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Study on the safety risk and capacity of the one-way circulation air route in China[1]

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1. Research objective

There are many problems in the current route network in China, First, the air route network of the East is intensive, the west is sparse, which is unbalanced regional development. Air transportation shows an situation of west easy and east busy, even in the west, it is a problem that local pressure is too big. China civil aviation traffic flow heat map as shown in Figure 1.3,in which the Figure 1-1 (a) shows the overall flow distribution of the whole country, Figure 1-1 (b) shows China's western air traffic flow distribution. The distribution of airspace resources in China is consistent with the situation of population distribution and economic development.Eastern route network intensive, and western overall route sparse. However, the airspace resources of regional nodes, such as Xi'an, Lanzhou, Urumqi and other places are also very tight.This forms the eastern 20% of the land area concentrated 80% of the transport volume, the western 80% of the land area concentrated only 20% of the transport volume, and the transport volume in Tibet area is less than 1%. Obviously, regional development is highly uneven.

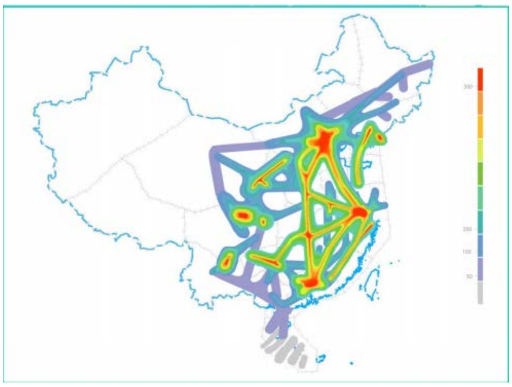

Figure 1-1 (a)

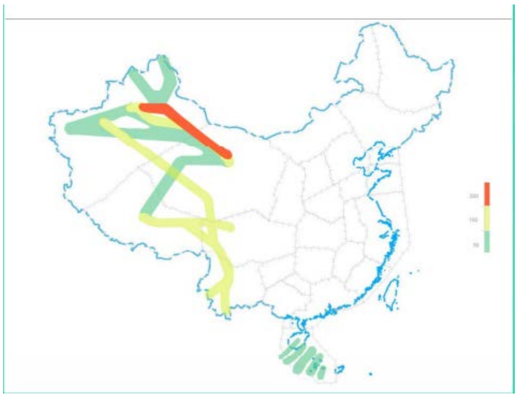

Figure1-2(b)

secondly, the number of air routes increased slowly, far from meeting the demand of transportation. Limited available airspace of civil aviation and rapidly growing air traffic volumes have becoming an increasingly prominent. With the rapid development of national economy, China's civil aviation transport has been growing at a rate of nearly 20% for many years, however,China's limited airspace resources, as well as the use of space resources without a more scientific optimization and sharing model has hindered the rapid development of air transport.At present, there are 199 restricted zones , 66 danger zones and 1 forbidden zone in China's airspace. The design of civil aviation route must avoid these restricted zones,danger zones and forbidden zone, and civil aviation airspace to strip mainly, its airspace is not enough to use, the traffic congestion is increasingly serious, and the safety pressure is increasing day by day.

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Thirdly, air route design have many unreasonable problems, for example, many air routes converge a point, there are many dead end air routes , the straightness of air route is not good, trunk line and the required branch line had an uneven distribution, Traffic demand is concentrating on backbone route, some of the backbone routes run almost around the clock overload; relatively, some of the branch routes are light, and the flow is small. Even in the high density region of the eastern route network, the utilization rate of branch routes that almost parallel to the busy backbone is also very low.

The distribution of points, lines and planes is uneven. Traffic flow is excessive in some of main waypoints, roads and aviation sectors, which become the main congested node and the main bottleneck of capacity. The overall efficiency of route network should be improved.

Re-air route network planning should be based on national conditions, step by step implementation, and gradually solve the problem. Currently, we should make efforts to resolve the heading flight conflict, relieve congestion and flight conflict, enhance the flight safety and punctuality rate. The One-way circulation route network provides a feasible idea for solving the problem of air network.

