CMC, vol.57, no.1, pp.151-166, 2018

Research on Operation of UAVs in Non-isolated Airspace

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Abstract: In order to explore the safe operation of UAVs in non-segregated airspace, a collision risk model for cylindrical UAVs based on conflict areas was constructed and the risk of conflict between manned and unmanned aerial vehicles was researched. According to the results of risk analysis, a strategy for solving the conflict of aircraft is proposed, and the risk assessment experiment of unmanned aerial vehicle (UAV) in non-isolated airspace conflict is carried out. The results show that under the experimental conditions, large unmanned aerial vehicles equipped with ADS-B, TCAS and other airborne sensing systems will indeed interfere with other aircraft in airspace when they enter non-isolated airspace. Especially when the number of aircraft in airspace is large, the automatic avoidance system of UAV will increase the avoidance time and trigger the safety alarm, but the safety level is still acceptable. This indicates that it is relatively safe for UAVs to enter non-isolated airspace under limited conditions. The results can be used as a reference for the safe operation of unmanned aerial vehicle (UAV) in non-isolated airspace.

Keywords: Unmanned aircraft vehicles, non-isolated airspace, safe operation, risk assessment.

1 Introduction

With the rapid development of UAV technology, its applications have become more and more popular. Integrating UAVs into non-isolated airspace is the future development trend, but at the same time, it also brings huge challenges for civil aviation safety and UAV development. Therefore, under current ATC (air traffic control) conditions, how to assess the level of safe operation of UAVs entering non-segregated airspace has become a hot topic research.

Nowadays, civil transport aviation has been equipped with more mature collision detection and collision avoidance techniques for aircraft, such as Prandini, Matsuno, and Jilkov using probabilistic models to study probabilistic conflict detection problems in various uncertain condition of ATC [Jilkov, Li and Ledet (2015); Matsuno and Tsuchiya (2014); Prandini, Hu, Lygeros et al. (2000)]. For conflict detection problems, a series of high-efficiency numerical algorithms such as list Viterbi algorithm and generalized

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CMC. doi:10.32604/cmc.2018.02890

polynomial chaos method are proposed, which improves the efficiency and accuracy of collision detection between aircrafts; some scholars also, analyze aircraft conditions in the actual enroute with clustering and geometric methods, and solve this problem by modifying the enroute [Dur and Alliot (2014); Chiang, Klosowski, Lee et al. (1997)]. In addition, it can also automatically achieve the resolution of the conflict by the software after iterative calculation of aircraft's four-dimensional track data [Visintini, Glover, Lygeros et al. (2006); Feron, Bicchi and Pallottino (2013); Erzberger (2005); Kuenz (2015)].

In the past few years, the United States and Europe have committed to integrating UAVs into non-segregated airspace. However, it is unclear whether UAVs will pose a security threat to other aircraft in the airspace after they enter non-segregated airspace. In this context, Schmitt et al. [Schmitt, Kaltenhäuser and Keck (2008)] confirmed in a simulation experiment that it is feasible for UAVs to enter non-isolated airspace operations. Mátyás et al. [Mátyás and Gábor (2012)] discussed the communication problems between the UAV system and the air traffic control system. The results show that the UAV airborne system is an effective means to ensure the safety of UAVs in non-isolated airspace. The work of European Organization for the Safety of Air Navigation (EUROCONTROL) shows that the establishment and specification of relevant rules and standards can ensure the integrity and correctness of technical specifications for UAV communications [Simpson and Stoker (2006)]. On the basis of multi-agent technology [Wu, Zapevalova, Chen et al. (2018)], Correa et al. [Correa, Camargo Jr, Rossi et al. (2012)] modeled UAVs in air traffic controlled airspace. The simulation results show that the major risk for UAVs is not necessarily the number of aircraft on UAVs enroute, but the reliability and availability of its own sensors. Wu et al. [Wu, Cai and Wang (2013)] proposed using the Automatic Dependent Surveillance-Broadcast (ADS-B) system to perform collision prediction for non-isolated airspace of UAVs and perform dynamic alarms. Rossi et al. [Rossi, Junior, Bondavalli et al. (2012)] use the Bayesian networks to model the faults of aviation communication, the safety and reliability analysis was carried out to evaluate the impact of Aeronautical Communications networking on the collision probability between the aircraft and the UAV. When the UAV enters the non-isolated airspace [Rossi, Junior, Bondavalli et al. (2012)].

In communication and surveillance, Sun et al. [Sun, Wang , Kou et al. (2017)] proposed an efficient and energy-saving distributed network architecture based on clustering stratification to solve the information security problem of unmanned aerial vehicle ad hoc network communication; Lin et al. [Lin, Wang, Wang et al. (2016)] proposed that establish a communication link and set up a sensor network without adopting spectrum holes to convey control information; Lin et al. [Lin, Wang, Ma et al. (2016)] introduced how to set up the model of multi-sensor network information fusion and discussed the problem of conflict information fusion in the framework of evidence and several improved methods were introduced. Girish et al. [Girish, Hema and Singh (2016)] conducted research on radar cross section.

