Modeling of 3-D Air Traffic Complexity Based on Route Structure Constraints

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Abstract: It is an important issue to assess traffic situation complexity for air traffic management. There is a lack of systematic review of the existing air traffic complexity assessment methods, and there is no consideration of the role of airspace and traffic coordination mechanism. A new 3-D airspace complexity measurement method is proposed based on route structure constraints to evaluate the air traffic complexity objectively. Firstly, the model of the impact on horizontal and vertical direction for "aircraft pair" is established based on the route guidance. After that, the coupled complexity model for 3-D airspace is given according to the modification on the model in terms of flight standardization. Finally, the global model of the airspace traffic complexity is established. It is proved by the experimental data from the actual operation in airspace that the proposed model can reflect the space coupling situation and complexity of aircraft. At the same time, it can precisely describe the actual operation of civil aviation in China.

Key words: air traffic management; traffic complexity; flight standardization; aircraft pair; 3-D airspace

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0 Introduction

The air traffic system is a complex system formed by the collaboration of airspace structures and traffic flow. The complexity of air traffic depends on the interaction of different aircraft in the airspace. However, the traffic flow made up of aircraft must adapt to the restriction of airspace structure by changing operating characteristics, which in turn leads to a further dynamic evolution of the traffic complexity. To ensure the safety of airspace traffic flow is the primarily responsibility of air traffic controllers. Workload of controllers also directly affects the operation safety of aircraft under their jurisdiction. Therefore, an accurate measurement of the complexity of airspace traffic and a reasonable division of the busyness of the sectors can effectively reduce or control the workload of controllers and ensure the safety of aircraft operations.

At present, the airspace complexity and the degree of busyness are mainly divided by methods based on the amount of flights, ignoring the impact of airspace structure on aircraft operation. In fact, the airspace route structure will have a serious impact on the air traffic flow in two inspects: The guiding influence will affect the trend of traffic flow and the restrictive effect, which means the traffic flow must fly along the specified route and meet its operating standards. However, due to the complexity of the relationship between airspace structure and traffic flow, the accurate assessment of air traffic complexity has become a thorny problem in air traffic management.

Since the complexity measured by route structure can evaluate the traffic flow status more comprehensively, this paper proposes a complexity calculation model based on "aircraft pair", after analyzing the guidance and normative constraints of the air-

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space route structure to the aircraft and evaluates the overall complexity of the airspace. The proposed model can reveal the process of traffic complex situation changing from one "aircraft pair" to multiple "aircraft pair" environment, and evaluate the complexity of the air traffic more objectively.

1 Related Work

In recent years, domestic and foreign scholars have carried out a series of researches on the issue of air traffic complexity and made some achievements.

Focusing on the impact of air traffic complexity on controller's workload, Chatterjr et al. [1] analyzed and expanded the factors affecting traffic complexity and studied the nonlinear relationship between controller's workload and traffic flow complexity. Gianazza[2] studied the relationship between air traffic complexity and controller's workload based on artificial neural network and put forward the idea of airspace division based on traffic complexity. Djokic et al. [3] analyzed the components of air traffic complexity and analyzed the relationships among various factors affecting traffic complexity by clustering and regression analysis. Jelena also defined task requirements and regulatory behaviors, and studied the relationship between traffic complexity and controller's workload.

Focusing on the idea of dynamic density, Kopardekar et al.[4-5] proposed the concept of dynamic density, which considers dynamic density as a set of all factors that affect the complexity of air traffic. Toy[6] built two models of traffic behavior complexity assessment: One modeling approach based on dynamic density, including the number of aircraft, the reciprocal of the average weighted horizontal interval, the reciprocal of the minimum horizontal interval, the standard deviation of velocity, the average difficulty of conflict resolution and other factors; the other is based on the complexity of the trajectory measurement, taking into account sector size, weather effects, violation of standard intervals and other factors.

Focusing on the static and dynamic factors, Netjasov[7] studied the traffic complexity in the terminal area and concluded that the traffic complexity was caused by the combination of the static factors of the airspace structure and the dynamic characteristics of the traffic flow. The static elements of airspace structure include the distribution of flight segments in airspace, the degree and number of intersections, etc. The dynamic characteristics of traffic flow include the distribution of flights on each flight segment, and the number of aircraft changing altitude, etc. Song et al. [8] summarized the research on air traffic complexity and concluded that the complexity factors include both static and dynamic ones. Static factors generally have less change, including routes, airports and so on. Dynamic factors include changes in the status of the aircraft itself or regulatory instructions.

