when loss time is bigger than the initial time separation means longitudinal time separation is compromised. The probability that the longitudinal separation is infringed when the initial time separation is equal to *t* (defined *p(t)*) is calculated using the following expression:

$$P_x(t) = \int_{\tau}^{\infty} l_m(\tau) d\tau \qquad (1)$$

4.2 Risk value using loss time

A collision between two aircraft happens when all of the longitudinal, lateral and vertical separations are simultaneously infringed. Even when the longitudinal separation is infringed, as long as the aircraft deviates laterally and vertically, a collision will be avoided. Considering a three dimensional collision, the expected risk of collision *Nax*, which is defined as the expected number of accidents per flight hour due to loss of assigned longitudinal separation, is calculated by the following expression (2).

The values correspond to the worst case scenario, so the expected risk of collision is higher than the actual risk of collision.

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

Parameter Symbol	Parameter Definition	Parameter Value	Source for Value
Py(0)	Probability that two aircraft on the same track are in lateral overlap	0.2	EMA handbook
Pz(0)	Probability of vertical overlap in operational risk estimation for the aircraft flying as a same flight level	0.5380	ICAO SASP safety assessment
$\overline{\lvert\dot{y}(0)\rvert}$	The average relative speed between two aircraft, across track.	1kt	EMA handbook
$\overline{\lvert\dot{z}(0)\rvert}$	Average vertical speed of aircraft pairs	1.5 kt	ICAO SASP safety assessment
λx	Average aircraft length	0.0393 nm	A380, conservative selection
λy	Average aircraft width	0.0431 nm	
λz	Average aircraft height	0.0132 nm	
T	The average time to fly the segment.		FDPS data (NOPAC)
Ex(t)	The proportion of aircraft initial separation		
$P_x(t)$	The probability of the loss of longitudinal separation.		

Table 3: Parameters for risk calculation

4.3 Data acquisition and airspace considered

ATS route A590 and R220 in the NOPAC route system are selected. The statistics are shown in Table 4.

No.	Segments	Distance	No. of Flight pairs
1	NUBDA-NOGAL (R220)	300 NM	11,706
2	NOGAL-NIPPI (R220)	300 NM	11,709
3	POXED-PUGAL (A590)	300 NM	9,462
4	PUGAL-PASRO (A590)	300NM	9,698

(Data: 2011/01/01-2011/06/30)

Table 4: Data source information

The actual time over the fixes were collected from recorded FDPS data between 1st January 2011 and 30th June 2011. From the data the aircraft-pairs were extracted according to the following conditions. The extracted flights for these two routes are totaled 33,970 flights. Number of flight pairs for each segment is listed in Table 4. The flight files these routes usually fly over all fixes along the routes. The number of flights in segment No.1 and No.2 are different. The tendencies are more conspicuous between segment No.3 and No.4. The reason for this difference is not yet thoroughly investigated, but there are several possible reasons for this discrepancy. For instance in cases some flight shortcut the first fix and makes entry into the NOPAC system at second fix, even though the entry fixes are correctly filed. This kind of procedural practices causes some difficulties in estimating correctly the loss distribution. The aircraft pair is collected using following criterion.

1) *A pair of the aircraft flies on the same flight level and the same route segment, and does not change the flight level during the segment.*

2) *Either of the aircraft does not have an ADS system equipped and does not apply Mach number technique.*

3) *The initial time separation is 15 minutes or greater.*

4.4 Data acquisition and estimation of the probability density function

First, the probability density distribution of the initial time separation *Ex(t)* is obtained. Herein *Ex(t)* is considered up to 30 minutes, which assumes a zero risk of collision when the initial time separation exceeds 30 minutes. The empirical distribution of *Ex(t)* is shown in Figure 5.

Then, the loss distribution is estimated. The loss time depends on the initial time separation. In the case of big initial time separation, the wind condition is likely to change which resulting in the big loss time. Therefore, the loss time should be calculated within the limited range of initial time separation, otherwise it might cause an over-estimation.