Based on the above studies, combined with the theory of aircraft collision avoidance, relying on ADS-B, Traffic Collision Avoidance System (TCAS), Airborne Collision Avoidance System (ACAS) and other advanced monitoring data links, the collision risk model with civil aircraft and large-scale UAV mixed operation was established. The collision risk model studies the safe operation of UAVs in non-segregated airspace under complex conditions and conducts risk assessment verification.

2 Airspace security operation model

2.1 Collision risk model

1) Reich Model. It was first proposed by Reich in 1966. In the absence of navigation and radar surveillance equipment, longitudinal, lateral and vertical collision risks are studied by setting collision templates and adjacent layers [Reich (1966a, 1966b, 1966c)].

2) Collision risk model based on conflict region. Hsu [Hsu (1981)] has developed a calculation method for aircraft collision probability in intersecting enroutes. The overlapping density of the aircraft is represented by parameters such as the crossing angle of the enroute, aircraft speed, and aircraft spacing. Anderson et al. [Anderson and Lin (1996)] presented a mathematical model for the separation of aircraft against the collision risk on the cross route, and gave sensitivity analysis of the crossing angle, required navigational performance (RNP) values, and aircraft speed variation.

On the basis of the above theories, several improved models of aircraft reserve are developed, such as cylindrical type, spherical type and ellipsoid type. Here, taking the cylindrical protected area model is described as Fig. 1.

Taking the aircraft particle as the center of the cylinder, the minimum security interval is used as the radius in the horizontal separation, and the protection area model is established in the vertical separation with twice the vertical interval. At this time, there is no conflict between the two aircrafts when the protected areas do not touch or overlap; but when the outer boundaries of the two protected areas of the aircrafts that fly towards each other at the same height touch each other, the two aircrafts just reach the minimum safety interval, there is a conflict and it is necessary to reconcile the conflict.

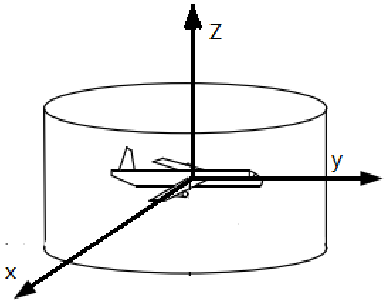

Figure 1: Cylindrical protection area model

If it is determined that the conflict occurs, that is, another aircraft enters the protection area, H is the vertical direction safety interval of the aircraft, R is the minimum horizontal interval of the aircraft, and W is the airspace extent, the scope of the aircraft cylindrical protection area can be expressed as:

$$\begin{cases} |z| \le |\mathrm{H}| \\ x^2 + y^2 \le \mathrm{R}^2 \end{cases} x, y, z \in \mathrm{W}^2 \tag{1}$$

2.2 Deterministic conflict detection model

The aircraft collision probability refers to the possibility of determining collisions between aircraft pairs over a period of time based on the trajectory characteristics of the aircraft and the trajectory prediction.

This study takes the process of conflict as the object of study, and takes the position, speed and course of aircraft provided by ADS-B, TCAS, ACAS, radar and other equipment as the source of information to introduce the severity of the conflict. And analysis of the risk of conflict arising from the loss separation between two aircraft R [Shi (2014)] can be expressed as:

$$\mathrm{R} = P_{ij}\mathrm{S} \tag{2}$$

where P_{ij} is the probability of collision between aircraft i and j; S is the severity of the conflict between aircraft i and j.

According to aircraft track characteristics, the conflict between aircraft is related to the aircraft track error distribution and the distance distribution between aircrafts. The distance density function L_{ij} between aircrafts is:

$$L_{ij} = P_i P_j D_{ij} \tag{3}$$

where P_i is the track error distribution for aircraft i; P_j is the track error distribution for aircraft j; and D_{ij} is the distance distribution for aircraft i and j.

The aircraft track error can be decomposed into three parts: lateral error, longitudinal error and vertical error. Following the three-dimensional Gaussian distribution with mean zero, each error can be regarded as a zero-mean Gaussian distribution random variable. That is, assuming that there are two planes i and j flying along their respective paths at time $[0,T]$, the path error of the aircraft at any time t obeys the Gaussian distribution. At this time, the three-dimensional Gaussian distribution probability density function of aircraft i and j is:

$$P_i = \frac{1}{\sigma_{ix}\sigma_{iy}\sigma_{iz}(2\pi)^{3/2}}\exp\left[-\frac{1}{2}\left(\frac{{}_T X_i^2}{\sigma_{ix}^2}+\frac{{}_T Y_i^2}{\sigma_{iy}^2}+\frac{{}_T Z_i^2}{\sigma_{iz}^2}\right)\right] \tag{4}$$

$$P_j = \frac{1}{\sigma_{jx}\sigma_{jy}\sigma_{jz}(2\pi)^{3/2}}\exp\left[-\frac{1}{2}\left(\frac{{}_T X_j^2}{\sigma_{jx}^2}+\frac{{}_T Y_j^2}{\sigma_{jy}^2}+\frac{{}_T Z_j^2}{\sigma_{jz}^2}\right)\right] \tag{5}$$

