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Lateral conflict model of training flight based on subjective factors

Kaijun Xu*, Yusheng Yao, Shanshan Li

Institute of Flight Technology, Civil Aviation Flight University of China, Guanghan Sichuan 618307, China

The flight lateral conflict model which is based on human subjective factors has always been a research hotspot for training flight. In order to effectively evaluate the safety interval and lateral collision risk in training airspace, in this paper, pilot subjective factors were modeled. It was studied in lateral conflict risk of low altitude complex flight by flight performance shaping factor. By analyzing flight data of a flight training institution in China, it is pointed that the lateral collision risk in specific training airspace meets the requirement of safety target level of international civil aviation organization. The collision risk of circle procedure and eight characters procedure is 2.9264×10^{-13} and 3.19232×10^{-13}. The results indicate that the lateral conflict model of training flight based on subjective factors is an effective method to analyze collision risk of low altitude complex flight.

Keywords: Subjective factors; flight performance shaping factor; lateral conflict risk; low altitude complex flight; air traffic control

1. INTRODUCTION

The aircraft flight safety under pilots' subjective manipulation is always of intriguing interest as well as difficulty in international aviation research. In addition, the flight accident rate of aircraft under manual operation is ten times more than that of normal flight. While, when having low-altitude complex training flight, whether pilots can manually operate aircraft under subjective manipulation to complete the instructions still lacks in-depth exploration.

During flight, a thought or the mood fluctuation all play a vital role in flight safety. In the past 20 years, accidents relating to subjective manipulation of pilots can be found everywhere: in 1999, the Egyptian Airways flight MS990 flew from New York to Cairo crashed into the Atlantic Ocean and 216 passengers were killed; in 2013, Mozambique flight TM470, bound for Luanda from Maputo, crashed on the way and killed 34 passengers, including a Chinese citizen. Later, the wreckage was found in Namibia; in 2014, Malaysia Airlines flight MH370 lost during flight, and more than 300 people on board are still missing; in 2015 German wing 4U9525 flight crashed in The French Alps, leaving no survivors ... These examples are all closely related to pilot's behavioral intentions and mood fluctuations.

Whether pilots can perform correct maneuvering under low-altitude and complex conditions is directly linked to human reliability, including: human cognitive behavior description, human error cause analysis, human error probability quantification, human events probabilistic risk assessment and human error avoidance measures and so on. Along with thorough research, it has become a general consensus among researchers that human error is induced by one's scenario [1, 2]. Methods such as TRACEr (Technique for the Retrospective and Predictive Analysis of Cognitive Errors) [3, 4] and HFACS (Human Factor Analysis and Classification Systems) [5,6] both used PSF (Performance Shaping Factors) as the surface characteristics to analyze the cause of human error. In order to quantify the human error probability, researchers analyze performance shaping factors by applying different models of THERP [7, 8], HEART [9], SLIM [10, 11], ATHEANA [12, 13] and CREAM [14, 15, 16] and other methods. HEART and IDAC [17, 18] and other methods based on performance shaping factors are also used to reduce and avoid human error and provide specific measures. At present, the study of human reliability is mainly applied to the field of nuclear power security, while, and the risk of flight conflict caused by human reliability in flight is rarely studied.

In this paper, the risk of lateral conflict under low-altitude complex training flight condition is discussed, and the human reliability under subjective manipulation is modelled. Firstly, with cognitive model, this paper studies the human reliability problem of lateral conflict risk in low-altitude complex training flight. Then, by analyzing the risk factors of lateral collision, a

*Corresponding author. E-mail: k_j_xu@163.com

collision model based on flight performance shaping factors is established, and the probability value of flight behavior model change is discussed according to the scenario of the pilot, and the collision risk under the influence of subjective factors is quantitatively calculated. At last, the validity of the subjective factors model for the risk assessment of lateral flight conflict in training flight is verified by examples.

2. TRAINING FLIGHT CHARACTERISTICS AND LATERAL COLLISION MODEL UNDER SUBJECTIVE FACTORS

2.1 Characteristics of Low-level complex training flight

China's civil aviation regulations state that low-altitude airspace, in principle, includes all airspace below 1000 meters true height. According to CCAR-91/141, flight training in China falls under the category of general aviation, and is mostly conducted in low-altitude airspace. The high intensity and concentration of training aircraft in low-altitude airspace is subject to diverse terrain, obstacles, extreme weather and other complex environmental factors, which presents a high risk of lateral collision for aircraft at the same level.

Civil aviation flight training has its unique characteristics. Pilots should perform the training with primary, intermediate or advanced trainer aircraft, in designated training airspace and at the designated training altitude, and in accordance with the pre-established training flight plan. Training airspace and height are all restricted to low-altitude, while subjects for training are all types of trainer aircraft, which are heterogeneous aircraft because of their diverse flight performances. Furthermore, pilots' lack of relevant flight skills and experiences brings many uncertainties.