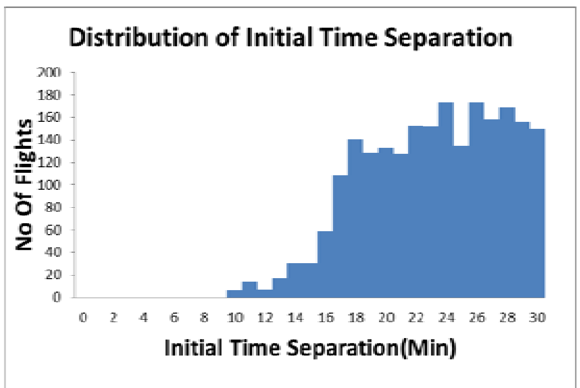


Figure 5: Initial time separation

Here, the restriction of the initial time separation is set to 30 minutes. The recorded time in the FDPS data is discredited by 1 minute, so the probability density is also discredited by 1 minute. In this airspace 87% (10,384 flights) of the pair of aircraft have 30 minutes or more initial time separation. Each segment is designed to have exactly same distance of 330NM, and the average flying time was 0.69282 hours, which was about 40 minutes. So the aircraft pair which has 30 minutes separation at entry fix has almost no risk of collision. Note that we assumed 15 minutes initial separation. 10-minute longitudinal separation minimum without mandatory MNT only limited within Fukuoka FIR. For aircraft-pairs entering neighboring FIRs, the applicable longitudinal time separation at the FIR boundary is 10 minutes with MNT or 15 minutes. The total number of aircraft pairs which had less than 15 minutes separations were only 74 pairs. (10min-6, 11min-14, 12min-7, 13min-17, 14min-30)

Next, the probability density function should be constructed based on the actual loss distribution. When fitting the probability density function, the maximum likelihood estimation (MLE) is often used. But, MLE gives the same importance to all the data, which indicates the smaller loss time highly affects the distribution, because there are more data sets of the small loss time. In order to avoid under-estimation, the least square method (LSM) is introduced.

4.5 Calculation result of the expected risk of collision

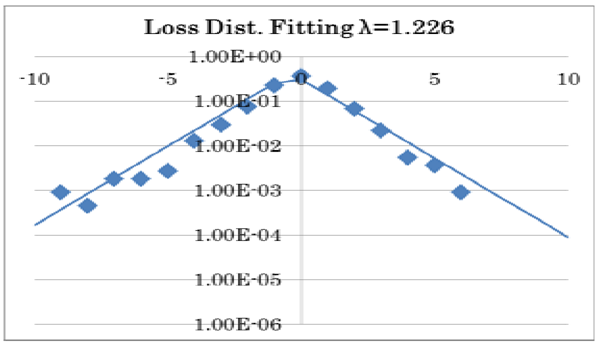
4.5.1 Risk analysis using original data

Based on the data obtained above, the risk of collision is calculated under 10-minute time separation. However, the current probability density of the initial time separation *Ex(t)* is obtained under 15-minute time separation, so $E_{x\_est}(t)$ under 10-minute time separation is estimated shifting *Ex(t)* by 5 minutes.

$$E_{x\_est}(t) = E_x(t+5) \qquad t \geq 10 \qquad (3)$$

Finally, the risk of collision is calculated for these two routes. ***The calculated risk value is 3.62798 x 10^{-08} and this does not satisfy TLS.***

This is because of the existence of relatively big loss time. See Figure 6 below.

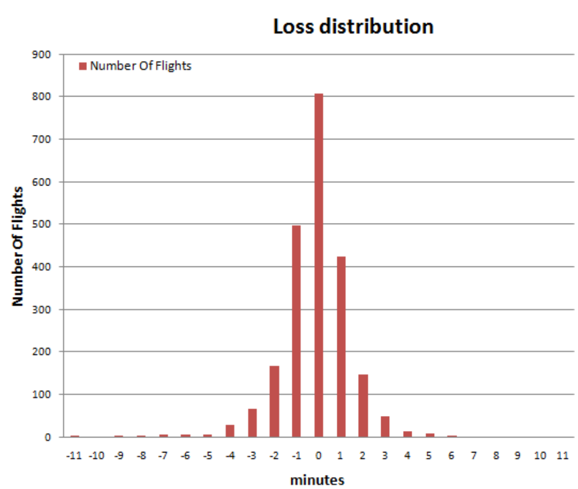


$\lambda = 1.226$ $\qquad \mu = -0.38162$

Figure 6: Fitting using original data

4.5.2 To improve the loss time distribution by checking the big loss values

The LSM is designed to minimize difference and well fit even to the small number of relatively large values of loss time. This characteristic will secure the safety by considering extreme cases so that we can be at least on the safe side. It helps not to underestimate the risks caused by extreme cases. But on the other hand, this means the theoretical function derived from LSM is greatly affected by large loss values. The large variations lead directly high risk values. The extraction of parameter is automatically done once the pertinent data is available. So, to calculate the risk value correctly to peruse real causes of high loss values have vital importance. We had 2,222 loss time data. It is shown in Figure 7.