Let r_i and r_j be the position vectors of the aircraft, and the distance distribution D_{ij} of the two aircrafts can be expressed as a δ function:

$$D_{ij} = \delta\left(r_i - r_j\right) \tag{6}$$

The probability of collision between two aircraft can be obtained by Eq. (4) along the position of aircraft i and j:

$$P_{ij} = \iint L_{ij} dr_i dr_j = \iint P_i P_j \delta\left(r_i - r_j\right) dr_i dr_j \tag{7}$$

According to the sifting of δ function, we can obtain:

$$\int f\left(r_j\right)\delta\left(r_j - r_i\right) dr_j = f\left(r_i\right) \tag{8}$$

r_i, r_j is the position vector of an aircraft. When integrating the two, it is necessary to consider that the aircraft i and j are in the same inertial coordinate system. Therefore, the aircraft should be converted from the coordinate system that uses the aircraft itself as the coordinate origin to the inertial coordinate system. The steps are as follows:

In the first step, set the inertial coordinate system to $\left(\mathrm{X_C}, \mathrm{Y_C}, \mathrm{Z_C}\right)$. Take the aircraft as the origin. When the rotation angle is $-\varphi$, get a $\mathrm{X,Y,Z}$ that is parallel to $\left(\mathrm{X_C}, \mathrm{Y_C}, \mathrm{Z_C}\right)$. $+\varphi$ is the angle between the aircraft heading and the X axis in the inertial coordinate system. The aircraft's X coordinate is converted to $\left[X_R \cos\left(\varphi\right) + Y_R \sin\left(\varphi\right)\right]$, and the aircraft's Y coordinate is converted to $\left[-X_R \sin\left(\varphi\right) + Y_R \cos\left(\varphi\right)\right]$, where R represents the rotated coordinate system.

In the second step, $-\alpha, -\beta, -\gamma$ is added to the three directions of the rotated coordinate system $\mathrm{X,Y,Z}$, so that the rotated coordinate system can be transformed into the ordinary coordinate system.

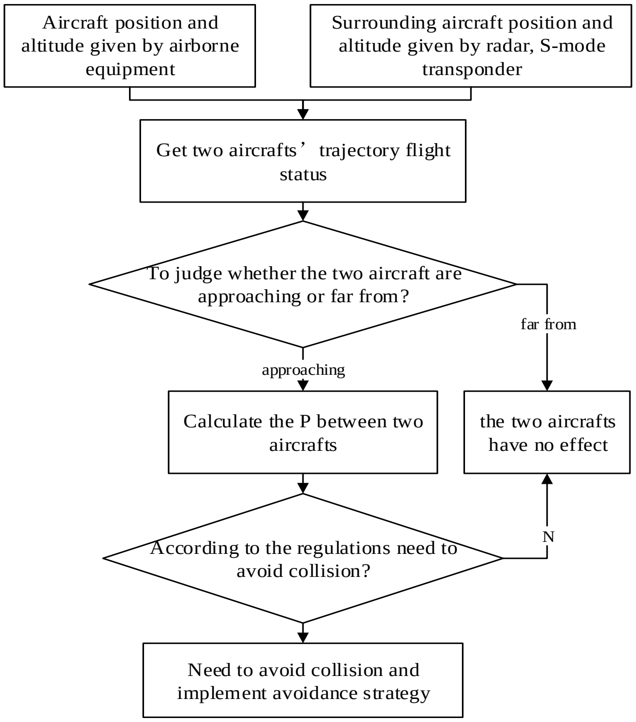

Figure 2: Flow chart of deterministic conflict analysis algorithm

In summary, the probability of collision P_{ij} between two aircrafts is obtained. The algorithm flow is shown in Fig. 2.

According to the security assessment theory [Peter and Philip (2000)], the risk comprehensive level needs to be determined from both the possibility and severity.

According to the ICAO recommendation standards and national characteristics of countries, this paper revises the possibility, severity and risk tolerance matrix of risk. Combined with the calculation result of Eq. (7), the aircraft flight conflict risk probability level and the corresponding severity risk level can be obtained. See Tab. 1 for the probability of conflict occurrence assessment table, Tab. 2 for the risk severity level rating assessment table, furthermore, the tolerance of the risk can be determined by the quantitative table of risk assessment matrix in Tab. 3.

Table 1: Probability of conflict occurrence assessment table

Level	Risk probability range (Airspace system and ATC operation)	Risk occurrence possibility
5	$\geq 10^{-3}$	It is highly likely to happen, meaning that it occurs immediately or in the short term;
4	$\geq 10^{-5}$ & $<10^{-3}$	It may happen, meaning that it happens by chance;
3	$\geq 10^{-7}$ & $<10^{-5}$	Rarely occurs, the time of occurrence can be reasonably predicted;
2	$\geq 10^{-9}$ & $<10^{-7}$	Unlikely to happen, rare;
1	$\geq 10^{-9}$	It is very unlikely to happen, meaning it will hardly happen;

