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Analysis on Potential Conflict Frequency of Intersected Air Routes in Terminal Airspace Design

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Abstract: In order to obtain accurate conflict risks in terminal airspace design, the concept and calculation model of potential conflict frequency for intersected routes are proposed. Conflict frequency is represented by the product of horizontal conflict frequency and vertical conflict probability. The horizontal conflict frequency is derived from the probability density distribution of conflicts in a period of time. Based on the recorded radar trajectory data, the concept and model of ROUTE distance are proposed, and the probability density function of aircraft height at a specified ROUTE distance is deduced by kernel density estimation. Furthermore, vertical conflict probability and its horizontal distribution are achieved. Examples of three intersected arrival and departure route design schemes are studied. Compared with scheme 1, the conflict frequency values of the other two improved schemes decrease to 53% and 24%, respectively. The results show that the model can quantify potential conflict frequency of intersected routes.

Key words: air traffic management; terminal airspace design; horizontal conflict frequency; vertical conflict probability; kernel density estimation (KDE)

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1 Introduction

Terminal airspace is the transitional space between aerodromes and en-route networks, so there are inevitably several intersected arrival and departure routes in it, especially in the intersecting areas. In intersected route design with less conflicts, the air traffic controllers' workload of predicting and solving conflicts can be reduced significantly, and the safety and efficiency of air traffic system are also greatly improved[1-2]. Hence, the calculation of conflict number is very important for improving not only the design of intersected routes but also the performance of terminal airspace.

Over the past few years, estimation of conflict number between intersected routes has been widely studied, whereas most researches focused on en-route flight phase. For example, Schmidt applied circular protection zone to deduce the mean and variance of the potential conflict number in an hour[3]; Friedman considered the lasting time of conflicts as a very important factor in risk, and calculated the number of conflicts with different lasting time[4]; Zhao proposed a concept of separation between two intersected routes using rectangular protection model, and estimated the conflict number in a given time[5]; Netjasov designed a geometric model to identify the key route segments for calculating potential conflicts between converging aircraft on the intersected routes, but did not consider the multi-aircraft situation on the same key route segment[6]. Notably, most the above mentioned researchers only focused on the horizontal flight, and neglected the vertical conflicts. Although Geisinger proposed a three-dimensional elliptical conflict area model under the assumption of constant flight

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path angle, the assumption was always not corresponding with the real height distribution in terminal airspace[7].

Since terminal airspace has gradually become the bottleneck of improving safety and efficiency of the whole air traffic system, the calculation of potential conflicts on intersected routes in terminal airspace attracts more and more attentions in this field. In this paper, the concept and content of conflicts in the design of intersected arrival/departure routes are briefly introduced first, and then a probability calculation model of horizontal conflict frequency is established. On the basis of recorded radar trajectory data, the concept of ROUTE distance is proposed, and the probability density function at a specified ROUTE distance is deduced for aircraft height data distribution using kernel density estimation method. Furthermore, a calculation model of vertical conflict probability is given. Finally, the proposed calculation model of conflict frequency is used in the design work of improving arrival and departure routes.

2 Conflict Model for Traffic Flows of Intersected Routes

2.1 Conflicts of intersected routes in terminal airspace

In terminal airspace, arrival flights descend and converge into the runway threshold from different entrances, and departure flights take off from the runway and diverge out. Consequently, it is inevitable that several routes intersect.

According to the definition of International Civil Aviation Organization (ICAO), air traffic conflict means that both the horizontal and vertical distances between two aircraft do not meet the minimum horizontal and vertical separation at the same time[8]. When the traffic flows of the intersected routes increase to a certain level, the aircraft on different routes will compete for the spatio-temporal resources, and when a contradiction happens, an air traffic conflict will appear[9].

2.2 Potential conflict frequency

In the design phase of terminal airspace, it is necessary that designers well learn the overall situation of probable traffic conflicts in a certain route structure within a certain period. Airspace designers always focus on the analysis of interaction between traffic flows rather than an individual conflict event between two aircrafts. For the traffic flows of intersected routes, the number of conflicts is mainly affected by the crossing angle between two routes and the traffic flow rate, which is of some uncertainty. Given a specified route structure with a constant traffic flow rate, if the aircraft are not interfered by air traffic control, the possible number of air traffic conflicts during a certain period can be defined as conflict frequency. Conflict frequency reflects the inherent risk in the route structure, and should be reduced as much as possible by improving the design of arrival and departure routes.

