Airspace Safety Assessment for Implementation of the Japanese Domestic Reduced Vertical Separation Minimum

*Osamu Amai[1] and Sakae Nagaoka[1]

[1]Electronic Navigation Research Institute, Independent Administrative Institution
(E-mail: {amai, nagaoka}@enri.go.jp)

Abstract

The Reduced Vertical Separation Minimum (RVSM), which is the reduced minimum from 2,000 ft to 1,000 ft at flight levels (FL) between 290 and FL410 inclusive, was implemented in 30 September 2005 within the Japanese domestic airspace. Prior to the implementation, safety assessment for the airspace in assumed RVSM environments was carried out. Some model parameter values of collision risk model were estimated using flight plan (progress) data and radar data. An estimate of vertical collision risk including operational risk was calculated using these together with given parameter values. The results obtained from this analysis are as follows.

(1) Contribution of the vertical collision risk for the crossing routes is about 9 percents of the total technical risk.

(2) The estimate of the collision risk is 4.1×10^{-9} [fatal accidents / flight hour] and the value is smaller than a maximum allowable level of collision risk, i.e. 5×10^{-9} [fatal accidents / flight hour], called the Target Level of Safety.

Keywords: Air Traffic Control, Aircraft, Safety Assessment, Domestic Reduced Vertical Separation Minimum

1. Introduction

For safe aircraft operation, separation minima are used in air traffic control (ATC). Until recently, the vertical separation minimum above or at flight level (FL) 290 was 2,000 ft in Japanese domestic airspace. Reduction of the vertical separation minimum had been requested for more economical aircraft operation.

The reduced vertical separation minimum (RVSM), which is the reduced minimum from 2,000 ft to 1,000 ft at flight levels between FL290 and FL410 inclusive, was implemented on 30 September 2005 within the Japanese domestic airspace. Prior to the implementation, safety assessment for the airspace in assumed RVSM environments was carried out.

The safety of RVSM airspace can be assessed by the collision risk due to loss of planned vertical separation [1]. The collision risk consists of the followings:

(1) Technical risk, which is associated with aircraft height-keeping performance

(2) Operational risk, which is the risk due to operational errors, such as a flight crew misunderstanding or a coordination failure between ATC units

Passing frequency and occupancy are one of the most important parameters of the collision risk model. These passing frequency values (for the same route) and occupancy values (for crossing routes) for whole domestic airspace were estimated. An estimate of technical risk was calculated using these together with given parameter values. Moreover, an operational risk is estimated on the basis of large height deviation reports.

This paper describes a method for estimating these risks and results of the analysis.

2. Collision Risk Model

Fig.1 shows the concept of collision due to loss of nominal separation. A pair of aircraft flying on an adjacent flight levels on the same route. The Reich model [2] deals with the collision risk which is defined by the expected number of the fatal accidents per flight hour in the airspace under consideration.

In this paper, collision risks were calculated by distinguishing the risk for the same route from that for crossing routes.

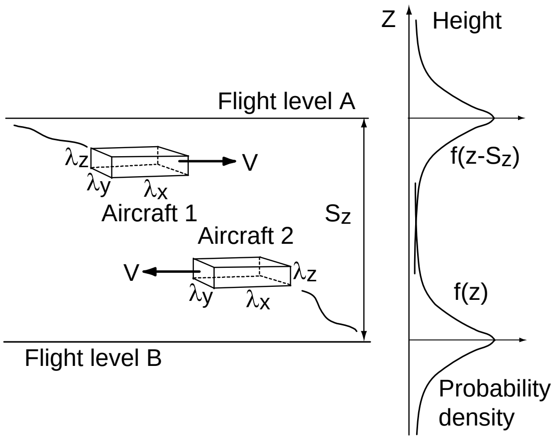

Figure 1. Model of collision. f(z) is the probability density function of height-keeping errors.

2.1 Technical Risk for the Same Route

Consider the aircraft pairs flying on the same route at the adjacent flight levels separated by Sz. The tracks whose intersecting angles are less than 5 degrees are regarded as the same track. A technical risk due to loss of the planned separation in the vertical dimension, $N_{az}^{tech}(o+s)$, is calculated by the following model [3].

$$N_{az}^{tech}(o+s) = P_z(S_z) P_y(0) N_x^{z}(e) K(o) \qquad (1)$$

where

$P_z(S_z)$: the vertical overlap probability for a typical aircraft pair assigned to the adjacent flight levels separated vertically by S_z on the same route.