Table 2: Risk severity level rating assessment table

Grade	Severity	Consequence loss
A (key)	Disastrous	Sources of risk can lead to death of personnel, loss of equipment supplies, collision of aircraft, or significant damage to assessed items;
B (severe)	Harmful	Risks may cause serious injuries, loss of safety intervals, or serious damage to the assessment items;
C (medium)	Larger	Risks may cause moderate injuries with large gaps, but the assessment project still meets some important requirements;
D (small)	Smaller	Risks cause less damage to personal safety, equipment, materials, etc., with small intervals, and all indicators can still be met;
E (ignorable)	Ignorable	Risk has little effect on the evaluation project;

Table 3: Quantitative table of risk assessment matrix

Risk level		The possibility of an event				
		1	2	3	4	5
The severity of the incident	E	Low (acceptable)	Low (acceptable)	Low (acceptable)	Medium (tolerable)	Medium (tolerable)
	D	Low (acceptable)	Low (acceptable)	Medium (tolerable)	Medium (tolerable)	High (unacceptable)
	C	Low (acceptable)	Low (acceptable)	Medium (tolerable)	High (unacceptable)	High (unacceptable)
	B	Low (acceptable)	Medium (tolerable)	Medium (tolerable)	High (unacceptable)	High (unacceptable)
	A	Medium (tolerable)	Medium (tolerable)	High (unacceptable)	High (unacceptable)	High (unacceptable)

2.3 Conflict resolution method

If a potential flight conflict is detected in 2.2, in order to prevent the conflict, a conflict resolution procedure must be performed, which can generally be analyzed in accordance with Fig. 3, and then the conventional resolution strategy can be calculated. According to the actual situation and the results of calculation, the most suitable scheme is selected for conflict resolution. Conflict resolution is mainly realized by changing altitude, adjusting speed and changing the course of aircraft. As three means of conflict resolution, they can be used separately or synergistically. Among them, changing the flight level is the simplest and most direct way to control command.

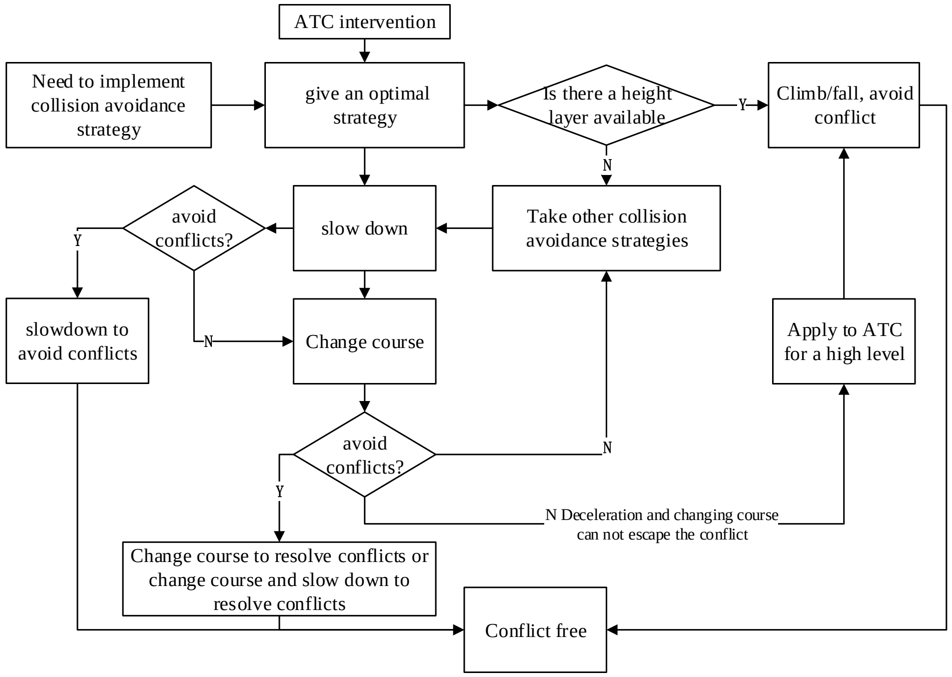

Figure 3: Program diagram of conflict resolution algorithm

3 UAV programs operation in non-segregated airspace

1) UAV adopts integrated navigation technology based on satellite-based, land-based navigation systems and airborne navigation. Regardless of which integrated navigation method is used, the technical route is basically the same. Here we take the ADS-B and TCAS-based navigation combination as an example. This paper proposes a technical line of monitoring perception based on a comprehensive situation, as observed in Fig. 4.

2) In order to ensure the safe operation of UAVs, UAVs must be able to integrate the target information of the airborne detection system, other aircraft information sent by the ADS-B system, and a series of ground control information. According to above information, UAVs can achieve autonomous threat perception, and determine the best conflict resolution strategy based on the air situation. Then it can plan the optimal conflict resolution route in real time, in the end UAV can flight on the optimal route via onboard flight control system. The technical route is shown in Fig. 5.