Focusing on the dynamic factors of aircraft, Delahaye et al.[9-10] objectively described the changes in complexity by using the aircraft's intrinsic attribute, such as speed and heading, constructed a traffic disorder model and analyzed its complexity. However, in the description of the overall traffic situation, the simple addition of single aircraft was considered, but the interaction between aircraft was ignored. Therefore the coupling complexity cannot be accurately explained. Based on the route structure, Ye et al. [11] defined two complexity factors: Distance and conflict to reflect the influence of the relative distance between aircraft and the cross-track interaction on the complexity. Xu et al. [12-13] established a complexity measurement model which took into account the approach time, aggression function, relation matrix, correlation function and other dynamic factors of "aircraft pair".

It is noteworthy that the domestic scholar Zhang is committed to a study of airspace traffic complexity in recent years and has achieved some significant results. They reviewed the researches of complexity, analyzed the advantages and disadvantages of different models, and focused on the theoretical achievements in dynamic density, traffic chaos and the modeling of complex systems in airspace[14]. They studied the disorder and perturbation of air traffic flow and constructed a spatial complexity model based on intrinsic complexity[15]. They studied the interaction of "aircraft pair" in a two-dimensional airspace and used the inner product of the relative velocity vector and the relative position vector of the "aircraft pair" to determine the situation of the two aircraft. When two aircraft are in a state of convergence, it is considered to be a conflict tendency at the time. However, the conclusions reached by this method are still different from the actual operation, which may be explained by the following two reasons. One is that the relative movement tendency of "aircraft pair" is not only related to its own relative position and relative speed, but also influenced by the orientation and restrictiveness of the route structure[16-18]. The other is that airspace is three-dimensional and the "aircraft pair" situation presented in a single dimension can not determine their conflict. For example, two aircraft at different levels in same route, seem to converge in the horizontal direction, and there is no conflict between them[19].

Inspired by the above work, this paper attempts to establish a three-dimensional traffic complexity measurement model for the entire airspace based on the interaction between aircraft and the impact of route structure on "aircraft pair".

2 Complexity Model of "Aircraft Pair" Based on Route Structure

2.1 Constrain of route structure to aircraft

To regulate and guide traffic, route structure constrains and limits the aircraft's flying path to make the traffic from disordered to ordered and to reduce the complexity of the overall traffic situation. If the aircraft within the sector deviates from the prescript route, the traffic complexity will increase sharply, thereby increasing the workload of the controllers. In Fig.1, aircraft "a" in the horizontal direction satisfies the route constraint, however, aircraft "b" and "c" deviate from the prescript route. Although aircraft "d" is on the route, there is a tendency to deviate from the prescribed flight direction. After a period, it may deviate from the original route and no longer comply with the restrictions of airspace structures. The relationship between aircraft "d" and other aircraft may be changed from the original conflict-free interaction to an expected conflict-like interaction, which not only increases the complexity of the entire transportation system but also brings about the potential safety hazard of air traffic.

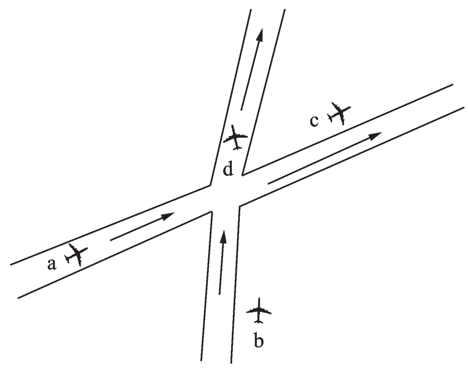

Fig.1 Constrain of route structure to aircraft

2.2 "Aircraft pair" interaction model

2.2.1 Aircraft pair

In three-dimensional space, the relative movement between the aircraft can be divided into convergence and dispersion, and the dynamic relationship between aircraft determines whether there are conflicts and security threats in traffic flow. To facilitate the description of aircraft-to-aircraft relationships, any two aircraft within a particular airspace are defined as "aircraft pair". The traffic complexity mainly depends on the interaction between different "aircraft pair" and the consistency of traffic flow, such as the similarity of each "aircraft pair" in the airspace.