$P_y(0)$: the lateral overlap probability for a typical aircraft pair assigned to the same route.

$N_x^{\,z}(e)$: the equivalent opposite-direction passing frequency (defined in section 2.1.1) of aircraft pair assigned to the adjacent flight levels.

$K(o)$: the value associated with average size of aircraft and average relative speed of the aircraft pair.

In the notation, o stands for the opposite direction traffic and s stands for the same direction traffic.

2.1.1 Passing Frequency

The event that two aircraft flying on the same route at the adjacent flight levels are in longitudinal overlap is called vertical passing event. Fig.2 shows the concept of vertical passing event.

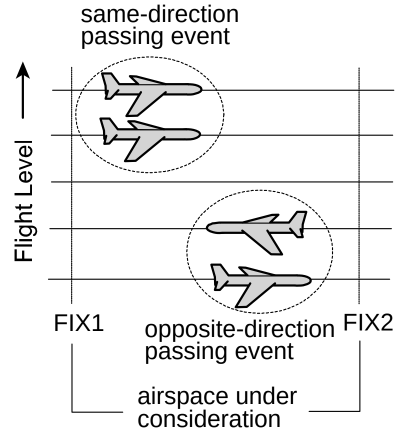

Figure 2. Vertical passing event

The vertical passing frequency is the expected number of longitudinal overlaps (passing events) met by a typical aircraft per flight hour, for the opposite or same direction traffic on the adjacent flight levels. The passing frequency is given by

$$N_z^{\,z}(o/s)=\frac{2n_p^{\,z}(o/s)}{H}\,. \tag{2}$$

where

$n_p^{\,z}(o/s)$: the number of passing events for the opposite / same direction traffic during an observation period in the system (airspace) under consideration.

H : the total flying hours of aircraft within the system during the observation period.

Herein, the factor 2 means that the one passing event consists of two passing aircraft. The unit of $N_x^{\,z}(o/s)$ is the number of passing aircraft per flying hour.

$N_x^{\,z}(e)$ is called the equivalent opposite-direction passing frequency. It is obtained by combining the estimates of the passing frequency for the opposite / same direction traffic into one value. It is given by

$$N_x^{\,z}(e)=N_x^{\,z}(o)+\frac{K(s)}{K(o)}N_x^{\,z}(s)\,, \tag{3}$$

$$K(s)=1+\frac{\lambda_x}{\overline{|\Delta V|}}\left(\frac{\overline{|\dot y|}}{\lambda_y}+\frac{\overline{|\dot z|}}{\lambda_z}\right), \tag{4}$$

$$K(o)=1+\frac{\lambda_x}{2\overline{|V|}}\left(\frac{\overline{|\dot y|}}{\lambda_y}+\frac{\overline{|\dot z|}}{\lambda_z}\right). \tag{5}$$

where

$\lambda_x,\lambda_y,\lambda_z$: the average length, width and height of aircraft.

$\overline{|V|}$: the average along track speed.

$\overline{|\Delta V|}$: the average relative along track speed of aircraft pairs in the same direction traffic.

$\overline{|\dot y|}$: the average relative cross track speed of aircraft pairs.

$\overline{|\dot z|}$: the average relative vertical speed of aircraft pairs.

2.2 Technical Risk for Crossing Routes

In this section, the collision risk of aircraft pair flying on the routes with crossing angle θ is calculated. Crossing routes under consideration include a junction of three or greater number of routes. The technical risk for crossing routes, $N_{az}(cross)$, is calculated using the occupancy, $E_z^{\,cross}(\theta)$, and horizontal overlap probability, $P_h(\theta)$, by means of the method described in Ref.[4]. The risk is given by

$$N_{az}^{\,tech}(cross)=P_z(S_z)\sum_{\theta}\left\{P_h(\theta)E_z^{\,cross}(\theta)\left[\frac{2\overline{|\dot h(\theta)|}}{\pi\lambda_{xy}}+\frac{\overline{|\dot z|}}{2\lambda_z}\right]\right\} \tag{6}$$

where

$P_h(\theta)$: the probability of horizontal overlap for aircraft pairs at adjacent flight levels separated by 1,000 ft on crossing routes with crossing angle θ.