According to the analysis on traffic conflicts in Section 2.1, the horizontal and vertical aspects are the focus of this paper.

In a certain period, the conflict number that the horizontal distance between aircraft is less than the horizontal separation minimum is defined as horizontal conflict frequency, noted as F_{hoz}; the probability that the vertical distance between an aircraft and other aircraft is less than the vertical separation minimum is defined as vertical conflict probability, noted as P_{ver}.

Assuming there are two intersected traffic flows L_1 and L_2, within an enough time ΔT, the total number of aircraft that fly over a certain position on L_1 is F, and the number of aircraft that conflict with aircraft on L_2 is N_c. As described in Section 2.1, there will be inevitably horizontal intersecting and vertical overlapping between arrival/departure routes. The closer the aircraft to the aerodrome, the more obvious their convergence will be. As a result, a lot of events that vertical distances between aircraft are less than the vertical separation minimums occurr in terminal airspace. Probability theory and mathematical statistics principle point out that if the number of trials is large enough, the occurrence probability of one event is approximately equal to the frequency of that event happens[10]. On this basis, the probability that an aircraft conflicts vertically with aircraft in other traffic flows can be called as vertical conflict probability (VCP), which can be expressed as follows

$$P_{\text{ver}} \approx \frac{N_c}{F} \tag{1}$$

Different from level flight, although arrival and departure routes intersect in horizontal profile, they may be separated in vertical profile. Obviously, only the aircraft which conflicts with other aircraft in horizontal profile and overlays in the vertical profile can result in a real conflict. Therefore, the overall conflict frequency F_c of the intersected air traffic flows can be described as

$$F_c = F_{\text{hoz}} \cdot P_{\text{ver}} \tag{2}$$

3 Horizontal Conflict Frequency

3.1 Model of intersected routes

In conflict detection, cylindrical protected zone model is intuitive and easy to operate, so this study adopts this model to judge whether a conflict occurs or not. Here, only conflicts in horizontal profiles are involved.

A typical schematic of intersected routes is given in Fig. 1. There are two intersected routes L_1 and L_2 at same flight level at an angle of α, and all aircraft strictly adhere to the centerline of their air routes without any lateral error. The traffic flows on L_1 and L_2 are respectively noted as F_1 and F_2, and the corresponding traffic flow rates are λ_1 and λ_2. The average velocity of the aircraft in F_1 is $\overline{V}_1$, and that of the aircraft in F_2 is $\overline{V}_2$. F_1 and F_2 firstly encounter at intersection point S, and then spread out.

3.2 Determination of conflict section

Assume an aircraft f_a in F_2 is located at the intersection point S at time t, and that another aircraft f_d in F_1 is on L_1. As shown in Fig. 1, set a circle protection area with the center S and the radius A, and the straight lines L_{21} and L_{22} are the tangent lines to the circle protected area, satisfying $L_{21} // L_2$, $L_{22} // L_2$. S_1 is the crossover point of L_{21} and L_1, and S_2 the crossover point of L_{22} and L_1.

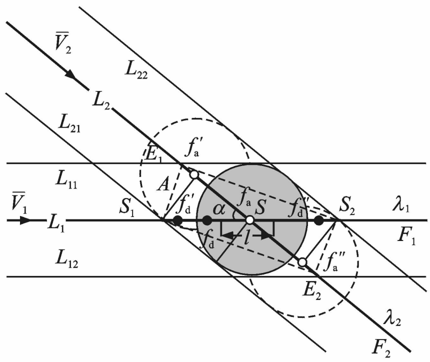


Fig. 1 Conflict segments of intersected routes

At the moment when aircraft f_a is over S, any aircraft of F_1 on segment S_1S_2 is likely to conflict with f_a in the past (f_d'), future (f_d'') or present. Obviously, the length of the segment on L_1 where conflicts probably happen, noted as D_1, can be expressed as follows[6]

$$D_1 = |S_1S_2| = |S_1S| + |SS_2| = \frac{A}{\sin\alpha} + \frac{A}{\sin\alpha} = \frac{2A}{\sin\alpha} \tag{3}$$

If the horizontal separation minimum in F_1 is also A, we can get $|E_1E_2| = D_1$. Thus, the area surrounded by $S_1E_1S_2E_2$ is the potential conflict area of intersection S, which can be called as conflict zone for short.