One-way circulation route network is defined by the beginning and end of a one-way cycle route, which constitutes the backbone air route network. The main idea is to open up the broken air road, enable the temporary route , idle route around the busy route, forming a closed loop cycle route network of one-way. Thereby, The air traffic operation distribution would be redistributed, the busy route controller’s workload would be reduced, airspace utilization would be improved. In this study, a one-way circulation routes collision risk model and capacity assessment model would be developed to calculate one-way circulation route operation safe interval and capacity to provide science guidance for the application of one-way circulation route

2. Research content

2.1 One-way circulation route collision risk assessment model

In this paper, the improved REICH model was used to calculate collision of one-way circulation route. this model substitutes the cylinder collision template for the traditional rectangular collision template. When the airplane deviates from the route, the two planes distance and collided criterion are not affected, the computed results are more accurate and reasonable. The improved REICH model can be used to calculate parallel routes collision risk under VOR navigation condition and a one-way circulation route calculation interval.

The plane A as a center, 2D as diameter, $2\lambda_z$ as height, a cylinder area can be virtualized. When the edges of two aircraft cylinder are tangent, the aircraft body contact will take place, equivalently, the collision appear. Collision rate CR, i.e., the number of collisions per unit time, in other words, the number of particle B entering aircraft A template in unit time.

Gives the following definition:

N_x : the frequency that Longitudinal distance of two aircraft is less than D, that is to say, the frequency that two aircraft longitudinal overlap occur

P_x :the probability that Longitudinal distance of two aircraft is less than D, that is to say, the probability that two aircraft longitudinal overlap occur

t_x :the average time that aircraft A cross the template of aircraft B longitudinally.

V_x : the relative velocity of A, B aircraft longitudinally

Because there is no flight conflict outside the adjacent layer, in the paper, the conflict aircraft appear in the adjacent layer. The value is equal to the ratio between the number of B in the adjacent layer and A longitudinal distance is less than D and the time needed for B longitudinal cross adjacent layer, as well as the ratio between the time that aircraft B pass through the template of aircraft A and the time that aircraft B pass through the adjacent layer longitudinally.

The necessary and sufficient condition of aircraft conflict is two aircraft conflict in the longitudinal, lateral and vertical directions at the same time. Therefore, the longitudinal collision probability is $N_x \times 1 \times p_y \times p_z$, similarly, the lateral and vertical collision probability would be acquired. The total collision probability is equal to the sum of three directions collision probability.

$$
\begin{aligned}
CR &= N_x p_z p_y + N_y p_x p_z + N_z p_y p_x \\
&= p_x p_y p_z \left(\frac{1}{t_x} + \frac{1}{t_y}\right) + N_z p_y p_x
\end{aligned} \quad (1)
$$

(1) Lateral collision risk model

The role of lateral spacing is to allow the aircraft to maintain a certain distance between the side at any time, so as to prevent aircraft collision.

Factors which affect the lateral position of the aircraft during flight mainly include that meteorological condition, the deviation of airborne navigation equipment and the error caused by piolt who can not fly along a predetermined route in accordance with the instructions of the navigation device. The lateral yaw of the aircraft should be mainly considered in the one-way route.

In the r direction, overlap frequency N_r is defined as the number of overlapping times in unit approach time:

$$N_r = \frac{C_{L_r < \lambda_r}}{T} \quad (2)$$

In which, $C_{L_r < \lambda_r}$ represents the times of the distance L_r between two aircraft in r direction less than λ_r in approach time.

In the r direction, overlapping probability P_r is defined as the probability that the r direction distance L_r between two aircraft is less than λ_r:

$$P_r = \frac{T_{L_r < \lambda_r}}{T} \quad (3)$$

In which, $T_{L<\lambda}$ represents the time of the distance L_r between two aircraft in r direction less than λ_r in approach time.