$E_z^{\,cross}(\theta)$: the occupancy on crossing routes with crossing angle θ.

$\overline{|\dot h(\theta)|}$: the average relative horizontal speed during horizontal overlap for aircraft pairs on routes with crossing angle θ.

λ_{xy} : the diameter of the cylinder representing a typical aircraft (the maximum value for λ_x or λ_y).

Total technical risk was calculated by

$$N_{az}^{\,tech}=N_{az}^{\,tech}(o+s)+N_{az}^{\,tech}(cross)\,. \tag{7}$$

2.3 Operational Risk

Operational risk is the risk of collision which is not due to technical reasons. The risk is due to operational errors and in-flight contingencies, such as pilot/controller errors, height deviations due to emergency procedures, and turbulence.

We estimated the risk due to any vertical deviation of an aircraft from the correct flight level as a result of incorrect action by ATC or the aircraft crew.

The risk is given by the following equation.

$$N_{az}^{\,ope}(o+s)=\frac{\sum_{i=1}^{n}P_z(z_i)T(z_i)}{H}P_y(0)N_x^{\,z}(e)K(o) \tag{8}$$

where

$P_z(z_i)$: the vertical overlap probability for a typical aircraft pair assigned to an altitude separated vertically by z_i on the same route.

$T(z_i)$: the time length during which the concerned aircraft fly with vertical deviation z_i from the assigned altitude as a result of incorrect action by ATC or the aircraft crew.

n : the number of large height deviation events.

In Eq.(8), z_i is vertical distance between the altitude of a considering aircraft and nearest flight level.

This equation is obtained by substituting $\frac{\sum_{i=1}^{n} P_z(z_i)T(z_i)}{H}$ for $P_z(1{,}000)$ in equation (1).

For crossing routes, operational risk is given by

$$N_{az}^{\ ope}(cross) = \frac{\sum_{i=1}^{n} P_z(z_i)T(z_i)}{H} \sum_{\theta} \left\{ P_h(\theta) E_z^{\ cross}(\theta) \left[\frac{2\left|\overline{\dot{h}(\theta)}\right|}{\pi\lambda_{xy}} + \frac{\left|\overline{\dot{z}}\right|}{2\lambda_z} \right] \right\} \qquad (9)$$

This equation is obtained by substituting $\frac{\sum_{i=1}^{n} P_z(z_i)T(z_i)}{H}$ for $P_z(1{,}000)$ in equation (6).

Total operational risk is

$$N_{az}^{\ ope} = N_{az}^{\ ope}(o+s) + N_{az}^{\ ope}(cross)\,. \qquad (10)$$

2.4 Lateral Overlap Probability

The lateral deviation of an aircraft position from the centerline of the route is called the cross track deviation. We assume that cross track deviations are statistically independent for each route and the distributions for each route are the same. Let us denote the probability density function of cross track deviation by f(y). Then for the width of aircraft λ_y, the lateral overlap probability of aircraft pair which fly on routes separated laterally by S_y is given by

$$P_y(S_y) = \int_{S_y-\lambda_y}^{S_y+\lambda_y} \int_{-\infty}^{\infty} f(y) f(y+u)\,dy\,du \qquad (11)$$

To evaluate $P_y(S_y)$, estimates of λ_y and f(y) are required. A model of f(y) can be obtained by analysis of the distribution of cross track deviations.

3. Target Aircraft and Data Used

We only consider aircraft pairs which meet the following conditions:

1. Flying within Japanese domestic airspace except for the exclusive RVSM airspace.
2. Flight levels between FL290 and FL410 inclusive.
3. For the same route, the case of the angle which is less than 5 degrees is calculated as the same-direction passing frequency and the case of more than 175 degrees is calculated as the opposite-direction passing frequency. The crossing angles between 5 degrees and 175 degrees inclusive for crossing routes.
4. The altitude difference of the aircraft pair is less than or equal to 2,000 ft (only for crossing routes).