3.3 Probability distribution of horizontal conflict number

According to the research of Muller[11], let n be the number of arrival aircraft on an air route, and n obeys Poisson distribution during a given time. Assume the arrival rate is λ, and that the number of arrival aircraft at time t is a discrete random variable, and thus the mean value of arrival aircraft is λt. Then, the probability of n aircraft on route L that arrive at point S within time t can be deduced as[12]

$$P_L(n) = \frac{(\lambda t)^n \mathrm{e}^{-\lambda t}}{n!} \tag{4}$$

From the assumption in intersected route model in Section 3.1, the traffic flow rate on L_1 is λ_1. For a stationary Poisson process, assume the probability that k aircraft arrive within time $t' = \frac{D_1}{\overline{V}_1}$ is $P_{D_1}(k)$ as

$$P_{D_1}(k)=\frac{(\lambda_1 t')^k \mathrm{e}^{-\lambda_1 t'}}{k!}=\frac{\left(\lambda_1 \dfrac{D_1}{\overline{V}_1}\right)^k \mathrm{e}^{\left(-\lambda_1 \frac{D_1}{\overline{V}_1}\right)}}{k!} \quad (5)$$

Thus, the probability that there are k aircraft in an arbitrary range of D_1 in a certain time t is $P_{D_1}(k)$. The longitudinal radar separation provided by traffic control is usually more than 10 km, and the number of aircraft on any segment with the length of $l=10$ km will be no more than one. Therefore, the situations that there are more than two aircraft on l segment should be excluded. Assuming $P_l(k\geqslant 2)$ is the probability that there are more than two aircraft on l segment, then the probability that there are no more than one aircraft on an arbitrary 10 km segment can be expressed as

$$P_{D_1}(k>0)=P_{D_1}(k=1)+\sum_{m=2}^{M}(P_{D_1}(k=m)-P_l(k\geqslant 2)) \quad (6)$$

where $M=|D_1/10|$ denotes the maximum possible number of aircraft in the range of D_1, which ensures that $P_{D_1}(k=m)\geqslant P_l(k\geqslant 2)$.

The arrival of aircraft on L_1 or L_2 is a discrete random event. When one aircraft is arriving at intersection S, if there are m aircraft on L_2, there will be m conflicts happening at the same time, so the probability that an aircraft on L_2 at S exactly conflicts with the aircraft on L_1 can be expressed as

$$P_{\mathrm{hoz}}(n=1)=P_{D_1}(k=1)+\sum_{m=2}^{M}m\cdot(P_{D_1}(k=m)-P_l(k\geqslant 2)) \quad (7)$$

During a period of time t, there will be n aircraft on L_2 which arrive at intersection S, and the number of horizontal conflicts with aircraft on segment D_1, noted as $F_{\mathrm{hoz}}(n)$, can be calculated as

$$F_{\mathrm{hoz}}(n)=n\cdot P_{D_1}(k>0) \quad (8)$$

Based on Eqs. (4, 8), the relationship of conflict number and its probability can be obtained as shown in Fig. 2, which reveals the probability distribution of conflict number under the condition of $t=1$ h. According to the definition of mathematical expectation of discrete random variables, the conflict frequency $\overline{F}_{\mathrm{hoz}}$ in an hour at the intersection S can be obtained as follows

$$\overline{F}_{\mathrm{hoz}}=\sum_{n=1}^{\infty}F_{\mathrm{hoz}}(n)\cdot P_{L_2}(n) \quad (9)$$