In the flight training, the situation of an aircraft's surrounding airspace should be monitored in real time so that collision risk can be identified and avoided timely. Low-altitude complex airspace training activities must also consider the subjective reliability of the pilots' correct operation in order to achieve the planning and guidance of intensive flight mission. Therefore, the key to ensure safety and efficiency of the flight training is to realize the mapping between the aircraft motion state and the collision risk under low-altitude complex conditions and to construct the lateral collision risk model under the influence of the pilot's subjective manipulation.

2.2 Analysis of Subjective Influencing Factors of Collision Risk

Traditional flight situation monitoring considers more about the objective flight conditions, while ignores the most important subjective cognitive activities of decision makers and executors—human. In current air traffic control, controllers, the decision makers, or pilots, the executors, all need take mental and physical interactive activities in complex and unpredictable environment. Thus, controllers and pilots are required to, by making full use of limited resources, constantly perceive, make decisions, learn and manipulate equipment in a confined space. The pilot's own subjective emotions and flight intentions play a very important role in the correct judgment of flight decisions and the correct execution of flight operations. The objective flight state of the aircraft formed by pilots' subjective operation will directly affect the lateral conflict risk (Figure 1).

2.3 Lateral impact model based on flight performance shaping factors

Performance Shaping Factors (PSF) is defined as: Scenario environmental factors [24], which influence human behaviour, are proposed by Swain when constructing the THERP method. Performance shaping factors is the representation of scenario environment, and various scenario environmental factors constitute the connotation of performance shaping factors. Human behaviour is the result of the combined effect of all the performance shaping factors. Task characteristics, available task time and specific conditions, which fall into the category of scenario environment, should be regarded as a part of the performance shaping factors. Therefore, in this paper, the formation of performance shaping factors is discussed in broad sense, and should include all the factors that can affect the behaviour of the pilots, as shown in table 1.

The influence of different states of performance shaping factors on pilots' behavioral patterns is different. In this paper, the experts' choice, scoring range setting, scoring method construction and synthesis of scoring result— the four aspects will be used to regulate the expert judgment method for evaluating flight performance shaping factors. The association between the rating scale and the value is designed as follows: severe change $\rightarrow$ 0, change $\rightarrow$ 0.5, not obvious $\rightarrow$ 1. The score of the performance shaping factors is given by (1)

$$score = \frac{n_1 \times 0 + n_2 \times 0.5 + n_3 \times 1}{n} \tag{1}$$

n_1 is the number of experts who consider the performance shaping factors to be a "serious change" in the behavioural pattern of the pilots, while n_2 "change" and n_3 "not obvious"; n is the total number of experts.

Considering the relative weights of different experts, formula (1) can be modified:

$$score = \sum_{i=1}^{n} \lambda_i \cdot r_i \tag{2}$$

λ_i is the weight of the expert i, and $\sum_{i=1}^{n} \lambda_i = 1$; r_i is the expert's score of the performance shaping factors.

In actual manual flight, the flight performance shaping factors have different influences on pilot's behavioural patterns, which shows that there are differences in weights of the flight performance shaping factors. In the collision analysis of subjective factors, the weights of performance shaping factors are, on the one hand, the basis of the collision probability quantification

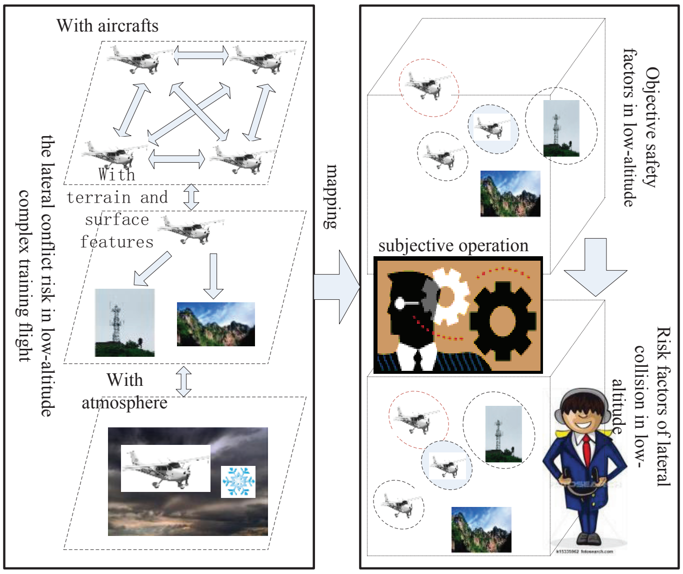

Figure 1 Risk factors of lateral collision in low-altitude complex flight.