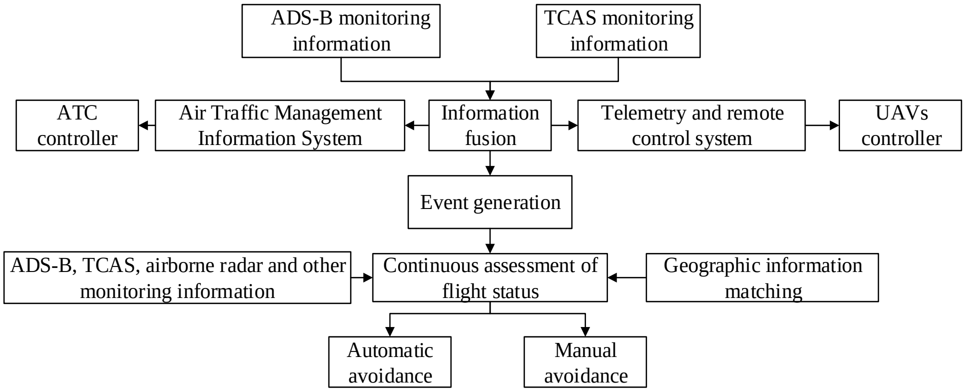

Figure 4: A schematic diagram of flight conflict detection technology route for UAV operation

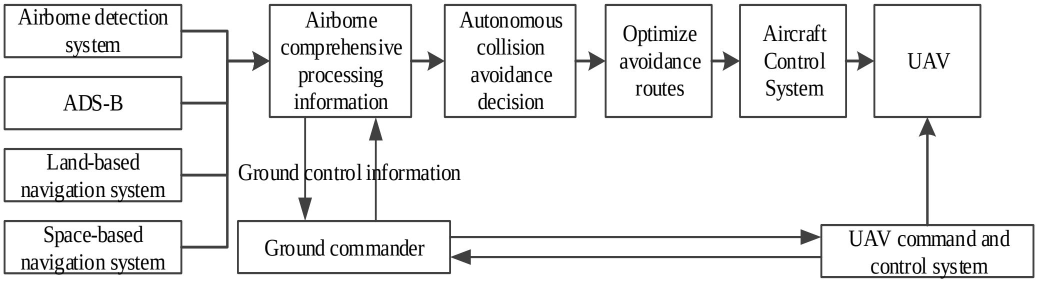

Figure 5: Technical roadmap of UAV optimal avoidance route

4 Conflict risk assessment experiment

4.1 UAV protection area model

Due to the limitations of maneuverability of UAVs and the influence of factors such as the corners of the turn, the length of the track segments, and the flight altitude, UAVs avoidance conditions are more stringent. As the cylinder protection area model is based on the Reich model, and can fully meet the required safety intervals, so that, this study establishes a UAV protection area model based on the cylinder protection area model. Set the radius of the cylindrical UAV protection area to $R = R_{ori} + R_{add}$, its increasing radius $R_{add} = D + V \times T$, D is the length of the minimum track segment, V is the average cruising speed, and T is the time required for conflict resolution. In order to enable the UAVs to change the flight track to escalate the conflict without affecting the operation of the aircraft in the airspace, it is necessary to satisfy $D = 1000\text{m}, V \times T = 2000$ m:

Horizontal direction $$R = R_{ori} + R_{add} = R_{ori} + D + V \times T, R = 13 \text{ km} \quad (9)$$

Vertical direction $$Y = Y_{ori} + Y_{add} = Y_{ori} + D + V \times T, Y = 500 \text{ m} \quad (10)$$

Therefore, the UAV extended protection area model is shown in Fig. 6.

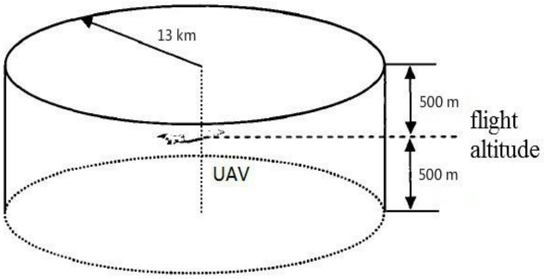

Figure 6: UAV extended protection area model

4.2 UAVs conflict scenario

This paper focuses on the research of large UAVs equipped with ADS-B, TCAS, etc. The potential conflict of definition means that all the aircraft that invade the UAV's protected area are potential sources of conflict. The potential conflict resolution is to make the interval between UAV and civil aviation aircraft larger than the UAV protection area. The following data obtained through simulation experiments are used to calculate the collision probability and the conflict resolution capability. The experimental scenario is shown in Fig. 7.

Experimental scenes are divided into 4 categories:

(1) UAV1 is manually evaded, and there is no special situation; it executes the job when it arrives at the operation area at the bottom of the airport from LUX, approaching the LUX-2A approach procedure; appearance time: 00 min; height 2400 m;

(2) UAV2 is manually evaded; there are special situation; it executes the job when it arrives at the operation area at the bottom of the airport from LUX, approaching the LUX-2A approach procedure; appearance time: 00 min; height 2400 m;

(3) UAV3 automatically avoids evacuation; it executes the job when it arrives at the operation area at the bottom of the airport from LUX, approaching the LUX-2A approach procedure; appearance time: 00 min; height 2400 m;

(4) UAV4 is manually evaded, but because of the large number of aircraft in the airspace,

the controller cannot perform manual evasion, and the UAVs automatically performs automatic evasion; it execute the job when it arrives at the operation area at the bottom of the airport from LUX, approaching the LUX-2A approach procedure; appearance time: 00 min; height 2400 m.