The flight plan data obtained from 1 July, 2004 to 30 June, 2005 are used for estimating passing frequency and occupancy. The information on the time passed over position reporting fix and altitude are used for calculation. The data of secondary surveillance radar obtained by the Hachinohe Air Route Surveillance Radar from 1 August 2001 to 22 July 2002 are used for estimating the distribution of the cross track deviations.

4. Results

The vertical collision risk for the domestic airspace was calculated under the following assumptions.

(a) The passing frequencies estimated in 2,000 ft separation environment are assumed to be retained in the RVSM environment.

(b) The height keeping performance of all aircraft is assumed to satisfy the vertical overlap probability $P_z(1{,}000)$ of $1.7\text{x}10^{-8}$ [1].

4.1 Estimating Equivalent Opposite-Direction Passing Frequency $N_x^{\ z}(e)$

4.1.1 Method of Calculation

The passing frequency of aircraft pairs assigned to flight levels separated vertically by 2,000 ft was estimated for the Japanese domestic airspace under above-mentioned assumptions.

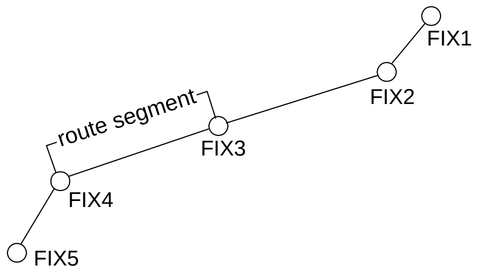

Figure 3. Route segment configuration

The passing frequency was evaluated for all route segments consisting of two fixes shown in Fig.3 assuming that the aircraft fly on the segment with a constant speed estimated from the arrival times of each fix and the segment length. The passing frequency for the airspace including several route segments was calculated by

$$N_x^{\ z}(o/s) = \frac{2\sum_{i=1}^{m} \left[n_p^{\ z}(o/s) \right]_i}{\sum_{i=1}^{m} H_i} \qquad (12)$$

where

$\left[n_p^{\ z}(o/s) \right]_i$: the number of passing events counted within the route segment i.

H_i : the total flight hours for the route segment i within the airspace under consideration. Herein, $H = \sum_{i=1}^{m} H_i$.

m : the number of route segments.

The number of passing events was calculated using the following procedures.

(1) A passing event observed at an end of the route segment was counted as 0.5 events in order to avoid a double counting at

both ends.

(2) When an aircraft changes its flight level within a route segment, we assumed that the aircraft changed the flight level immediately at the entrance fix.

4.1.2 Result of Estimating $N_x{}^z(e)$

The equivalent opposite-direction passing frequency averaged in the whole airspace under consideration was calculated. Table 1 shows estimates of average sizes of aircraft and average relative speeds. Using these estimates, $K(o)$ and $K(s)$ are 1.02 and 1.64, respectively.

Table 1. Estimates of average sizes of aircraft and average relative speeds

Parameter	Estimate	Data source
λ_x	0.0364 NM	Ref.[5]
λ_y	0.0321 NM	Ref.[5]
λ_z	0.0101 NM	Ref.[5]
λ_{xy}	0.0364 NM	Ref.[5]
$\overline{\lvert \Delta V \rvert}$	28.9 knots	Ref.[6]
$\overline{\lvert V \rvert}$	480 knots	Ref.[6]
$\overline{\lvert \dot{y} \rvert}$	11.6 knots	Ref.[6].
$\overline{\lvert \dot{z} \rvert}$	1.5 knots	Ref.[4]

Table 2 shows monthly estimates of the equivalent opposite-direction passing frequency. The largest value of $N_x{}^z(e)$ is 0.89 [aircraft / flight hour] observed in September 2004.