Table 1 Flight performance shaping factors.

performance shaping factors categories	Primary performance shaping factors elements	Secondary performance shaping factors elements
pilots	Knowledge, experience	Personality, natural skills
Flight instruments and control systems	Effectiveness of information display	Shape and color of display devices; Display mode and layout of display devices;
Flight mission	Available task time, the novelty of the task	Complexity of the tasks, number of tasks, the correlation between tasks
Flight organization team	Management system, safety culture	The division of task / responsibility
Flight environment	Sound, light, vibration, temperature, humidity	Other natural environmental factors, comfort, safety
auxiliary system	Air - ground assistance personnel	Air traffic controllers

method, and on the other hand, it can provide valuable guidance for the formulation of subjective factor error avoidance measures.

Generally speaking, the flight practice will accumulate a certain number of data about objective and subjective conflict, which will contain information about the change of the flight pattern and its causes. The causes of the change of the flight pattern are the performance shaping factors in different states. Therefore, the flight data can be processed by a certain statistical analysis method, and the correlation between each factor's cause and the flight behavioural pattern can be obtained, so as to determine the weight of the performance shaping factors.

Association rules are the implications which can be expressed as $X \Rightarrow Y$. Among them, X is called rule premise, and Y is called rule result. Thus, the meaning of association rule $X \Rightarrow Y$ is: If Xappears, Y will also appear. There are two indicators to measure the validity of association rules: support and confidence.

The support degree of association rules refers to the frequency of the association rules appearance in data sets, which reflects the prevalence and university of association rules. For association rule $X \Rightarrow Y$, its support is usually defined as the ratio of the number of items in the data set that contains both items $X$and Y to the number of all data, and it denoted as $\text{Support}(X \Rightarrow Y)$,

$$\text{Support}(X \Rightarrow Y)=P(XY) \tag{3}$$

The confidence degree of association rules refers to the credibility degree of association rules, reflecting the degree of association between two items. For association rule $X \Rightarrow Y$, the confidence of the association rule is defined as the ratio of the number of data in a data set that contain both items X and Y to the number of data only containing item X, and it denoted as Confidence(X $\Rightarrow Y$)

$$\text{Confidence}(\text{X} \Rightarrow Y)\text{=P}(\text{Y}\,|X\,) \tag{4}$$

Since different flight behavioural patterns are often caused by different performance shaping factors, so it is necessary to determine the weights of the corresponding performance shaping factors for different flight patterns in order to effectively guide the flight practice. Based on the classification Table 1 of flight performance shaping factors, the flight behavioural pattern and performance shaping factors data set, which association rule mining method need, can be obtained by sorting out human factors events report, flight pattern change and performance shaping factors data report accumulated in flight practice, as shown in Table 2.

According to the definition of association rules confidence, the confidence of association rule ′Flight behavior model $\Rightarrow$ Flight behavior formation factor′ is equal to the ratio of the flight behavioural pattern and the number of one behavior formation factor to the total number of flight behavioural patterns in the data set, and the meaning is: the possibility of a behavioural pattern caused by a certain behavioural factor. Therefore, by calculating the confidence in the association rule ′Flight behavior model $\Rightarrow$ Flight behavior formation factor′ for all the behaviour-formed factors associated with the flight behavioural pattern, and then normalizing the confidence factor, the behavioural formation factor weights corresponding to the flight behavioural pattern can be obtained.

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Note: N_{EM_i} indicates the times of the i type flight behavioural pattern occurs , $n_{EC_{ij}}$ indicates the number of the j type performance shaping factor leading to the i type flight behavioural pattern, Sn_{ECi} indicates the total number of the performance shaping factors leading to the i type flight behavioural pattern , Sn_{ECj} represents the total number of the j type performance shaping factor, SN_{EM} represents the total number of all flight behavior occurrences, Sn_{EC} represents the total number of all the performance shaping factor. Since some flight behaviors may be caused by a variety of performance shaping factors, so $\text{SN}_{EM} \leqslant Sn_{EC}$.

From formula (4), it can be known that the formula of association rule EMi $\Rightarrow$ ECj confidence is

$$\text{Confidence}(\text{EMi} \Rightarrow \text{ECj})\text{=}\frac{n\text{ECij}}{N\text{EMi}} \tag{5}$$

For the flight behavior model EMi, the corresponding performance shaping factor weight is:

$$\omega ij = \frac{\text{Confidence}(\text{EMi} \Rightarrow \text{ECj})}{\sum_{k=1}^{m} \text{Confidence}(\text{EMi} \Rightarrow \text{ECk})},\ j = 1, ..., m,$$
$$\sum_{j=1}^{m} \omega ij = 1 \tag{6}$$

After obtaining the score and weight of performance shaping factors, the scenario can be evaluated synthetically. Assuming $s_1, s_2, ..., s_n$ are the scores of the performance shaping factors (n is the number of performance shaping factors), $\varepsilon_1, \varepsilon_2, ..., \varepsilon_n$ are the weight corresponding to the performance shaping factors, the comprehensive score of the scenario is

$$s_{scenario} = s_1 \times \varepsilon_1 + s_2 \times \varepsilon_2 + ... + s_n \times \varepsilon_n \tag{7}$$

In this paper, the logarithmic linear relationship is used to describe the relation between the comprehensive score of performance shaping factors and the probability of lateral collision of the pilots under manual operation, as shown in formula (8):

$$\log MLC = a \times score_{scenario} + b \tag{8}$$

Among them, MLC is the probability of lateral collision of the pilots under manual operation; a and b are the undetermined coefficients of the logarithmic linear equation. Their values are determined by the "anchor point"; $score_{scenario}$ is the comprehensive score of the performance shaping factors.