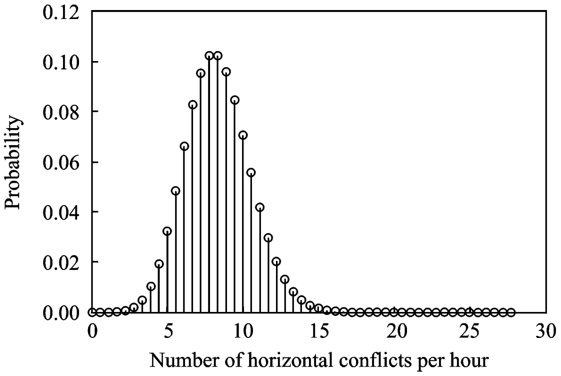


Fig. 2 Probability density distribution of conflicts

4 Probability of Vertical Conflict

4.1 ROUTE distance and distribution of aircraft height

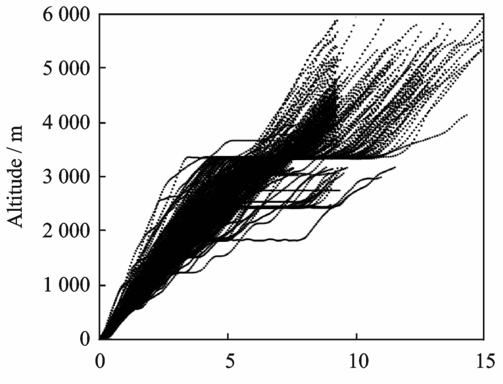
Departure aircraft always climb to the cruising level as soon as possible with a gradient of 3% to 10%, while arrival aircraft always descend with a flight path angle between the optimum descent gradient and maximum descent gradient[13]. The performance of climb and descent in vertical profile is a very important constraint to aircraft operation in terminal airspace. However, because of some random effects, e. g. weather, there is inevitably some uncertainty for the weight and the height of an aircraft, as well as flying and air traffic control. Thereinto, height distribution with different distances from the aerodrome is an essential pre-condition for analyzing vertical conflict probability. Hence, it is necessary to do some researches on the regular pattern of height distribution for different positions.

Assume trajectory data generated by all aircraft in a certain period is $T=\{t_1, t_2, \cdots, t_i, \cdots, t_n\}$, where $t_i=\{p_{(i,1)}, p_{(i,2)}, \cdots, p_{(i,j)}, p_{(i,n_i)}\}$ is the trajectory data of a departure or arrival aircraft. $p_{(i,j)}$ indicates the jth track in the ith trajectory, and the track is ranked according to time. $p_{(i,j)}=\{x_{(i,j)}, y_{(i,j)}, z_{(i,j)}\}$, where $x_{(i,j)}$, $y_{(i,j)}$ and $z_{(i,j)}$ denote the latitude, the longitude and the altitude of $p_{(i,j)}$, respectively.

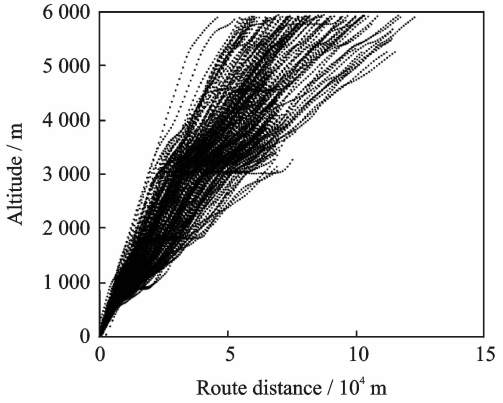
Track data can describe the moving trajectory of aircraft in 3D airspace. According to the requirement of studying vertical conflicts, a method called dimension reduction of trajectory data is used to reveal the relationship between aircraft height and distance from aerodrome. In this method, ROUTE distance of a track is defined as a horizontal distance, i. e. ROUTE distance of track $p_{(i,j)}$ is expressed as the horizontal distance of the track away from a certain position of the aerodrome. For a departure aircraft, ROUTE distance is the horizontal distance that the aircraft has flown over from taking off and noted as $R_{\mathrm{dep}(i,j)}$; for an arrival aircraft, ROUTE distance is the horizontal distance that the aircraft need to get to the touchdown point and is noted as $R_{\mathrm{arr}(i,j)}$. Thus, the ROUTE distance of track $p_{(i,j)}$ can be expressed as follows

$$\begin{cases} R_{\mathrm{dep}\,(i,j)} = \sum\limits_{j=1}^{n} \sqrt{(x_{(i,j)} - x_{(i,j-1)})^2 + (y_{(i,j)} - y_{(i,j-1)})^2)} \\ R_{\mathrm{arr}\,(i,j)} = \sum\limits_{j=n}^{1} \sqrt{(x_{(i,j)} - x_{(i,j-1)})^2 + (y_{(i,j)} - y_{(i,j-1)})^2)} \end{cases} \tag{10}$$

According to the radar data from 1 092 arrival and departure flights in a certain day in K airport, the ROUTE distance and their height distribution can be obtained as shown in Figs. 3(a,b).