To reveal the emergence of traffic complexity from a single "aircraft pair" to a multi-aircraft environment, it is necessary to set out from the microscopic relationship of "aircraft pair" and establish interaction models for conflict-expected state and conflict-free state. Based on these two models, we can further consider the correction of the route structure to the model, and finally construct a model to describe the overall complexity of the airspace.

2.2.2 Interaction model of conflict-expected

Assuming that the minimum over-time interval for a waypoint is ST_{sep}, the relative position between two aircraft is D_{ij} and their speeds are $\boldsymbol{V}_i$ and $\boldsymbol{V}_j$ (vectors). Then, the minimum safety distance is: $D_{\text{sep}} = \left|\boldsymbol{V}_i - \boldsymbol{V}_j\right| \cdot ST_{\text{sep}}$ and the time for aircraft i flighting from the conflict point to the estimated collision point can be presented by following expression

$$ST_i = \frac{D_{\text{sep}}}{\boldsymbol{V}_i} = \frac{\left|\boldsymbol{V}_i - \boldsymbol{V}_j\right| \cdot ST_{\text{sep}}}{\boldsymbol{V}_i} \tag{1}$$

Conflicts occur when either one of the two aircraft arrives at the collision point. The approaching factor is presented as

$$T_{ij} = ST_{\text{sep}} \cdot \left(\frac{ST_{ij}}{ST_{\text{sep}}}\right)^{\alpha} \quad \alpha \geqslant 1 \tag{2}$$

where $ST_{ij} = \min\left(ST_i, ST_j\right)$. Then the "aircraft pair" interaction model in the horizontal direction can be constructed as

$$\text{LvlPair}_{ij} = \mathrm{e}^{-\lambda \cdot T_{ij}} = \mathrm{e}^{-\lambda \cdot ST_{\text{sep}} \cdot \left(\frac{ST_{ij}}{ST_{\text{sep}}}\right)^{\alpha}} \tag{3}$$

where $\lambda > 0$ and $\alpha > 0$ are the complexity adjustment parameters of horizontal direction (discussed in Section 2.3.3). It can be seen from the formula that the horizontal complexity LvlPair_{ij} will increase exponentially with the decrease of T_{ij}, that is, the closer the aircraft is to the collision point, the more horizontal traffic complexity will sharply increase.

For the interaction of "aircraft pair" in vertical direction, since only the current relative speed and relative position of aircraft are related, the interaction model can be expressed as

$$\text{VerPair}_{ij} = \mathrm{e}^{-\mu \frac{HD_{\text{sep}} \cdot \left|HD_{ij}\right|}{\left|\left(HD_{ij}, HV_{ij}\right)\right|} \left(\frac{\left|HD_{ij}\right|}{HD_{\text{sep}}}\right)^{\beta}} \tag{4}$$

where $\beta > 0$ and $\mu > 0$ are the complexity adjustment parameters of vertical (discussed in Section 2.3.3). HD_{sep} is the vertical minimum safety distance, HD_{ij} and HV_{ij} are vertical relative distance and relative speed. It can be seen from the formula that the vertical complexity VerPair_{ij} increases exponentially with the increase of relative velocity HV_{ij} and the decrease of relative position HD_{ij}. That is, the greater the relative speed, the closer the distance, the more vertical traffic complexity will sharply rise.

2.2.3 Interaction model of conflict-free

When two aircraft are in a conflict-free state, the convergence and dispersion of "aircraft pair" in horizontal and vertical directions will still affect the overall traffic complexity. In horizontal direction, the discrete stress is mainly reflected by the time of the aircraft near or away from the convergence point. The discrete stress model is constructed as

$$T_{ij} = \left(1 + \frac{\left|ST_{ij}\right|}{ST_{\text{sep}}}\right) \cdot \mathrm{e}^{\alpha \cdot \left(1 - \frac{\left|ST_i - ST_j\right|}{\sqrt{ST_i^2 + ST_j^2}}\right)} \tag{5}$$

where $\alpha \geqslant 0$; $ST_{ij} = \min\left(ST_i, ST_j\right)$ is the equivalent approaching factor. ST_i and ST_j represent the time of two aircraft from the convergence point. If there is no convergence point, the "aircraft pair" is considered as irrelevant, ST_i, ST_j are infinite, and the mutual influence is set to 0.