According to Bibliography [25], the risk of lateral collision for two aircraft is

$$C_{risk} = 2N \cdot MLC \tag{9}$$

Where N is the number of aircraft in the low-altitude airspace.

3. ANALYSIS OF EXAMPLES TRAINING FLIGHT LATERAL COLLISION BASED ON SUBJECTIVE FACTORS

Based on the questionnaire survey of 25 flight instructors, 25 ground controllers and 10 human factors engineering analysts from a certain flight training institution in China and combined with engineering practice, this paper concludes three flight performance shaping factors: heart rate, respiration and the change of flight plan (controller instruction), and grades the questionnaire. The results are shown in Table 3.

Table 2 Flight behavioural patterns and performance shaping factors.

Flight behavioural pattern number	Number of flight	Flight Performance Shaping Factors Occurrence				
		performance shaping factor 1	performance shaping factor 2	…	performance shaping factor m	total
1	N_{EM_1}	$n_{EC_{11}}$	$n_{EC_{12}}$	…	$n_{EC_{1m}}$	n_{EC1}
2	N_{EM_2}	$n_{EC_{21}}$	$n_{EC_{22}}$	…	$n_{EC_{2m}}$	n_{EC2}
3	N_{EM_3}	$n_{EC_{31}}$	$n_{EC_{32}}$	…	$n_{EC_{3m}}$	n_{EC3}
…	…	…	…	…	…	…
n	N_{EM_n}	$n_{EC_{n1}}$	$n_{EC_{n2}}$	…	$n_{EC_{nm}}$	n_{ECn}
合计	SN_{EM}	Sn_{EC1}	Sn_{EC2}	…	Sn_{ECm}	Sn_{EC}

Table 3 Training flight scenarios behavioural patterns and classification.

Flight performance shaping factors	Serious impact	Impact	Not obvious
Heart rate within standard value	42	18	0
Respiration within the standard value	33	19	8
Flight plan (controller instruction) change	53	7	0

Assuming that flight instructors, ground controllers, and human factor engineering analysts share the same weight, from formula (1) :

$$score_1 = 0.167, \quad score_2 = 0.333, \\ score_3 = 0.083 \tag{10}$$

In manual flight, by applying Biopac MP150 Multiphasic Instrument, BioHarness Portable Physiometer, Tobii Eye Tracker and Acknowledge © analysis software, 84 student pilots'physiologic parameters are measured, including 1254 measurements in the track of circle procedure and 854 measurements of eight character procedure. And real-time physiological indicators of student pilots can be checked and analyzed, as shown in Figure 2&3.

After measuring the 84 student pilots'physiology parameters, then applying the method described above to process the data of the fifth track point in the circle procedure and the fourth point in the eight character procedure, as shown in figure 4,5.

According to the items listed in Table 2 above, in combination with the data in Figure 4-9, the number of occurrences of flight behavior factor PSF1 is increased once when the measured heart rate data is in the standard range (90-140 / min); the number of flight behavior factor PSF2 is increased once when the measured breath data is in the standard range (28-35 / min); the number of occurrences of flight behavior factor PSF3 is increased once when the controller command is issued.

The number of three kinds of flight behavior factors PSF, the confidence level and the weight statistics of the fifth track point in circle procedure and the fourth track point in 8 characters procedure are shown in Table 4.

It is shown that the flight performance shaping factors weight of the fifth point in the circle procedure is $\varepsilon_{51} = 0.255$, $\varepsilon_{52} = 0.255$,$\varepsilon_{53} = 0.489$ respectively. From formulae (7), (10), $S_{scenario5} = 0.168$.

Formula (8) shows that there is a logarithmic linear relationship between the probability of lateral collision MLC and the comprehensive score of performance shaping factor$S_{scenario5}$. According to [26,27], both the ICAO and CAAC have regulated that the safety target level in each direction is 5×10^{-9}, and this paper uses the expression of the human error probability range and the level of the route safety target level in the SHARP method [28] to put forward that in the process of manual flight, the mapping relationship between flight performance shaping factors and the conflict probability interval which is caused by subjective factors satisfies the probabilistic interval of knowledge-based behavioural pattern and ICAO provision, and it is between 5×10^{-15} and 5×10^{-13}. According to the upper and lower limits of the human error probability interval, it is generally set at 0.05 and 0.95 points of the probability distribution function of the human error probability, we regard the probability interval of the collision caused by the subjective factors as 0.05 and 0.95 point of the probability distribution function of the subjective factor conflict probability.