Table 2. Monthly estimates of $N_x{}^z(e)$

Month	$N_x{}^z(e)$ **[aircraft / flight hour]**	H [flight hour]
July 2004	0.79	61,242.3
August 2004	0.86	47,920.3
September 2004	0.89	44.184.3
October 2004	0.85	50,760.4
November 2004	0.85	59,060.9
December 2004	0.75	57,564.2
January 2004	0.77	61,476.2
February 2004	0.80	61,476.2
March 2004	0.56	54,403.1
April 2004	0.51	50.962/5
May 2004	0.55	64,225.7
Jun4 2004	0.63	61,373.8

4.2 Estimating Lateral Overlap Probability $P_y(0)$

The cross track deviations of aircraft which flew on a route segment, namely PEONY-KAEDE, of the route Y11 were evaluated. Fig.4 shows the frequency distribution of cross track deviations.

In the figure, s.d. stands for the standard deviation. Although the figure shows only a core region of the distribution, the minimum value of cross track error is -20.39 NM and the maximum is 20.92 NM. The shifted distribution (whose median was changed into zero by subtracting 0.116 from each datum) is shown in Fig.4.

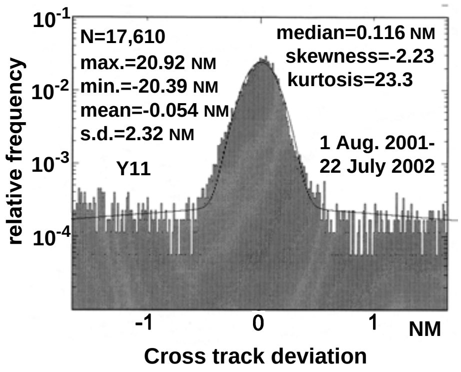

Figure 4. Distribution of cross track deviations (in semi-logarithmic scale)

A result of fitting for the shifted distribution indicates that N-DE distribution, which is a mixed distribution of the Normal (Gaussian) distribution and Double Exponential distribution, is well fitted. The probability density function of the N-DE distribution is represented by the following equation.

$$f(y) = (1-\alpha)\frac{1}{\sqrt{2\pi\sigma^2}}e^{-\frac{y^2}{2\sigma^2}} + \alpha\frac{1}{2\lambda}e^{-\frac{|y|}{\lambda}} \qquad (13)$$

Parameters, α, σ and λ, were estimated by the maximum likelihood method. These are α=0.198, σ=0.132 NM and λ=3.60 NM. Assuming that f(y) is the N-DE distribution with these parameter values, $P_y(0)$ was estimated by Eq.(11) with λ_y=0.0321 NM and S_y=0 NM. This results in $P_y(0)$ =0.091**.**

Table 3. Estimates of collision risk for crossing routes

Range of crossing angle [degrees]	$E_z{}^{cross}(\theta)$	$P_h(\theta)$	$\overline{\lvert \dot{h}(\theta) \rvert}$ [knots]	$N_{az}{}^{tech}(cross)$ [fatal accidents / flight hour]
5-15	7.44×10^{-4}	7.98×10^{-4}	115.6	2.11×10^{-11}
15-25	6.78×10^{-4}	4.74×10^{-4}	184.4	1.80×10^{-11}
25-35	5.48×10^{-4}	3.34×10^{-4}	260.2	1.44×10^{-11}
35-45	3.01×10^{-4}	2.62×10^{-4}	336.8	7.99×10^{-12}
45-55	1.23×10^{-4}	2.20×10^{-4}	412.1	3.35×10^{-12}
55-65	1.19×10^{-4}	1.94×10^{-4}	485.0	3.36×10^{-12}
65-75	8.24×10^{-5}	1.78×10^{-4}	554.5	2.44×10^{-12}
75-85	1.01×10^{-5}	1.69×10^{-4}	620.1	3.17×10^{-13}
85-95	3.35×10^{-5}	1.67×10^{-4}	681.2	1.14×10^{-13}
95-105	2.11×10^{-5}	1.69×10^{-4}	737.2	7.89×10^{-13}
105-115	2.21×10^{-5}	1.78×10^{-4}	787.7	9.28×10^{-13}
115-125	5.10×10^{-5}	1.94×10^{-4}	832.3	2.46×10^{-12}
125-135	4.34×10^{-5}	2.20×10^{-4}	870.7	2.48×10^{-12}
135-145	4.35×10^{-5}	2.62×10^{-4}	902.5	3.08×10^{-12}
145-155	1.28×10^{-4}	3.34×10^{-4}	927.5	1.18×10^{-11}
155-165	1.20×10^{-4}	4.74×10^{-4}	945.5	1.60×10^{-11}
165-175	8.27×10^{-5}	7.98×10^{-4}	956.4	1.88×10^{-11}
Total	3.2×10^{-3}			1.3×10^{-10}