The interaction model of the "aircraft pair" in the horizontal direction is as

$$\text{LvlPair}_{ij} = \mathrm{e}^{-\lambda \cdot T_{ij}} = \mathrm{e}^{-\lambda \cdot \left(1 + \frac{|ST_{ij}|}{ST_{\text{sep}}}\right) \cdot \mathrm{e}^{\alpha \cdot \left(1 - \frac{|ST_i - ST_j|}{\sqrt{ST_i^2 + ST_j^2}}\right)}} \tag{6}$$

The interaction model of the "aircraft pair" in the vertical direction is represented as

$$\text{VerPair}_{ij} = \mathrm{e}^{-\mu \cdot \frac{|HD_{ij}|}{HD_{\text{sep}}} \cdot \mathrm{e}^{\beta \cdot (HD_{ij}, HV_{ij})}} \tag{7}$$

where $\beta > 0, \mu > 0$. The definition and value of λ, α, β and μ are the same as the previous ones.

2.3 Model correction based on route constraints

2.3.1 Normative model

The normative degree of an aircraft refers to the conformity between the trajectory profile of an aircraft and the prescribed route, in both horizontal and vertical directions. For the norms in the horizontal direction, the horizontal offset distance between the flight track of the aircraft and the route and the degree of fluctuation of the flight track of the aircraft in horizontal plane should be considered. Therefore, the aircraft's horizontal normative model can be constructed as

$$\text{LevelNorm}_i = \frac{1}{\left(1 + \left|\frac{\text{LvlDiv}_i}{LD_{\text{sep}}}\right|\right)^{\tau} \cdot \mathrm{e}^{\omega \cdot \text{LvlVAR}_i}} \tag{8}$$

where LvlDiv_i is the average distance of the flight track deviating from the route in horizontal plane in previous period. LD_{sep} is the width of the protection zone. LvlVAR_i is the deviation variance of the flight track from the route in horizontal plane in previous period. It can be concluded that the greater the distance deviation or fluctuation, the lower the normative degree of the flight.

Aircraft movements in vertical direction are in two kinds: Cruise, climb or descend. When the aircraft cruises, its vertical normative is mainly described by its offset and volatility in vertical direction. The model is expressed as

$$\text{VerticalNorm}_i = 1/\left(1+\left|\frac{\text{VerDiv}_i}{VD_{\text{sep}}}\right|\right)^{\rho}\cdot \mathrm{e}^{\sigma\cdot\text{VerVAR}_i} \tag{9}$$

When the aircraft climbs or descends, its vertical normative is mainly described by its volatility in vertical direction. The model is expressed as

$$\text{VerticalNorm}_i = 1/\mathrm{e}^{\sigma\cdot\text{VerCVAR}_i} \tag{10}$$

where VerDiv_i is the average distance value of the flight track deviating from the route in vertical plane in previous period. VD_{sep} is the height of the protection zone. VerVAR_i is the deviation variance of the flight track from the route in vertical plane in previous period. VerCVAR_i represents the deviation variance of the climb rate (descent rate) from the planned climb rate (descent rate) in previous period. τ,ω,ρ,σ are adjustment parameters, $\tau,\rho \geqslant 1$. It can be concluded that the larger the offset distance or the fluctuation, the lower the normative degree of the flight, and the closer the value of VerticalNorm_i is to 1, the stronger the ability of the aircraft to fly along the route during the previous period.

2.3.2 Model correction

Based on the definition of flight normative in last section, the correction parameters $\text{LA}P_{ij}$ and $\text{VA}P_{ij}$ for "aircraft pair" (i,j) in the horizontal and vertical directions can be defined as

$$\text{LAP}_{ij} = \text{LevelNorm}_i\cdot\text{LevelNorm}_j \tag{11}$$

$$\text{VAP}_{ij} = \text{VerticalNorm}_i\cdot\text{VerticalNorm}_j \tag{12}$$

The range of LAP_{ij} and VAP_{ij} is $(0, 1)$. The closer the value is to 1, the better the flight normative and stability.

Therefore, for the "aircraft pair" (i,j) in conflict-expected state, the corrected interaction models in horizontal and vertical directions can be expressed as

$$\text{LvlAdjPair}_{ij} = \mathrm{e}^{-\lambda\cdot\text{LAP}_{ij}\cdot ST_{\text{sep}}\cdot\left(\frac{ST_{ij}}{ST_{\text{sep}}}\right)^{\alpha}} \tag{13}$$

$$\text{VerAdjPair}_{ij} = \mathrm{e}^{-\lambda\cdot\text{VAP}_{ij}\cdot\frac{HD_{\text{sep}}\cdot|HD_{ij}|}{\left|\left(HD_{ij},HV_{ij}\right)\right|}\cdot\left(\frac{|HD_{ij}|}{HD_{\text{sep}}}\right)^{\alpha}} \tag{14}$$

where $\lambda > 0,\alpha \geqslant 1$.