That is, when the comprehensive score of flight performance shaping factors is 0.05, the subjective factor conflict probability value corresponds to the 0.95 points of the probability distribution function; and when the comprehensive score of flight performance shaping factors is 0.95, the subjective factor conflict probability value corresponds to the 0.05 points of the probability distribution function.

From formula (8), $a = 7.3821$, $b = -47.8761$, and then

$$\log MLC = 7.3821 \times score_{scenario} - 47.8761 \tag{11}$$

The probability of the lateral collision of the fifth track point of the circle procedure in manual operation is $MLC_5 = 9.145 \times 10^{-15}$.In a flight training institution, a flight brigade with 32 aircraft performing training tasks, and the logarithm of aircraft

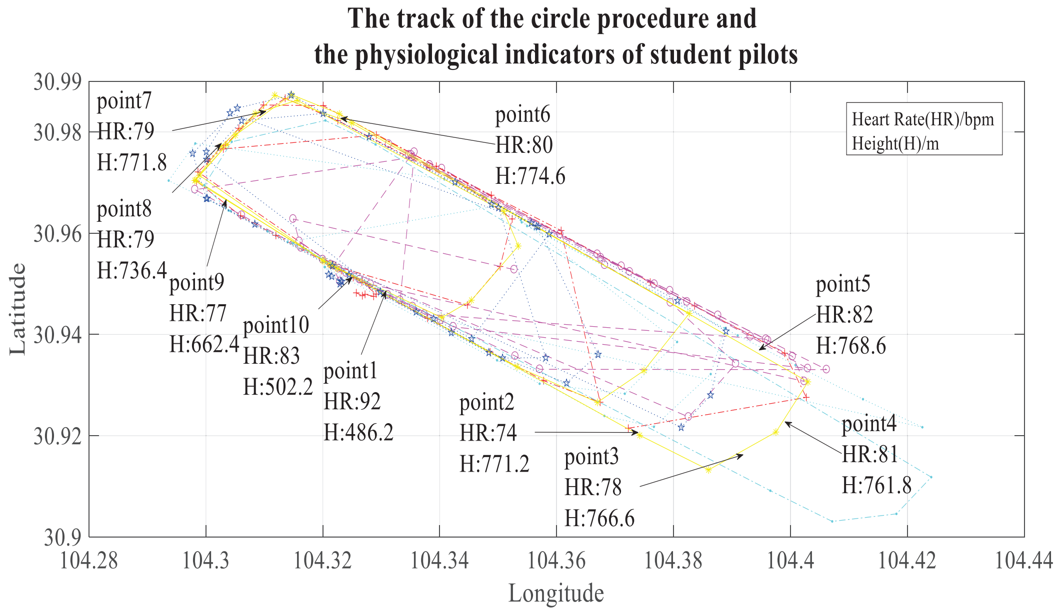

Figure 2 Flight data of the circle procedure in a domestic flight training institution.

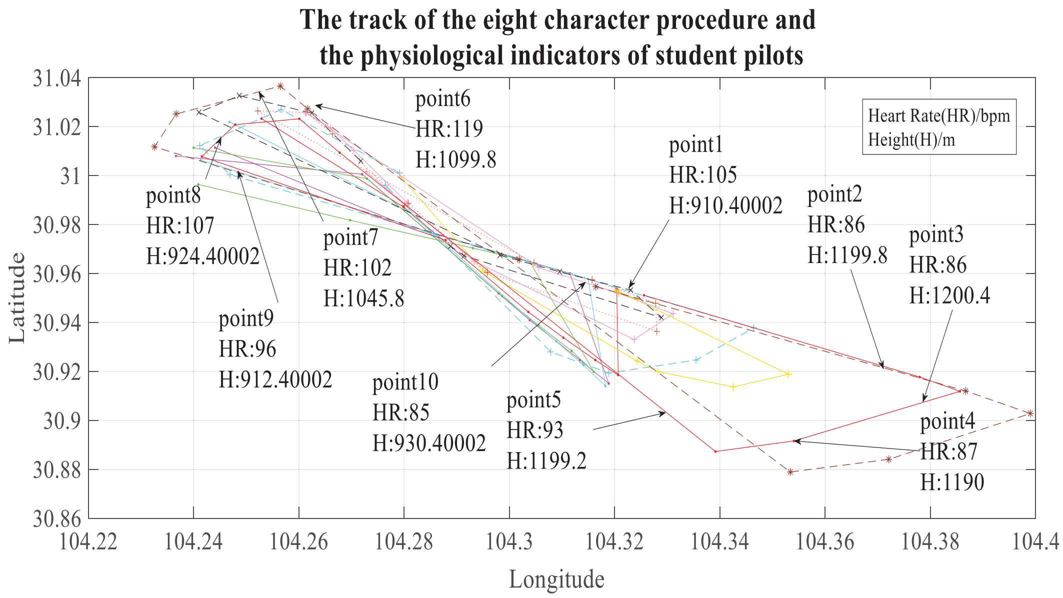

Figure 3 Flight data of the eight character procedure in a domestic flight training institution.

is $N = 16$, and from (9),the risk of two aircraft lateral collision risk is $C_{risk} = 2.9264 \times 10^{-13}$.