(a) Arrival flights



(b) Departure flights

Fig. 3 Relationship between height and ROUTE distance

4.2 RH model based on kernel density estimation

As shown in Fig. 3, at a specified ROUTE distance (such as $R_{\mathrm{arr}}=50$ km), height of aircraft presents a certain type of random distribution. Assume the height random variable of n arrival aircraft at a given ROUTE distance as U, $U_{R=r}=\{u_1, u_2, \cdots, u_n\}$; and that of m departure aircraft as H, $H_{R=r}=\{h_1, h_2, \cdots, h_n\}$. Since the probability density function of discrete random variables U and H is unknown, Kolmogorov-Smirnov method[14] is used to test the distribution of U and H, and the results indicate that U and H do not obey normal, negative exponential, Poisson distribution or else.

Kernel density estimation (KDE) is a non-parametric test method, which is always used to estimate unknown density function of any distribution. Therefore, KDE method can be used to estimate the distribution function of U and H in the questions above.

Assume $z_1, z_2, \cdots, z_j, \cdots, z_n \in Z$, Z is the discrete height sample recorded by the radar whose probability density is unknown. Then, the KDE function can be expressed as follows[15]

$$f_{R=r}(z,w) = \frac{1}{nw^*}\sum_{j=1}^{n} K\left(\frac{z-z_j}{w^*}\right) \tag{11}$$

where $K(\cdot)$ represents a kernel function, w^* the optimized bandwidth, and r a specified ROUTE distance. Here, Gauss kernel function as follows is adopted for its good smoothing performance

$$K(t) = \frac{1}{\sqrt{2\pi}} \mathrm{e}^{-\frac{t^2}{2}} \tag{12}$$

To optimize the bandwidth of a Gauss Kernel function, Silverman gave a formula by simulation method[16] noted as $w^* = 1.05\sigma n^{-\frac{1}{5}}$, where σ is the sample standard deviation. Substitute $K(t)$ and w^* into Eq. (11), and the Gauss KDE function of the height distribution for arrival aircraft can be rewritten as

$$f_{R=r_1}(u,w_1)=\frac{1}{\sqrt{2\pi}\,nw_1}\sum_{j=1}^{n}\mathrm{e}^{-\frac{(u-u_j)^2}{2w_1^2}} \tag{13}$$

Similarly, the Gauss KDE function of the height distribution for departure aircraft is

$$g_{R=r_2}(h,w_2)=\frac{1}{\sqrt{2\pi}\,mw_2}\sum_{j=1}^{m}\mathrm{e}^{-\frac{(h-h_j)^2}{2w_2^2}} \tag{14}$$

Thus, we can obtain the probability density function of height distribution for arrival and departure aircraft. As Fig. 4 shows, the thick curve line represents the probability density function of height distribution for arrival aircraft at $R_{\text{arr}}=50$ km, while the thin curve line represents that for departure aircraft at $R_{\text{arr}}=25$ km.

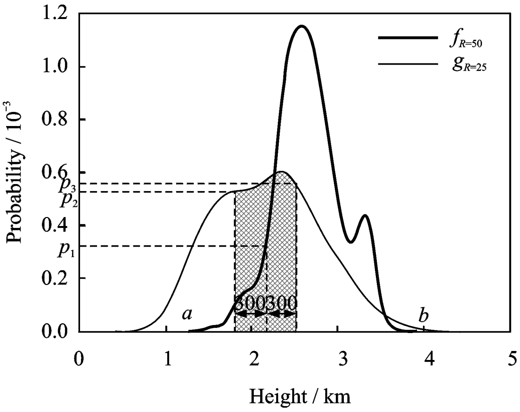


Fig. 4 KDE function of aircraft height and calculation of vertical conflict probability

4.3 Calculation of vertical conflict probability and its spatial distribution

Assume there are two crossed air routes as shown in Fig. 1, and that there is an intersection point S on segment S_1S_2 which is located at $R_{\text{arr}}=r_1$ on an arrival route as well as $R_{\text{dep}}=r_2$ on a departure route (r_1 and r_2 are specified ROUTE distance values). Generally, vertical separation minimum in air traffic control is 300 m. Hence, when the height difference of two aircraft is less than 300 m, vertical conflict occurs.