For the "aircraft pair" (i,j) in conflict-free state, the corrected interaction models in horizontal and vertical directions can be expressed as

$$\text{LvlAdjPair}_{ij} = \mathrm{e}^{-\mu\cdot\text{LAP}_{ij}\cdot\left(1+\frac{|ST_{ij}|}{ST_{\text{sep}}}\right)\cdot \mathrm{e}^{\beta\cdot\left(1-\frac{|ST_i-ST_j|}{\sqrt{ST_i^2+ST_j^2}}\right)}} \tag{15}$$

$$\text{VerAdjPair}_{ij} = \mathrm{e}^{-\mu\cdot\text{VAP}_{ij}\cdot\frac{\left|HD_{ij}\right|}{HD_{\text{sep}}}\cdot \mathrm{e}^{\beta\cdot\left(HD_{ij}\cdot HV_{ij}\right)}} \tag{16}$$

where $\beta > 0,\mu > 0$.

2.3.3 Parameters in models

The approaching effect in the horizontal and vertical directions are divided into four levels: low, medium, high and very high, as shown in Table 1. The key parameters λ,α,μ,β of the models have different values referring to the level of approaching effect, as shown in Table 2.

3 Complexity Model of Global Traffic

From "Barrel Theory", we know that the overall capacity of a system is determined by the least capable component. Therefore, the interaction between two aircraft is important to the overall traffic complexity in two dimensions. To integrate the interactions in horizontal and vertical directions, a coupling parameter is defined as

$$\text{CAdiPara}_{ij} = 1-\frac{\left|\text{LvAdjPair}_{ij}-\text{VerAdjPair}_{ij}\right|}{\sqrt{\text{LvAdjPair}_{ij}^2+\text{VerAdjPair}_{ij}^2}} \tag{17}$$

The formula shows that the weaker one will weaken the impact of the stronger one. Therefore, the stronger one needs to be adjusted by the coupling parameter. Thus, the coupling complexity model for "aircraft pair" (i,j) is shown as

Table 1 Approaching effect levels

Horizontal approaching				
Relative distance/km	Relative velocity/($km \cdot h^{-1}$)			
	<370	<1 050	<1 480	≥1 480
≥130	Low	Low	Low	Medium
<130	Low	Low	Low	Medium
<75	Low	Low	Medium	High
<45	Low	Medium	Medium	High
<20	Medium	High	Very high	Very high
Vertical approaching				
Relative distance/m	Relative velocity/($m \cdot s^{-1}$)			
	<6	<13	<16	≥16
≥1 200	Low	Low	Low	Medium
<1 200	Low	Low	Medium	Medium
<900	Low	Low	Medium	High
<600	Low	Medium	Medium	High
<300	Medium	High	Very high	Very high

Table 2 Value of model parameters

Horizontal complexity parameter		Horizontal Proximity level	Vertical complexity parameter		Vertical Proximity level
λ_1	21.774	Low	μ_1	41.548	Low
λ_2	0.249	Medium	μ_2	0.478	Medium
λ_3	0.043	High	μ_3	0.082	High
λ_4	0.914	Very high	μ_4	1.728	Very high
α_1	1	Low	β_1	0.010 0	Low
α_2	2	Medium	β_2	0.000 4	Medium
α_3	3	High	β_3	0.001 0	High
α_4	4	Very high	β_4	0.000 2	Very high

$$\mathrm{Pair}_{ij}=\begin{cases}\mathrm{LvlAdjPair}_{ij}+\mathrm{CAdjPara}_{ij}\cdot\mathrm{VerAdjPair}_{ij} & \mathrm{VerAdjPair}_{ij}>\mathrm{LvlAdjPair}_{ij}\\ \mathrm{VerAdjPair}_{ij}+\mathrm{CAdjPara}_{ij}\cdot\mathrm{LvlAdjPair}_{ij} & \text{Else}\end{cases}\tag{18}$$