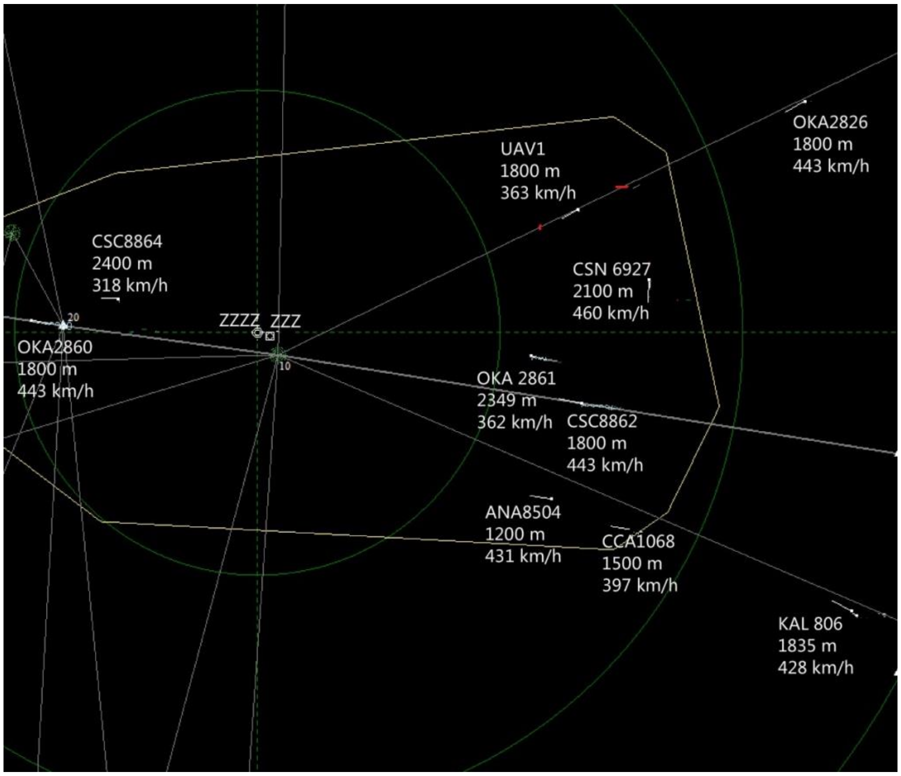

Figure 7: Experiment scene diagram of non-isolated airspace UAVs operation

1) Experiment (1) conflict analysis is shown in Tab. 4.

Table 4: UAVs conflict analysis table

Potential conflicts	Potential conflict liberation average time	Short-term collision alarms	Short-term conflict mitigation average time	UAVs collision probability
5	11.786 s	0	0	3.58452×10^{-6}

Experiment (1) the probability of conflict risk as shown in the following Fig. 8.

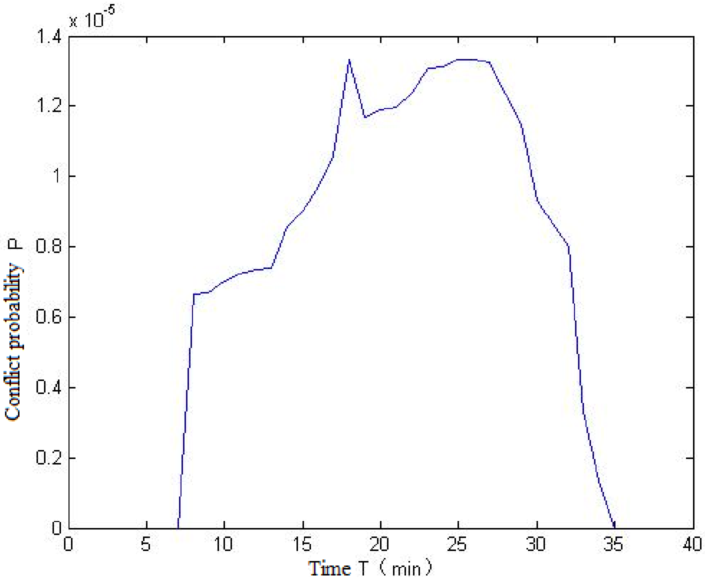

Figure 8: UAV1 conflict probability diagram

Experiment (1) shows that UAVs flight is safe under artificial avoidance conditions. There is no short-term conflict alert, indicating that the UAVs did not invade other airspace users' flight protection areas, protecting the safety of other users in the airspace. According to the UAV conflict analysis Tab. 1, the probability of occurrence of conflict events is P which is greater than 10^{-7}, less than 10^{-5}, and the level of P is 3. Conflict events are seldom seen and can be reasonably predicted at some time. According to the risk severity rating scale 2, UAV has no short-term conflict warning. The severity level is C (medium). It is considered that the risk may cause moderate injury (large interval loss), but the evaluation project still meets some important requirements. The final risk assessment as 3C, based on risk assessment matrix quantization Tab. 3, this program risk level 3C, is "tolerable" level, but still has a certain degree of risk, indicating the involvement of unmanned aerial vehicles increases the burden of limited space capacity, which has a large number of potential conflicts and a long time to remove potential conflicts.