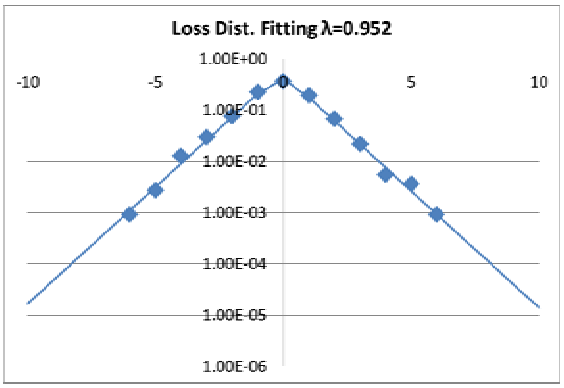


minutes	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	
No. Of Flights	1	0	2	1	4	4	6	28	65	166	496	
minutes	0	1	2	3	4	5	6	7	8	9	10	11
No. Of Flights	808	425	147	48	12	8	2	0	0	0	0	0

Figure 7: Loss distribution

We made a check on loss values greater than +/- 6 minutes and found out most of the big values are caused by incorrect time entry. After deleted these outlier values from loss time data, fitting is adjusted to new set of data.

The variation value and mean for this modified data are $\lambda = 0.939836$ and $\mu = -0.17806$. ***The calculated risk value is 2.4706 x 10^{-09} and this satisfies TLS.***



$\lambda = 0.939836$ $\mu = -0.17806$

Figure 8: Fitting using amended data

4.6 Refinement of loss time variation estimation using velocity factor.

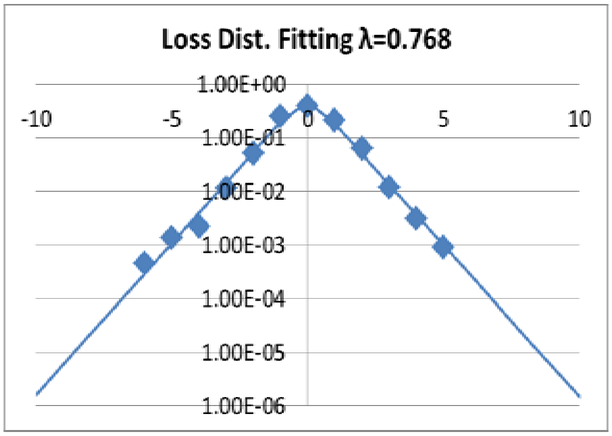
The theoretical distribution is used to model the original population. The distribution reflects the uncertainty factor of the system. If we could reduce the uncertainty we will be able to get more precise risk values. This section refers to the introduction of speed factor to reduce uncertainty. Assuming the case that the succeeding aircraft flies faster than the preceding aircraft, the time separation between these two aircraft will decrease. This means a positive loss time. Using the relation between the relative speed and the relative loss time, the uncertainty can be decreased. To compare the relative speed of two aircraft, ground speed (GS) of each aircraft is required. The FDP system has the true air speed (TAS) information. The wind factors for time estimation are considered if the wind zone information is used, but the TAS is not always equal to the GS. But if we consider only the short distance flight, the difference between GS and TAS will be relatively small. So, the filed TAS can be useful to decrease the predictable loss time. It is expected that the loss time increases almost linearly with the increase of the relative TAS and the length of the segment. Therefore, the relationship between the loss time and the relative TAS can be calculated for each airspace. A positive relative TAS is defined in the case when the following aircraft flies faster than the preceding aircraft. Finally, the refined probability where the longitudinal separation is infringed $P_x(t)$ is calculated based on the following function:

$$P_x^{new}(t) = \sum_{\Delta V} e(\Delta V) \int_{\tau}^{\infty} l_m^{new}\left(\tau - (a\Delta V + b)\right) d\tau \qquad (4)$$

$$\sum_{\Delta V} e(\Delta V) = 1 \qquad (5)$$

where $e(\Delta V)$ is the obtained probability density in each relative speed.

Using the proposed method, the expected collision risk is calculated. The variation value and mean for this modified data are λ =0.768 and μ = -0.03171. ***The calculated risk value is 6.003 x 10^{-10} and this satisfies TLS.***



λ =0.768 μ = -0.03171

Figure 9: Fitting using amended data and modified by speed factor

4.7 Other oceanic ATS routes

This section shows the risk calculation results on southern oceanic routes in Fukuoka FIR. The same methodology of risk calculation used for NOPAC routes is applied. Compared with NOPAC routes, the traffic volume is light on these routes, therefore we can collect relatively small samples. The route structure and data source information are shown in Figure 10 and Table 5 respectively.