As we know there are often several "aircraft pairs" in an airspace simultaneously. If there is an "aircraft pair" conflict, the complexity of the entire airspace will increase. Since the global traffic has different effect to each "aircraft pair", we should firstly calculate the weight. The weight may meet the following conditions: The weight needs to be proportional to the interaction of an "aircraft pair", and the global traffic will have an impact on every aircraft in it. The impact function is

$$\mathrm{RevPair}_i=\sum_{j=1}^{N}\mathrm{Pair}_{ij}\cdot\mathrm{Para}_{ij}\tag{19}$$

where the weight is calculated as

$$\mathrm{Para}_{ij}=\begin{cases}\dfrac{\mathrm{Pair}_{ij}}{\sum\limits_{k\neq i}\mathrm{Pair}_{ik}} & i\neq j\\ 0 & i=j\end{cases}\tag{20}$$

The weights reflect the differences of global traffic impact on any of its aircraft. The impact difference between aircraft i and j caused by global traffic can be calculated as

$$\mathrm{Distinct}_{ij}=|\mathrm{Para}_{ij}-\mathrm{Para}_{ji}|\Big/\sqrt{(\mathrm{Para}_{ij}^2+\mathrm{Para}_{ji}^2)}\tag{21}$$

Based on the degree of difference, the concept of similarity can be defined as

$$\mathrm{Similarity}_{ij}=(1-\mathrm{Distinct}_{ij}^{\rho})^{\frac{1}{\theta}}\tag{22}$$

where ρ and θ are adjustment parameters. The similar degree of impact of aircraft i and j reflects the relative impact of each aircraft on the overall traffic, that is the traffic consistency.

For airspace with N aircraft, its global traffic complexity can be presented as

$$\text{Complexity} = \sum_{i=1}^{N} \left(\text{RevPair}_i \cdot \sum_{j=1, j \neq i}^{N} \text{Similarity}_{ij} \right) \tag{23}$$

The model takes into account the impact of global traffic on each aircraft and the similarity between the aircraft.

4 Case Analysis

To verify the validity of the proposed complexity models, we apply them on the actual flight operation data and spatial structure data of Guangzhou 03 sectors to calculate the airspace complexity.

4.1 Analysis of the sector complexity

On the data from Guangzhou 03 Sector on October 11, 2017 from 15:00 to 16:00, the airspace complexity in this period is evaluated. Fig.2 shows the static structure of Guangzhou 03 sector. Fig.3 shows the relationship between the real-time complexity of the sector and the number of aircraft in the sector during the statistical period with the statistics interval 1 min.

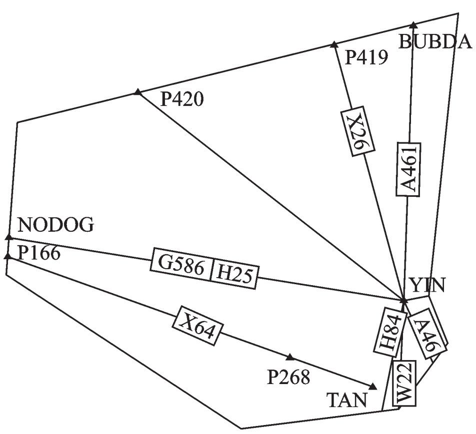

Fig.2 Guangzhou 03 sector structure

In Fig.3, 15:36 and 15:38 have the same flight amount, but the complexity is different. Compare the distribution of traffic patterns at 15:36 and 15:38, as shown in Figs.4(a,b), it can be seen that a convergence is occurring in Fig.4(b), so that the calculated traffic complexity of 15:38 is higher than 15:36. Similarly, the flight amount of 15:40 is greater than that of 15:38 but its complexity is smaller than that of 15:38, because although the

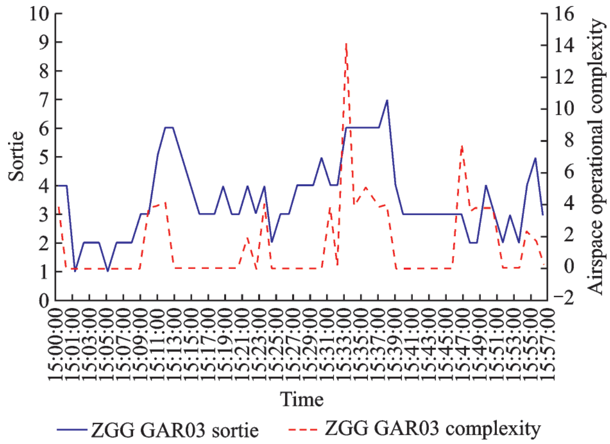

Fig.3 Relationship between airspace complexity and aircraft amount

number of flights is more at 15:40, the convergence tends is more moderate. It can be seen that the computational model of airspace complexity proposed in this paper can objectively and accurately reflect the impact of flight amount and traffic conditions on the airspace complexity.