At the intersection S, height random variable of arrival aircraft f_a is denoted as u, and departure aircraft with height difference relative to u less than 300 m will conflict with f_a. Assume the probability of u is p_1, and the probabilities that departure aircraft have the height of $u-300$ and $u+300$ are p_2 and p_3, respectively. Accordingly, their accumulative probability distributions are $F(u-300)$ and $F(u+300)$. Thus, the probability of arrival aircraft f_a conflicting with all departure aircraft can be expressed as

$$p(u)=p_1\cdot\int_{u-300}^{u+300}g_{R=r_2}(h,w_2)\mathrm{d}h= p_1(F(u+300)-F(u-300)) \tag{15}$$

Furthermore, the probability of the vertical conflict between arrival traffic flow and departure traffic flow can be expressed as

$$P_{\text{ver}}(r_1,r_2)=\int_a^b f_{R=r_1}(u,w_1)\mathrm{d}u\int_{u-300}^{u+300}g_{R=r_2}(h,w_2)\mathrm{d}h \tag{16}$$

where $u\in[a,b]$.

From Eq. (16), it can be known that vertical conflict probability near intersection point is a function of ROUTE distance of the relevant crossed routes. The vertical conflict probabilities and their distribution at different positions constituted by different R_{dep} and R_{arr} combinations are shown in Fig. 5. For example, for intersection S, $R_{\text{dep}}=50$ km and $R_{\text{arr}}=65$ km, then the probability of vertical conflict $P_{\text{ver}}(R_{\text{arr}}=65,\ R_{\text{dep}}=50)$ equals 0.263 5.

From Fig. 5, it is found that vertical conflict probability is large when R_{dep} and R_{arr} is approximately equal, while that it will be relatively smaller when R_{dep} and R_{arr} differ greatly. This indicates that in intersected route design, vertical conflict risk can be reduced by changing departure ROUTE distance or arrival ROUTE distance at

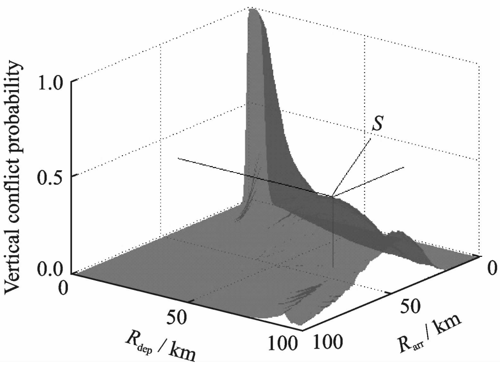


Fig. 5 Distribution of vertical conflict probability

intersection S.

Specifically, in intersected route design, if VCP at intersection S is too large, it can be reduced by changing the ROUTE distance in two aspects: (1) The location of the intersection S; (2) A trial of diversification of arrival or departure route if VCP cannot be reduced by changing the geographical location of S for navigation consideration, or it cannot be reduced evidently by only moving the location of S.

It is worth pointing out that VCP can also be used in the situation between any two points in airspace. Assume that there are two points O_1 and O_2 in a horizontal conflict zone, and O_1 is a point on arrival route with ROUTE distance R_{arr}, and O_2 is another point on departure route with ROUTE distance R_{dep}. Then, the probability of one aircraft at O_1 conflicting vertically with another aircraft at O_2 can be described as $P_{\text{ver}}(R_{\text{arr}}, R_{\text{dep}})$.

4.4 Calculation of vertical conflict probability in conflict zone

When calculating the VCP near intersection S, not only the vertical conflicts at S, but also the vertical conflicts near S should be considered. Usually, if one aircraft is flying out of the conflict zone of intersection S, horizontal conflicts are impossible to occur, so only the situation that aircraft are operating in conflict zone should be considered when calculating VCP. Moreover, if there are two aircraft operating along S_1S_2 and E_1E_2 respectively, the probability that the horizontal distance is more than the separation minimum also exists, and thus the VCP of these locations should not be considered either.

As shown in Fig. 6, in the conflict zone, two aircraft on different routes may maintain a status of continuous conflict, or the conflict may only occur in some period of the whole flight. Once a conflict occurs, safety risk is generated subsequently. Assuming there are several spatial discrete locations in the horizontal conflict zone, and that the maximum value of their VCP means the real extent of the possible vertical conflict in the overall conflict zone, then the maximum VCP can be used to represent the overall VCP in the whole conflict zone.