In the same way, the fourth track point's flight performance shaping factors weights, are $\varepsilon_{41} = 0.258$, $\varepsilon_{42} = 0.323$, $\varepsilon_{43} = 0.419$ respectively. From formulae (7) and (10),$S_{scenario4} = 0.185$. From formula (11), the probability of lateral collision of the fourth track point of the eight character procedure in manual operation is $MLC_4 = 9.976 \times 10^{-15}$. From (9), the lateral conflict risk of two aircraft is $C_{risk} = 3.19232 \times 10^{-13}$.

Comparing the risk value of the two aircraft lateral collision calculated by the flight performance shaping factors with the predetermined safety target level (ICAO regulates the route safety target level is 5.0×10^{-9}), it can be concluded that under the existing lateral safety clearance standard, the current flight training safety level meets the pre-defined safety target level requirements.

4. CONCLUSIONS

This paper discusses flight lateral conflict risk by applying pilot's subjective factors. Firstly, the flight performance shaping factors are used to construct the lateral conflict risk model under pilots' subjective factors. Based on the recognition of flight behavioural and the characterization of scenario, the synthetic evaluation of the manual flight scenario and the quantification of the risk probability of lateral collision between the two aircraft

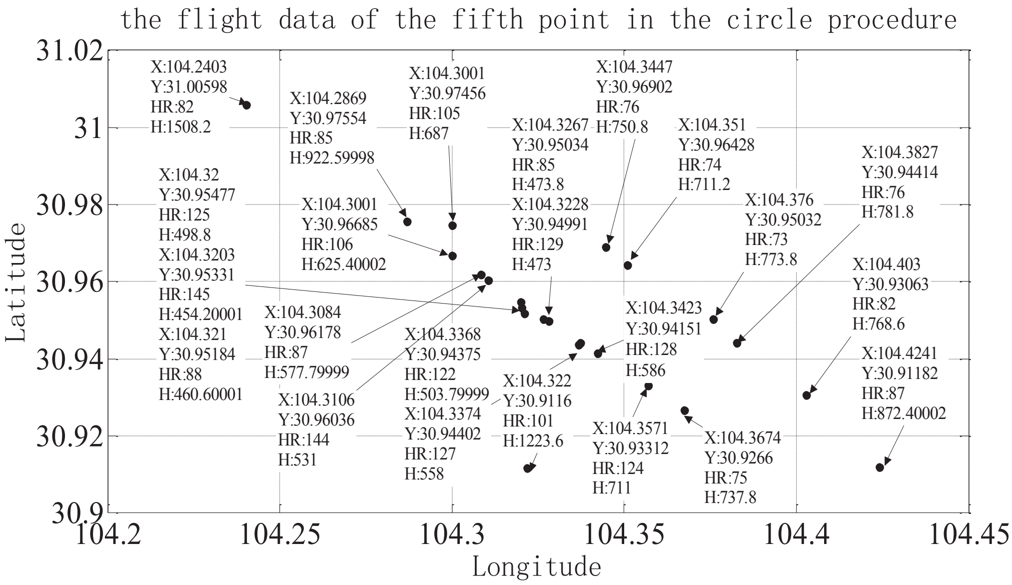

Figure 4 Flight data of the fifth point in the circle procedure.

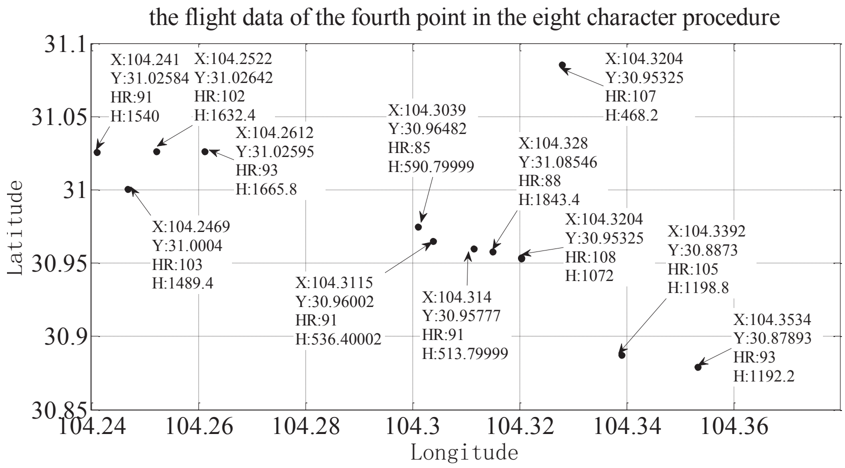

Figure 5 Flight data of the fourth point in the eight character procedure.