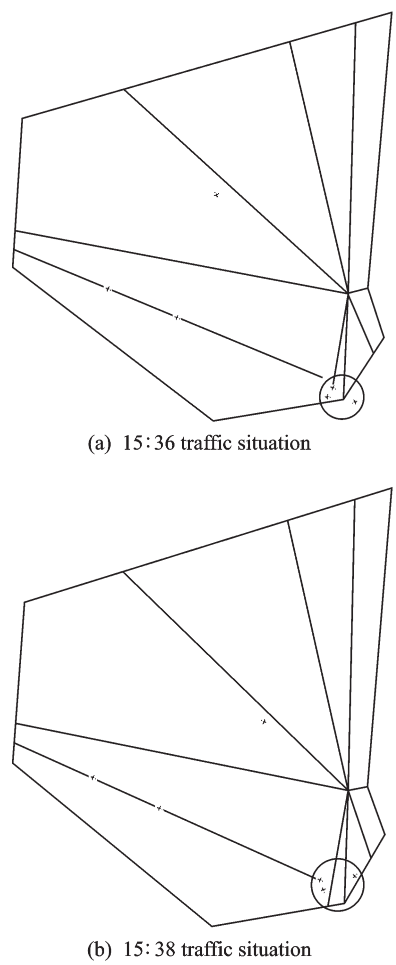

Fig.4 15:36 and 15:38 traffic distributions of Guangzhou 03 sector

4. 2 Influence of track deviation on complexity

In practice, factors such as navigation accuracy, meteorological conditions, and pilot capabilities may cause the trajectory of the aircraft to deviate from the actual route, which increases the risk of aircraft operation, and also affects the accuracy of the controller's predictions of traffic scenario evolution. To verify the influence of track deviation on airspace complexity, based on the data of Guangzhou 03 sector on October 11, 2017 from 15:00 to 16:00, the complexity of corrected track and uncorrected track are calculated, as shown in Fig.5.

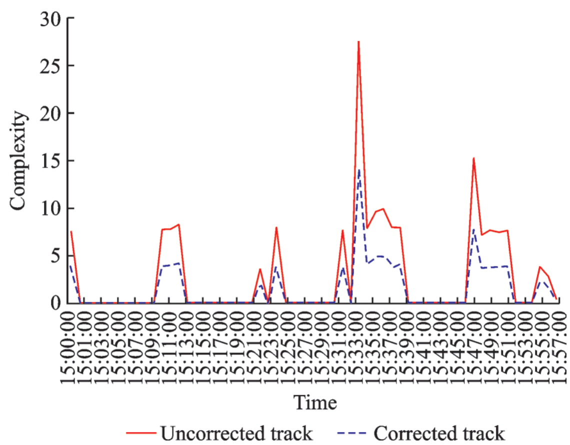

Fig.5 Influence of track deviation on complexity

As can be seen from Fig.5, the complexity of corrected track is not lower than that of uncorrected track. Especially around 15:38, the complexity of corrected track is greatly deviated from that of the uncorrected track. ZGGGAR03 sector reproduced 15:38 traffic scenario by processing radar data, as shown in Fig.4(b). At this moment, the flight track of multiple flights in the airspace obviously deviates from the planned route, so the increase of airspace complexity is in line with the actual operation.

5 Conclusions

This paper proposes a new three-dimension airspace complexity measurement method. Compared with other existing related works, the contribution of this paper can be summarized as follows: For the first time, considering the micro-realistic factor that the aircraft is constrained by the route, this paper proposes the concept of route guidance and flight norms and a three-dimensional coupled model of the "aircraft pair" based on this concept, and then establishes a three-dimensional air traffic complexity model. According to the experimental results of actual airspace operation data, the computational model of airspace complexity presented in this paper can truly reflect the aircraft coupling situation and its complexity, and is more suitable for the actual operation of civil aviation in China.

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