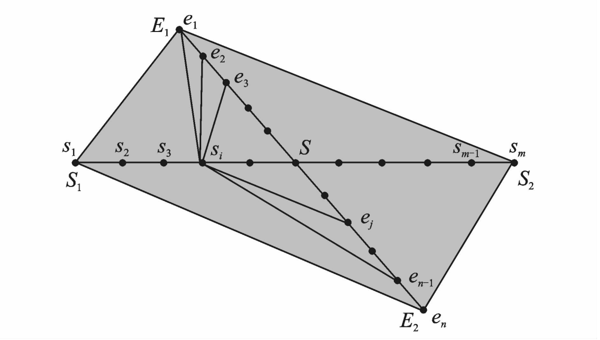


Fig. 6 Discretion of conflict area

In Fig. 6, S_1S_2 and E_1E_2 are divided into discrete segments according to a certain distance ΔL_i. The discrete points on S_1S_2 are s_1, s_2, …, s_m, and the discrete points on E_1E_2 are e_1, e_2, …, e_n. Assume there are two discrete points s_i and e_j, and that their ROUTE distance are expressed as $r_{\text{arr}}(i)$ and $r_{\text{dep}}(j)$ respectively. Then, the probability of arrival aircraft f_{a} at e_j conflicting vertically with departure aircraft f_{d} at s_i can be described as $P_{\text{ver}}(r_{\text{arr}}(i), r_{\text{dep}}(j))$. Calculating the VCP of all point pairs consisting of discrete points on S_1S_2 and E_1E_2 one by one, we can find the maximum value to express $P_{\text{ver}}(\text{S})$ of conflict zone generated at intersection S, as described below

$$\begin{cases} P_{\text{ver}}(S) = \max\limits_{i=1}^{n}\{\max\limits_{j=1}^{m}[P_{\text{ver}}(r_{\text{arr}}(i), r_{\text{dep}}(j))]\} \\ m = \left|\dfrac{D_1}{\Delta L_1}\right| \\ n = \left|\dfrac{D_1}{\Delta L_2}\right| \end{cases} \tag{17}$$

5 Example Analysis

Aerodrome K is an international civil aviation airport in China. For runway-in-use 27, with the runway center as the origin of coordinates, there are a standard arrival route A01 and a standard departure route D01 which intersect at location S (10 km, 15 km), as shown in Fig. 7(a). The aircraft arrival rate on A01 is described as λ_1, and $\lambda_1 = 12$ fight/h with the average velocity of $\bar{V}_1 =$

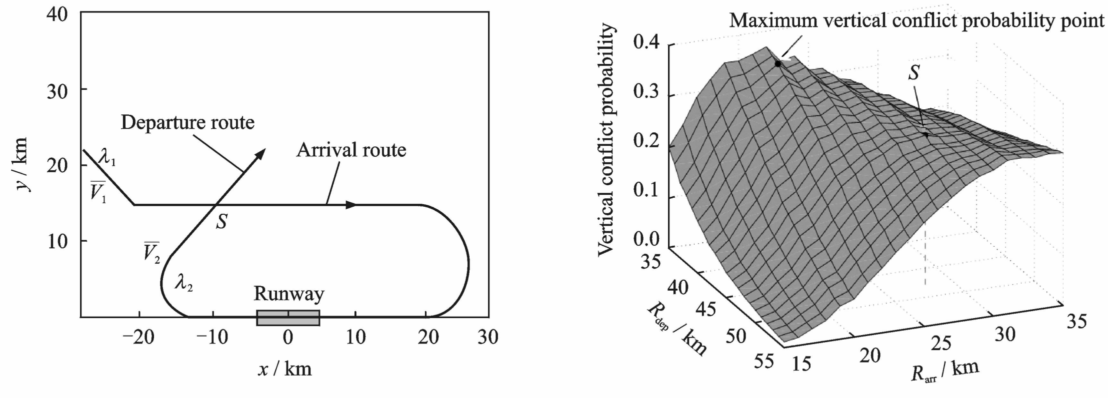
300 km/h. The aircraft departure rate on D01 is described as λ_2, and $\lambda_2 = 15$ fight/h with the average velocity of $\bar{V}_2 = 330$ km/h. The height distribution data of aircraft operating on aerodrome K is shown in Figs. 3 (a, b). According to the scheme in Fig. 7(a), on intersection S, $R_{\text{arr}} = 45$ km and $R_{\text{dep}} = 25$ km.