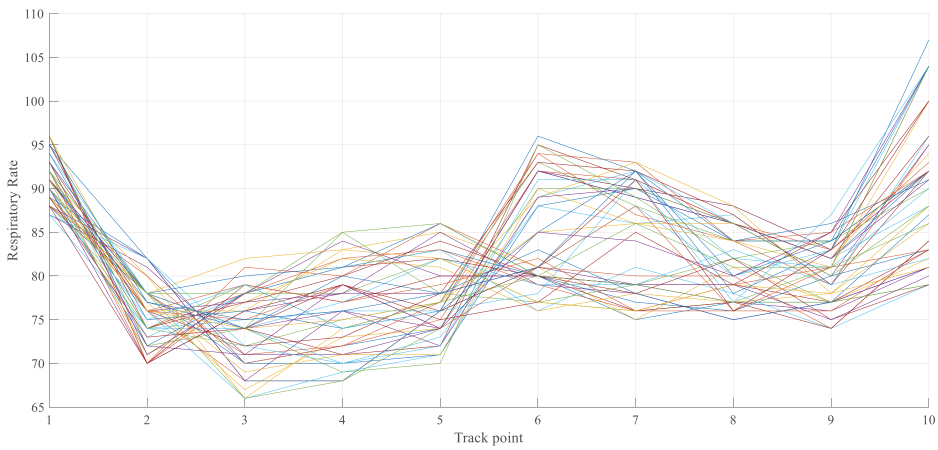

Figure 6 Heart rate in circle procedure.

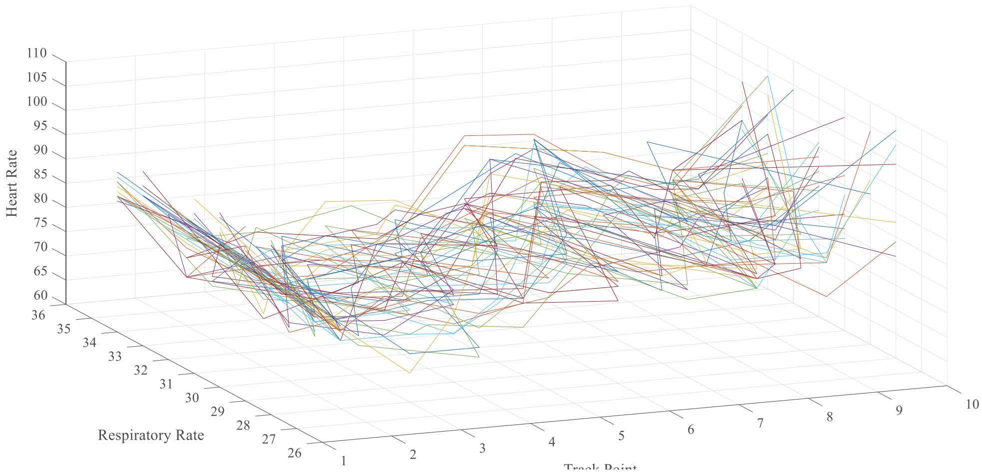

Figure 7 Heart-breath in circle procedure.

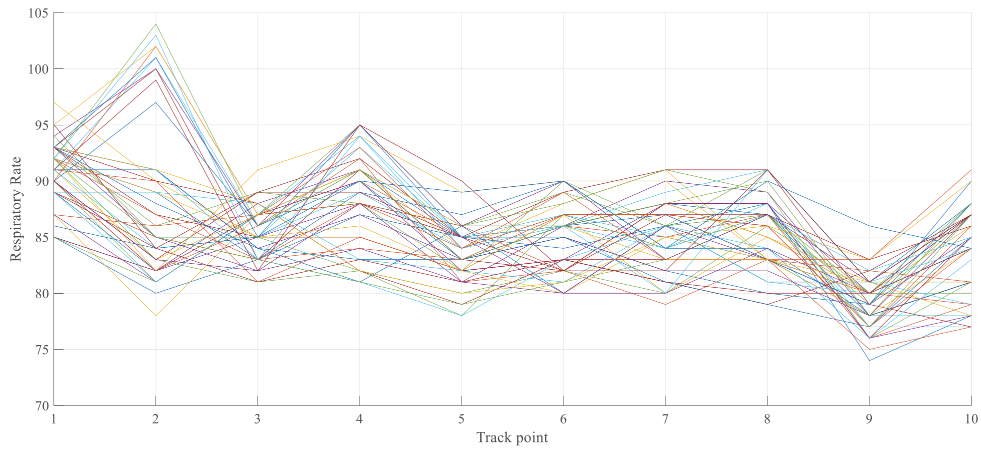

Figure 8 Heart rate in 8 characters procedure.