2) The conflict analysis of experiment (2) is shown in the following Tab. 5.

Table 5: UAVs conflict analysis table

Potential conflicts	Potential conflict liberation average time	Short-term collision alarms	Short-term conflict mitigation average time	UAVs collision probability
4	13.674 s	0	0	3.11292×10^{-6}

The probability of conflict risk for experiment (2) is shown in the Fig. 9 below.

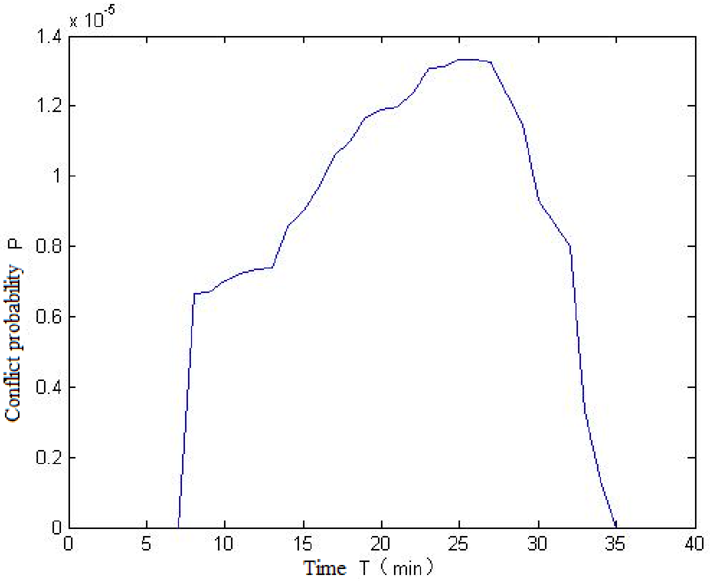

Figure 9: UAV2 conflict probability diagram

Experiment (2) shows that artificial evasive, under special circumstances, UAVs flight is more secure. There is no short-term conflict alert, indicating that the UAVs did not invade other airspace users' flight protection areas, protecting the safety of other users in the airspace. According to the UAV conflict analysis Tab. 1, the probability of occurrence of conflict events is P which is greater than 10^{-7}, less than 10^{-5}, and the level of P is 3. Conflict events are seldom seen and can be reasonably predicted at some time. According to the risk severity rating Tab. 2, the UAVs does not have a short-term conflict alert and the severity rating is C (moderate). The risk may cause moderate damage (larger interval), but the assessment project still meets some important requirements; the final assessment is 3C, according to the risk assessment matrix quantization Tab. 3, this program risk level 3C, is a "tolerable" level. However, it still has a certain degree of danger, indicating that as the UAVs as the key guarantee aircraft, the burden on the limited airspace capacity is increased when safeguarding the unmanned direct operation area, although the collision probability and quantity are smaller than the experiment (1), but the decrease is not obvious, and it takes a long time to free potential conflicts.

3) The conflict analysis of experiment (3) is shown in the Tab. 6.

Table 6: The average timetable for collisions between UAVs and liberation conflicts

Potential conflicts	Potential conflict liberation average time	Short-term collision alarms	Short-term conflict mitigation average time	UAVs collision probability
4	18.038 s	0	0	6.89629×10^{-6}

The probability of conflict risk for experiment (3) is shown in the Fig. 10.

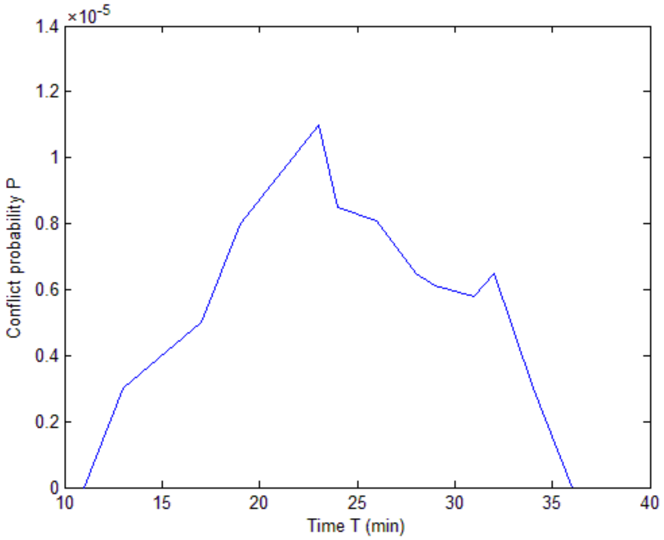

Figure 10: UAV3 conflict probability diagram

Experiment (3) can be seen that under the condition of automatic avoidance, UAVs flight is also relatively safe. There is no short-term conflict alert, indicating that the UAVs did not invade other airspace users' flight protection areas, protecting the safety of other users in the airspace. According to the UAV conflict analysis Tab. 1, the probability of occurrence of conflict events is P which is greater than 10^{-7}, less than 10^{-5}, and the level of P is 3. Conflict events are seldom seen and can be reasonably predicted at some time. According to the risk severity rating Tab. 2, the UAVs does not have a short-term conflict alert and the severity rating is C (moderate), The risk may cause moderate damage (larger interval), but the assessment project still meets some important requirements; the final assessment is 3C, according to the risk assessment matrix quantization Tab. 3, the program risk level 3C, is a "tolerable" level. However, it still has a certain degree of danger, which means that due to the automatic evasion of UAVs, it takes a long time to escape potential conflicts and imposes a burden on the limited airspace capacity.