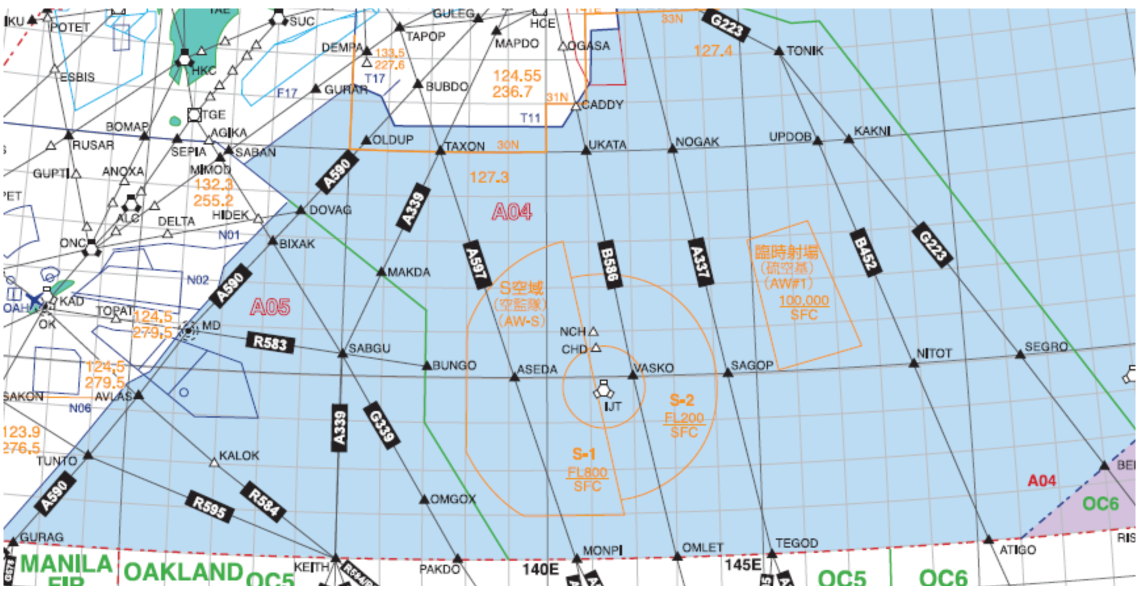


Figure 10: ATS routes in Pacific oceanic airspace of Fukuoka FIR except NOPAC routes

Air Space A*

No.	Segments	Distance	No. of Flight pairs
1	TAXON-ASEDA (A597)	317 NM	1,856
2	UKATA-VASKO (B586)	305 NM	942
3	NOGAK-SAGOP (A337)	306 NM	1,808
4	UPDOB-NITOT (B452)	318NM	37

Air Space B*

No.	Segments	Distance	No. of Flight pairs
1	ASEDA-MONPI (A597)	252 NM	1,814
2	VASKO-OMLET (B586)	246 NM	846
3	SAGOP-TEGOD (A337)	245 NM	1,810
4	NITOT –ATIGO (B452)	253NM	34

(DATA: 2011/01/01-2011/06/30)

*The distance between fixes is different in southern routes. Since the loss distribution is susceptible to the segment distance, the risk calculation is done divided the route into two segment groups Airspace A and B.

Table 5: Data source information

For air space A, the variation value and mean are λ =0.89761 and μ = -0.32668. ***The calculated risk value is 1.5444 x*** $\boldsymbol{10^{-10}}$ ***and this satisfies TLS***

For air space B, the variation value and mean are λ =0.837126 and μ = -0.13600. ***The calculated risk value is 1.40071 x*** $\boldsymbol{10^{-11}}$ ***and this satisfies TLS.***

5. Conclusion

In this paper, JCAB RMA conducted the safety assessment for the longitudinal separation standard with a focus on the time-based separation minimum. There are complex separation pairs depending on the navigation performance and the data link performance in oceanic airspace of Fukuoka FIR. However, the majority of aircraft-pairs are still applied time-based longitudinal separation.

Based on the results of the collision risk calculation with appropriate data treatment considering probability of entry time of time-based longitudinal separation, and further calculation with data modified by speed factor, TLS were satisfied on the 10-minute longitudinal separation without MNT in oceanic airspace of Fukuoka FIR.

The RNP4/ADS-C/CPDLC-based 30NM longitudinal separation minimum has been introduced throughout the Pacific oceanic airspace. JCAB RMA is planning to conduct the safety assessment for the distance-based separation minimum in the next step.

6. Reference

[1] M. Fujita, O. Amai & S. Nagaoka: Safety Assessment Prior to Implementation of 50NM Longitudinal Separation Minimum in R220 and R580, ICAO SASP WG/WHL/9 WP/14, 2006

[2] M. Fujita: Safety Assessment prior to 30NM Longitudinal Separation Minimum under ADS-C Environment, ICAO SASP WG/WHL/13 IP/8, 2008

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