The number of dangerous collision in unit approach time is:

$$CR = N_X P_Y P_Z + N_Y P_X P_Z + N_Z P_X P_Y \quad (5)$$

The relative velocity of the two aircraft in r direction is assumed to $\left|\overline{r}\right|$, so the time to pass through the collision template is $\frac{2\lambda_r}{\left|\overline{r}\right|}$. So, the CR is $P_x P_y P_z\left[\frac{\left|\overline{x}\right|}{2\lambda_x}+\frac{\left|\overline{y}\right|}{2\lambda_y}+\frac{\left|\overline{z}\right|}{2\lambda_z}\right]$, by $P_x = \frac{\lambda_x}{S_x}$ and $E = 2T / H$, we can obtain the result as follow:

$$N_{ay} = 10^7 P_y(S_y)P_z(0)\frac{\lambda_x}{\tilde{S}_x}\left[E_y(same)\left\{\frac{\left|\overline{\Delta V}\right|}{2\lambda_x}+\frac{\left|\overline{y}\right|}{2\lambda_y}+\frac{\left|\overline{z}\right|}{2\lambda_y}\right\}+E_y(opp)\left\{2\frac{\left|\overline{V}\right|}{2\lambda_x}+\frac{\left|\overline{y}\right|}{2\lambda_y}+\frac{\left|\overline{z}\right|}{2\lambda_y}\right\}\right] \quad (5)$$

(2) vertical collision risk model

The role of the standard minimum value of the vertical interval is to allow the aircraft to maintain a certain distance in the vertical direction at any time in order to prevent aircraft collision. Factors which affect the vertical position of the aircraft during flight mainly include that meteorological condition, the deviation of airborne altimetry equipment and manipulation error. One-way route to calculate the probability of vertical overlap mainly from the measurement error of airborne equipment that can affect aircraft altitude position error.

1) mixed route

$$N_{az} = 10^7 P_Z(S_Z)P_y(0)\frac{\lambda_x}{\tilde{S}_X}\left[E_Z(same)\left\{\frac{\left|\overline{\Delta V}\right|}{2\lambda_X}+\frac{\left|\overline{y}\right|}{2\lambda_y}+\frac{\left|\overline{z}\right|}{2\lambda_z}\right\}+E_z(opp)\left\{\frac{2\left|\overline{V}\right|}{2\lambda_X}+\frac{\left|\overline{y}\right|}{2\lambda_y}+\frac{\left|\overline{z}\right|}{2\lambda_z}\right\}\right] \quad (6)$$

Vertical overlap probability

$$f^{z_{12}}(z) = \int_{-\infty}^{\infty} f_1^{TVE}(z_1)f_2^{TVE}(S_z + z_1 - z)dz_1 \quad (7)$$

2) one-way route

$$N_{az} = 10^7 P_Z(2S_Z)P_y(0)\frac{\lambda_x}{\tilde{S}_X}\left[E_Z(same)\left\{\frac{\left|\overline{\Delta V}\right|}{2\lambda_X}+\frac{\left|\overline{y}\right|}{2\lambda_y}+\frac{\left|\overline{z}\right|}{2\lambda_z}\right\}+E_z(opp)\left\{\frac{2\left|\overline{V}\right|}{2\lambda_X}+\frac{\left|\overline{y}\right|}{2\lambda_y}+\frac{\left|\overline{z}\right|}{2\lambda_z}\right\}\right] \quad (8)$$

Since the standard vertical interval of one-way route is 600m , which is twice as much as mixed route. In the near layer of the Reich model,the minimum vertical interval S_z of one-way route should be twice as much as mixed route. In addition,the other model data about vertical collision risk of the two operation modes are the same.

(3) Longitudinal collision risk model

In one-way route, longitudinal distance between aircraft refers to the distance between the center of the two aircraft along the direction of the route. Factors that affect the longitudinal position of the aircraft during flight mainly include that navigation device measurement error and aircraft flying speed error, namely from the static angle and dynamic angle to study the position of aircraft in the air.The research on the longitudinal collision risk in one-way route starts with the flight speed.

1) mixed route

$$N_{ax} = 10^7 P_x(S_x) P_y(0) P_z(0) \frac{\lambda_x}{\tilde{S}_X} \left[E_x(same) \left\{ \frac{|\overline{\Delta V}|}{2\lambda_X} + \frac{|\overline{y}|}{2\lambda_y} + \frac{|\overline{z}|}{2\lambda_z} \right\} + E_x(opp) \left\{ \frac{2|\overline{V}|}{2\lambda_X} + \frac{|\overline{y}|}{2\lambda_y} + \frac{|\overline{z}|}{2\lambda_z} \right\} \right] \tag{9}$$