(1) Table 1 gives the horizontal conflict frequency and vertical conflict probability of design scheme 1. Set the discrete interval as $\Delta L = 1$ km, and then according to Eq. (16), the VCP distribution of the conflict zone can be illustrated as Fig. 7 (b). The conflict probability of intersection S is 0.354 8 by Eq. (17). The position of maximum vertical conflict probability is not at intersection S, but at the location of $R_{\text{dep}} = 22$ km and $R_{\text{arr}} = 37$ km. According to Eq. (2), the conflict frequency of S is 3.78 time/h.

(2) According to the methods of improving design of intersected routes in Section 4.3, design schemes 2 and 3 are proposed, as shown in Table 1 and Fig. 8(a). In scheme 2, R_{arr} is increased while R_{dep} is reduced, so that the departure route will pass through the arrival route beneath the intersection point. Since the inherent climb rate is usually larger than the descent rate of arrival aircraft, serious vertical overlapping still exists with the VCP of 0.292 1, and the improved outcome is

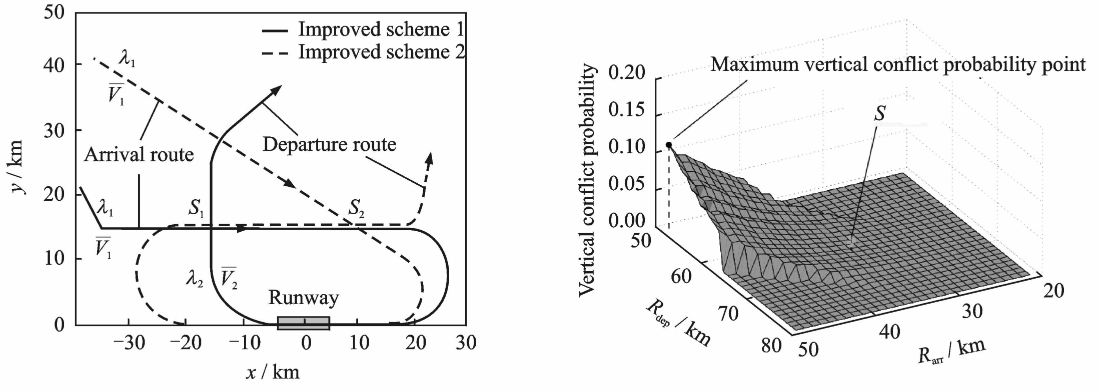
Table 1 Conflicts between different design schemes of intersected routes

Design scheme	Horizontal conflict parameter			Intersection point					Maximum vertical conflict probability			F_c
				Position/km				P_{ver}	Position/km		P_{ver}	
	D_1/km	α/(°)	$\bar{F}_{\text{hoz}}$	x	y	R_{arr}	R_{dep}		R_{arr}	R_{dep}		
1	23.09	45	10.56	−10	15	45	25	0.288 1	37	22	0.354 8	3.78
2	20.00	90	6.81	−15	15	65	20	0.030 6	48	27	0.292 1	1.99
3	28.28	60	8.31	10	15	35	65	0.003 5	49	51	0.112 8	0.94



(a) Horizontal view (b) Conflict area and calculation of VCP

Fig. 7 Original design of arrival and departure routes and its VCP distribution



(a) Horizontal view (b) Conflict area and its VCP distribution for schemes 2 and 3

Fig. 8 Improved design schemes

not obvious. In scheme 3, R_{arr} is shortened while R_{dep} is lengthened, and the departure route will go through the intersection S above arrival route. As a result, VCP is reduced to 0.112 8, and the improvement is distinct relatively. As shown in Fig. 8(b), the area with higher VCP just takes a small part of the whole conflict zone, whereas most of the conflict probabilities are lower than 0.05.

6 Conclusions

The overall conflict level of intersected routes is a very important factor that affects the safety and efficiency of air traffic operation in terminal airspace. Based on the consideration of horizontal conflict frequency of intersected routes, a vertical conflict probability model is studied, and a calculation method of vertical conflict probability based on KDE is proposed for the reason that aircraft height distribution does not obey the usual probability density distribution with a given ROUTE distance. According to our method, the estimation of conflict frequency between the intersected air routes is closer to that of the real air traffic operation.

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