4) The conflict analysis of experiment (4) is shown in the following Tab.7.

Table 7: The average timetable for collisions between UAVs and liberation conflicts

Potential conflicts	Potential conflict liberation average time	Short-term collision alarms	Short-term conflict mitigation average time	UAVs collision probability
6	24.645 s	1	1.033	9.9989×10^{-6}

The probability of conflict risk for experiment (4) is shown in the Fig. 11.

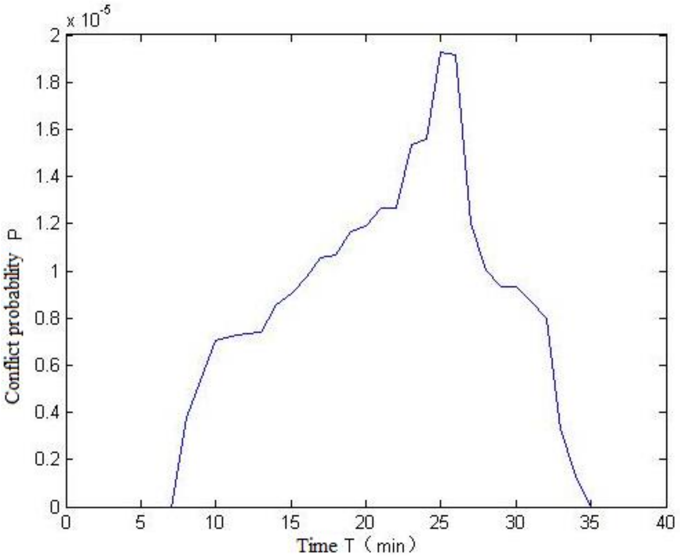

Figure 11: UAV4 conflict probability diagram

Experiment (4) shows that because of the large number of aircraft in the airspace, the controller cannot perform manual evasive maneuvers and the UAVs automatically switch to automatic evasion. Under such conditions, the flying safety of UAVs is facing great challenges. Experiments let the UAVs conflict with the manned aircraft and generate short-term conflict warnings. The UAVs intrudes into flight protection areas of other airspace users and affects the safety of other users. According to the UAV conflict analysis Tab. 1, the probability of occurrence of conflict events is P which is greater than 10^{-7}, less than 10^{-5}, and the level of P is 3. Conflict events are seldom seen and can be reasonably predicted at some time. According to the risk severity rating Tab. 2, the UAVs has a short-term conflict alert and the severity rating is B, considering that the risk may cause serious Injury, loss of safety intervals, or serious damage to the assessment project; final assessment is 3B, according to the risk assessment matrix quantization Tab. 3, this program risk level 3B, is “tolerable” level, but still has certain risks. It shows that after expanding the protected areas of UAVs, UAVs automatically turn to automatic avoidance conflicts, but it takes a long time to relieve them, causing dangers to other users and increasing the burden of limited airspace capacity.

The above experimental result indicates that UAVs entering non-isolated airspace do indeed interface with other aircraft in the airspace. However, in the above four types of experiments, the conflict risk level of the experimental scheme is “tolerable”, which indicates that the large UAVs with airspace situational awareness equipment such as ADS-B and TCAS enters the non-isolated airspace, the applicable conflict detection is applied and the resolution strategy will not cause major threats to civil aviation aircraft, and airspace operations will be relatively safe. In addition, due to the large number of aircraft in the airspace, when the controller cannot perform manual avoidance, the UAVs starts the automatic avoidance system, the probability of collision increases by two orders of magnitude and generates a conflict warning, but this risk is still within an acceptable range.

5 Conclusion

According to the performance characteristics of large UAVs, this paper establishes the protection model of the cylinder UAVs based on the Reich model, and analyzes the collision probability of large UAVs with airborne sensing systems such as ADS-B entering the non-isolated airspace. Comprehensively assess the risk level from the perspective of the possibility and seriousness of the conflict and propose conflict resolution methods. The results of the four simulation scenarios show that UAVs entering non-isolated airspace do indeed interface with other aircraft in the airspace, but under the controller evade, UAVs will not pose a threat to civil aviation. When the number of aircraft in the airspace is too large to perform manual evasive and the automatic avoidance system for UAVs is started, the probability of conflict increases by two orders of magnitude, which increases the avoidance time and triggers safety alerts. It can be known from the matrix of risk assessment matrixes, risk is still within an acceptable range. Above experimental results show that under certain conditions, it is relatively safe for large UAVs to enter non-isolated airspace. This research result can provide a reference for the future development of a safe operation plan for non-isolated airspace of UAVs.

Acknowledgement: The authors would like to thank National Nature Science Foundation of China under Grant (71701202). The special funding project of Civil Aviation University of China for the basic scientific research services of the Central University (3122013Z006).

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