2) one-way route

$$N_{ax} = 10^7 P_x(S_x / k) P_y(0) P_z(0) \frac{\lambda_x}{\tilde{S}_X} \left[\left\{ \frac{|\overline{\Delta V}|}{2\lambda_X} + \frac{|\overline{y}|}{2\lambda_y} + \frac{|\overline{z}|}{2\lambda_z} \right\} \right] \tag{10}$$

Solving the one-way route longitudinal collision risk, the situation of across the head does not exist, so we can ignore the reverse operation , only need to consider the relative speed of the two aircraft in the same direction, at the same time, the longitudinal distance of the adjacent layer is set to $\frac{1}{k}$ (K can be set according to the speed of the aircraft) times of the mixed route, which is $\frac{S_x}{k}$. In addition,the other model data about longitudinal collision risk of the two operation modes are the same.

2.2 One-way route operation capacity model under the influence of intersection point and terminal area.

For comparison one-way route and two-way route operation capacity, the model is based on the current actual control interval of ATC(air traffic control), the actual use air route level and the complexity of the airspace structure. Assume that meteorological conditions meet normal operating conditions, support system of ATC operate normally, the controller workload is in the acceptable range by dividing the sector rationally and providing the enough seats.

For a route, if it is no considered that the intersection point impact, the workload limit of weathermen, navigator and controllers, just consider the safety interval and level. Assume that the average flight speed of aircraft is V

From the definition of the concept of route capacity, we can obtain that as follow: $C = \frac{N}{T}$ (11)

N is equal to the ratio between the route length L and the control interval: $N = \frac{L}{X}$ (12)

The time considered for a period of route can be expressed as: $T = \frac{L}{V}$ (13)

So we can get the route running capacity model of the first i height layer: $C_i = \frac{N}{T} = \frac{\frac{L}{X}}{\frac{L}{V}} = \frac{V}{X}$ (14)

When there are multiple height layers, assuming that there are n available height layers, and the average speed of each height layer is the same. So we can conclude capacity formula

$$C = n \cdot C_i = n.\frac{V}{X} \quad (15)$$

Parameters:

V represents aircraft average speed in applicable route; X represents minimum safety interval that is controlled by controller; C represents route capacity; N represents aircraft sorties during the period of route service; n represents the number of available height layers.

C_i represents route capacity of single height layer.

In order to meet the reality operation, make the model practical significance, the intersection point and terminal area should be considered the impact on the system capacity. This paper proposes firstly, the intersection capacity reduction factor γ and the terminal capacity influence coefficient λ.

Finally, the routes operating capacity model

$$C = n \cdot \frac{N}{T} = n \cdot \frac{\frac{L}{X} \cdot \gamma \cdot \lambda}{\frac{L}{V}} = \frac{n \cdot \gamma \cdot V \cdot \lambda}{X} \quad (16)$$

Parameters:

V :the route average flight speed ; X : the minimum safety interval the controllers require; C : air route operating capacity; N :the number of aircraft within route service time; n : the number of available flight level; γ : the intersection capacity reduction factor; λ : the terminal capacity influence coefficient;

3. Research results

According to the flight data statistics of Northwest Air Traffic Control bureau in May 18 to 24, 2015, the safety interval of two aircraft could be calculated.

3.1 One-way route operation capacity calculation model

Taking $G212$ as an example, and selecting Xi'an - Beijing section. According to the actual operation of one-way route situation, when calculating the capacity, the running safety interval is 30km, and the average speed is 889km/h, available height layer is 2. For one-way route,

aircraft can adopt the way of rising or falling a height layer when crossing intersection, so there will be no confict. Intersection capacity reduction factor γ take 1, and terminal area capacity influencing factor is 1, so we can calculated capacity as follow:

$$C_{dan} = n \cdot \frac{N}{T} = n \cdot \frac{\frac{L}{X} \cdot \gamma \cdot \lambda}{\frac{L}{V}} == \frac{n \cdot \gamma \cdot V \cdot \lambda}{X} = \frac{889 n\gamma\lambda}{30} = 29.6n = 59.2 \tag{18}$$

If according to the front calculation of safety interval, for one-way route, minimum safety interval is 17km when there is no height crossing or 24km when height crossing is exist. Assuming the safe interval is 24km, so we can calculated capacity as follow:

$$C_{dan} = n \cdot \frac{N}{T} = n \cdot \frac{\frac{L}{X} \cdot \gamma \cdot \lambda}{\frac{L}{V}} == \frac{n \cdot \gamma \cdot V \cdot \lambda}{X} = \frac{889 n\gamma\lambda}{24} = 74.1 \tag{19}$$

3.2 Mixed route operation capacity calculation model

Taking $G212$ as an example, and selecting Xi'an - Beijing section. The intersection of the busy is 0.93. Using the actual survey data, the number of cross points are 1, the number of cross routes are 3.