4.3 Estimating Collision Risk for Crossing Routes

The collision risk for crossing routes was estimated by means of the method shown in Ref.[7]. The largest monthly collision risk for crossing routes is 1.3x10^{-10} [fatal accidents / flight hour] observed in October 2004. Table 3 shows the collision risks calculated for every 10-degrees interval based on the data of October 2004.

4.4 Estimating Technical Risk

We assume that all aircraft satisfy RVSM Minimum Aircraft System Performance Specification (MASPS), we use 1.7x10^{-8} as $P_z(1{,}000)$ according to the ICAO RVSM manual [1].

Using $P_y(0)$ =0.091 obtained in section 4.2, $N_x{}^z(e)$ =0.89 [aircraft / flight hour] estimated in section 4.1.2, $K(o)$ =1.02 shown in section 4.12 and $N_{az}{}^{tech}(cross)$ =1.3x10^{-10} shown in section 4.3, a total technical risk was calculated by Eq.(7). This results in

$$N_{az}{}^{tech} = 1.4\text{x}10^{-9} + 1.3\text{x}10^{-10} = 1.5\text{x}10^{-9} \quad \text{[fatal accidents / flight hour].} \qquad (14)$$

This value is smaller than 2.5x10^{-9} [fatal accidents / flight hour], namely the target level of safety (TLS) value for technical risk suggested by the ICAO RVSM manual [1].

4.5 Estimating Operational Risk

To evaluate the value of $T(z)$, Japan Civil Aviation Bureau (JCAB) requires that ATC controllers and pilots submit a large height deviations report when a height deviation at or above 300 ft occurred without intention after July 2004. Scrutinizing the reports, we used five cases shown in Table 4 for estimating operational risk.

Table 4. Cases of large height deviation

No.	Vertical distance [feet]	Time length of height deviation [second]	Situation
1	500	30	Avoidance by Traffic Collision Avoidance System (TCAS)
2	400	50	Avoidance by TCAS
3	4,000	10	Transmission error of flight level
4	4,000	120	Transmission error of flight level
5	400	20	Overshoot

Table 5. Values of $P_z(z)$ and data source

Parameter	Value	Data Source
$P_z(0)$	0.54	RVSM TF/9-IP/2 [8] Value calculated using the distribution of height keeping errors of North Atlantic (NAT)
$P_z(500)$	7.8x10^{-4}	Annex C of Ref.[3] Value calculated using the distribution of relative vertical distance obtained from Navigation Accuracy Measurement System (NAMS) in Japan from 1979 to 1985.
$P_z(600)$	2.7x10^{-4}	

Table 5 indicates values of $P_z(z)$ and data source. $P_z(600)$ is used for deviation of 400 ft because the vertical distance between aircraft is 600 ft in the case. Furthermore, a deviation of 4,000 ft is dealt with the case that vertical distance of aircraft pair is 0 ft.

Using these values and time length of height deviation shown in Table 4, $N_{az}{}^{ope}(o+s)$ was calculated by Eq.(8). In the same way, $N_{az}{}^{ope}(cross)$ was evaluated by Eq.(9). $N_{az}{}^{ope}(o+s)$ and $N_{az}{}^{ope}(cross)$ are 2.4x10^{-9} [fatal accidents / flight hour] and 2.2x10^{-10} [fatal accidents / flight hour], respectively. Total flight hours of one year operation H is 674,263.4 hours. It results in $N_{az}{}^{ope}$ =2.6x10^{-9} [fatal accidents / flight hour] by Eq.(10).

4.6 Estimate of Overall Risk

Let us define the overall risk N_{az} by the sum of two risks, i.e., the technical risk and operational risk. From the results of section 4.4 and 4.5, we obtain

$$N_{az} = 1.5\text{x}10^{-9} + 2.6\text{x}10^{-9} = 4.1\text{x}10^{-9} \quad \text{[fatal accidents / flight hour].} \qquad (15)$$

Target level of safety for the overall risk is 5x10^{-9} [fatal accidents / flight hour]. The estimate of N_{az} meets the TLS.