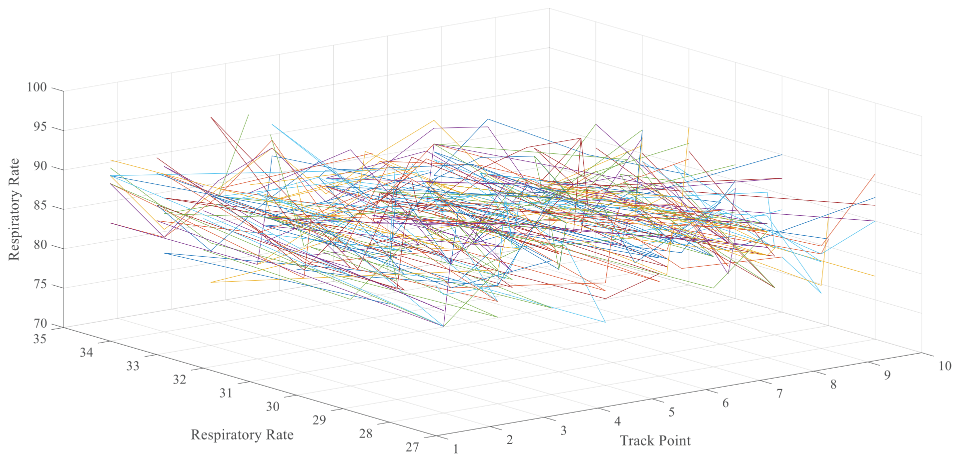

Figure 9 Heart-breath in 8 characters procedure.

are achieved.Then by analyzing flight data of a flight training institution in China, it is pointed that the lateral collision risk in specific training airspace meets the requirement of safety target level of international civil aviation organization. The collision risk of circle procedure and eight characters procedure is 2.9264×10^{-13} and 3.19232×10^{-13}. The results indicate that the lateral conflict model of training flight based on subjective factors is an effective method to analyze collision risk of low altitude complex flight.

In the analysis of examples, the collision risk probability

Table 4 Occurrences statistics of flight performance shaping factor.

			Phase of Flight				
			the circle procedure at point 5		the eight character procedure at point 4		
Occurrence number of PSF	PSF1(within the standard range of Heart Rate)	Occurrence number	986	986	656	656	656
		Confidence	1.091	1	2	4	0.889
		Weight	0.255	0.255	0.258	0.258	0.258
	PSF2(within the standard range of Respiratory Rate)	Occurrence number	986	986	821	821	821
		Confidence	1.091	1	2.5	5	1.111
		Weight	0.255	0.255	0.323	0.323	0.323
	PSF3(the change of flight plan(controllers' instructions)	Occurrence number	1890	1890	1068	1068	1068
		Confidence	2.091	1.917	3.25	6.5	1.444
		Weight	0.489	0.489	0.419	0.419	0.419
Summation			3862	3862	2876	2876	3287

derived from the models is compared with the ICAO's predetermined safety objective, which further improves the training airspace safety assessment. This method can make a scientific assessment of the safety level of the low-altitude training airspace or busy terminal area. It can also verify pilots' subjective operation meet the safety requirements.

Since the current study on PSF data statistics and reasons is still incomplete, and the reliability of pilots' subjective operation involves many human factors such as flight intentions, flight cognition and so on, more in-depth researches are required in this field. In conclusion, the lateral collision models established in this paper lay a solid foundation for further study of collision risk at low-altitude complex flight conditions.

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Kaijun Xu received Ph.D. degree in Traffic Information Engineering and Control at School of Information Science and Technology, Southwest Jiaotong University. He works at Institute of Flight Technology, Civil Aviation Flight University of China (CAFUC). He also works at Beihang University as Post-doctoral. He is Associate Professor in CAFUC and his research interests are cognitive affective computing, air traffic management, modern navigation technology. He has published more than thirty papers in international Journals, core Journals in China and international meeting, more than twenty papers are indexed by SCI and EI.

E-mail: k_j_xu@163.com, TEL:18602888859

Yusheng Yao is a master degree candidate of Institute of Flight Technology, Civil Aviation Flight University of China. His research interest is the theory and method of modern navigation.

E-mail: y_s_yao@163.com, TEL:18227109562

Shanshan Li is a master degree candidate of Institute of Flight Technology, Civil Aviation Flight University of China. Her research interest is the theory and method of modern navigation.

E-mail: feilin_li@163.com, TEL:15283829022