In the Xi'an -Beijing section, the intersection point is ZS, corresponding to the 7-8 route chart above, we can conclude that $\partial = 162^o$, $\beta = 95^o$, comparing the value of

Finally, substituted into

$$\frac{C_1}{C_2} = \frac{\frac{v \sin\partial}{X\sqrt{2+2\cos\partial}}}{\frac{v}{X}} = \frac{\sin\partial}{\sqrt{2+2\cos\partial}} \tag{20}$$

When $\partial = 162^o$, $\beta = 95^o$, assuming that $V_1 = V_2 = V$, estimated $D_+ < D_-$

so $\beta = 95^o$, then calculate capacity influencing factor of cross point:

$$f = \frac{\sin 95}{\sqrt{2+2\cos 95}} = 0.74 \tag{21}$$

And calculated the result as follow:

$$\gamma = \frac{(0.74)^{\frac{N_3}{2}} \cdot (0.95)^{N_1}}{m} = \frac{(0.74)^{\frac{1}{2}} \cdot (0.95)^3}{0.93} = 0.79 \tag{22}$$

Taking " the large capacity channel of Beijing-Kunming", which route connected three terminal areas of Taiyuan, Xi-an and Beijing. So the intersection number of terminal area is 3. The average percentage of affected taking off flights is 55.1%, and the usage rate of the low altitude layer is 10%.

$$\lambda = 1 - N_2 \omega\theta = 1 - 3 \cdot 55.1\% \cdot 10\% = 0.835 \tag{23}$$

Route run in two-way, there is reverse flight path. When calculate capacity , the operational safety interval applying 40km, taking the average speed of 889 km / h, available height layer is 4, intersection capacity reduction factor γ take 0.89, and impact factor of terminal area take 0.835. The calculated capacity is:

$$C_{shuang} = n \cdot \frac{N}{T} = n \cdot \frac{\frac{L}{X} \cdot \gamma \cdot \lambda}{\frac{L}{V}} == \frac{n \cdot \gamma \cdot V \cdot \lambda}{X} = \frac{889 n\gamma\lambda}{40} = 58.64 \tag{24}$$

All in all, In the two-way route, the 40km interval should be maintained in the same height and flight path. In the one-way route, the minimum safety interval is 10km. if 10s pilot technology error is considered, navigation tolerance is 1.6km in the RNAV 2 (GNSS Navigation source), the minimum safety interval is 14.1km; navigation tolerance is 3.2km in the RNP4, the minimum safety interval is 15.7km.

On the basis of the assessment of the safety interval, the capacity of one-way circulation route could be computed. The one-way circulation route operating capacity of Jing Kun large channel is 74.1（Vehicles/hour）, the mixed operating capacity is 58.64（Vehicles/hour）。

The analysis show that one-way circulation operation is no advantage for simple route, but, when the airspace situation becomes complicated, such as intersection point increasing, the advantage of one-way circulation route would become more and more obvious. The one-way circulation route provides a practical, safe and efficient mode for air route network planning in China

4 conclusion and advice

As can be seen from the above analysis, one-way route has no advantage in the simplest route, however, as the situation of airspace becomes more complicated, such as Intersection increase, one-way route has its advantages more and more.

One-way route has no cross-head, so the minimum safety interval of run-time control can be reduced. After reducing the minimum safety interval, the capacity of one-way route is larger than two-way, security has also been improved, and controller load is reduced.

There are many factors that affect the capacity, in different situations, the influence factors are different, and the influence of different regions is different. Above capacity numerical calculation, mainly consider the general operation, some of the parameter values are obtained based on experience. To obtain a more accurate and convincing result, we suggest that using simulation machine to obtain the related parameters and comparing the operating results, which will be more convincing.

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