5. Discussions

5.1 Main Findings

The main findings in this analysis are as follows.

(1) The lateral overlap probability $P_y(0)$ for observed aircraft is 0.091. This is about 1.6 times of the value, $P_y(0)$ =0.058, described in the ICAO RVSM manual.

(2) The risk for crossing routes is about 9 percents of the total technical risk of the whole airspace under consideration.

This analysis is based on the flight plan data. The actual traffic flow in congested route segments may be slightly different from the one based on the flight progress data. In this sense, more detailed analysis based on radar data is desirable for more accurate estimation of passing frequencies.

5.2 Consideration on the Feasibility of Collision Risk Reduction

As seen in Eq.(1), it is possible to reduce the risk by limiting one of the parameters such as the passing frequency, lateral overlap probability $P_y(0)$, or vertical overlap probability $P_z(1{,}000)$.

5.2.1 Passing Frequencies

Passing frequencies increase in general as traffic increases. This may be adjustable by changing route structures such as one-way traffic route or double alternate flight level system. In the one-way traffic route, all passing events are in the same direction. This results in smaller equivalent opposite-direction passing frequency. In the double alternate flight level system, equivalent opposite-direction passing frequency also can be smaller as the passing events in opposite direction can be reduced.

5.2.2 $P_y(0)$

$P_y(0)$ depends on the navigation performance of aircraft. This value becomes larger if the rate of GPS equipped aircraft among the aircraft population increases. As a method of reducing the lateral overlap probability without changing lateral navigational performance of aircraft, lateral offset may be useful for reducing $P_y(0)$. When considering the application of above mentioned method, factors which might give adverse effects on controllers'/pilots' workload, operational errors, ATC procedures and airspace management should be taken into account.

5.2.3 $P_z(1{,}000)$

Since the actual height-keeping performance of the expected fleets for the Japanese domestic RVSM was unavailable, we assumed the value of the specification, $P_z(1{,}000) = 1.7\text{x}10^{-8}$. This value may be updated if an estimate based on empirical data become available in the future. The estimate based on height monitoring data seems to be smaller than the specification value judging from the results obtained in other parts of the world.

6. Conclusions

Prior to the implementation of Japanese domestic RVSM, safety assessment for the airspace in assumed RVSM environments was carried out. The safety of RVSM airspace was assessed by the collision risk due to loss of planned vertical separation.

Passing frequencies (occupancies for crossing routes) were investigated using the flight plan data of one year. The lateral overlap probability was estimated using the empirical distribution of lateral deviations from the route center line obtained by a secondary surveillance radar (SSR). Radar data of one year were used for the estimation. The vertical collision risk for the domestic airspace was calculated under the following assumptions.

(a) The passing frequencies estimated in 2,000 ft separation environment are assumed to be retained in the RVSM environment.

(b) The height keeping performance of all aircraft is assumed to satisfy the vertical overlap probability $P_z(1{,}000)$ of $1.7\text{x}10^{-8}$.

The operational risk is also estimated on the basis of large height deviations reports which are submitted by air traffic controllers and airline pilots.

The results obtained from this analysis are as follows.

(1) An estimate of the average technical risk for the whole airspace under consideration is $1.5\text{x}10^{-9}$ [fatal accidents / flight hour]. The value meets the target level of safety, which is the maximum allowable level of collision risk. The TLS for the technical risk is $2.5\text{x}10^{-9}$ [fatal accidents / flight hour].

(2) Contribution of the vertical collision risk for the crossing routes is about 9 percents of the total technical risk.

(3) An estimate of operational risk is $2.6\text{x}10^{-9}$ [fatal accidents / flight hour].

(4) An estimate of overall risk is $4.1\text{x}10^{-9}$ [fatal accidents / flight hour]. This meets the TLS for overall risk, which is $5\text{x}10^{-9}$ [fatal accidents / flight hour].

Pre-implementation safety assessment indicates that both technical risk and overall risk meet the TLS. Safety assessment in the actual RVSM environment is required for future work.

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