Impact Analysis of RECAT to Terminal Airspace Capacity

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Abstract: With the rapid development of the civil aviation industry, the number of flights is increasing, the airspace is becoming saturated, flight delays are increased, and the wake turbulence separation standard is one of the main factors. This paper study the effects of different standards on the airspace capacity of the terminal area and simulates the FCFS model with real flights data to evaluate CAAC's and FAA's (RECAT) wake turbulence separation standards. The simulation results show that the RECAT's wake turbulence separation standards are more efficient than CAAC's and increase about 17% of the airspace capacity in the given case.

Nomenclature

CAAC	Civil Aviation Administration of China.
FAA	Federal Aviation Administration.
ASS	Arrival sequencing and scheduling.
ATC	Air traffic control.
FCFS	First-come first-served.
ATCC	Air Traffic Control Center

1. Introduction

Recent years, China's civil aviation industry has developed rapidly, and its transportation business has been increasing. With the demand for transportation increases, the airspace tends to be saturated, and the limited airspace resources causes contradictions arising. Also, the number of flights at major airports has also increased, resulting in an increasing load on the airport, from full load to overload, resulting in many flight delays. Flight delays not only caused huge economic losses, but also caused inconvenience to passengers. Most of the major domestic airports have or plan to build new runway to increase the throughput of the airport. In China's "The 13th Five-year Plan", China will build 53 new civil airports at the end of 2020 [1], and the number of airports in China will reach 260, which can further increase the transportation volume while optimizing and reducing flight delay.

In fact, flight delays have not been effectively avoided, even increased. The average delay times of passenger flights in the past three years are 21, 16, and 24 minutes, respectively [2-4]. The construction of the airport has many restrictions and costs lots of time and money. Therefore, in this situation of increasing flights, the construction and expansion of airports is not an effective solution. According to statistical results, the factors that lead to abnormal flights have weather, airline, ATC and so on. Different from weather and airline factor, ATC factor is more controllable. In 2015, 30.68% of abnormal flights is caused by ATC [4]. In fact, due to the increasing volume of civil aviation traffic, air traffic control has been studied for decades as a hotspot of transportation [5]. ASS is one of the most significant problems in ATC, many methods, such as travelling salesman problem modeling, dynamic programming, expert system, Monte Carlo optimization, and evolutionary computing, have been used to solve the position-shifting-based ASS problem [6-7]. But none of they consider the wake turbulence separation standards which is one of the most significant factors to ASS. This paper considers the different wake turbulence separation standards in CAAC's and FAA's

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order and studies the effect of the standards on the airspace capacity of the terminal area.

2. Wake turbulence separation standards

The wake is the accompanying product of the aircraft's lift. When the trailing aircraft encounter the wake turbulence affected zone of the lead aircraft, it will cause serious consequences such as roll, pitch, bump, and losing height. Therefore, the wake turbulence separation standards are established. Guarantee the flight safety of the aircraft. The current wake turbulence separation standards currently implemented in China is issued by CAAC in 2017, including Aircraft Wake Categories, Wake Turbulence Separation and so on.

Table 1. Aircraft Types Categorized by CAAC

Type	**Weight Range(m/kg)**	
	Minimal MTOW	***Maximal MTOW***
A388		
H	136000	
M	7000	136000
S		7000

Table 2. CAAC's Radar Separation - On Approach

Lead Aircraft	**Trailing Aircraft**			
	A388	H	M	S
A388		6	7	8
H		4	5	6
M				5
S				

The categorization of aircraft in CAAC's order is as shown in Table 1 according to the maximum take-off weight of the aircraft. The aircraft is divided into four categories: A388, H, M, and S. The Airbus A380 is divided individually because its wake turbulence strength is stronger than others'. Table 2 shows the standards of the wake turbulence separation in CAAC's order. The value in the table means the minimal radar separation when aircraft approaching. For example, the Category H aircraft should keep at least 6 nautical miles(nm) after the A388. The blanks in Table 2 indicate that there is no specific radar separation. In this case, the aircraft should keep the basic minimum radar separation which is 3.2nm or 2.6nm in some airports in CAAC's order [8].

The wake turbulence separation standards implemented by FAA are the Wake Turbulence Recategorization document [9] in the order named JO7110.123, which came into effect on March 8, 2016. The categorization of aircraft in the order is shown in Table 3. The minimum radar separation shown in Table 4.

Different from the CAAC aircraft categorization, as shown in Table 3, FAA divides the aircraft into 7 categories, from A to G. The symbols in Table 3 are ICAO's codes for aircraft, representing different models of aircraft. Both CAAC and FAA categorize Airbus A380 individually, but the FAA categorizes aircraft more specific. In addition, unlike CAAC, which categorizes aircraft according to its MTOW, the FAA categorizes specific models to different types. Compared with the specific models in the FAA, Category B, C and G correspond to the Category H in the CAAC's order, Category D and E correspond to Category M in the CAAC order, and Category E and F correspond to Category S in the CAAC's order. The FAA also lists some aircrafts which have strong wake and categories them into Category G. The values in Table 4 are the minimal radar separation should be maintained on approach. The blanks indicate that the basic minimum radar separation which is 2.5 nm [9]. The FAA's wake turbulence separation is shortened comparing to CAAC's standards. For example, if the lead aircraft is A388, the trailing aircraft is A332, the separation in FAA's standards is 4.5 nm, and in CAAC's standards is 6 nm. Obviously, the separation is shortened. This paper will make comparison under these two standards.

Table 3. AIRCRAFT TYPES CATEGORIZED BY FAA

A	B	C	D	D	D	E	F	G
A388	A332	A306	A318	CL60	F16	ASTR	BE10	A124
	A333	A30b	A319	CRJ1	F18H	B190	BE20	A342
	A343	A310	A320	CRJ2	F18S	BE40	BE58	B703
	A345	B762	A321	CRJ7	F900	B350	BE99	B74S
	A346	B763	AT43	CRJ9	FA7X	C560	C208	C135
	B742	B764	AT72	CRJX	GLF2	C56X	C210	DC87
	B744	C17	B712	CVLT	GLF3	C680	C25A	E3TF
	B748	Dc10	B721	DC91	GLF4	C750	C25B	E6
	B772	K35R	B722	DC93	GLF5	CL30	C402	L101
	B773	MD11	B732	DC95	GL5T	E120	C441	VC10
	B77l		B733	DH8A	GLF6	F2TH	C525	
	B77W		B734	DH8B	GLEX	FA50	C550	
	B788		B735	DH8C	MD82	GALX	P180	
	B789		B736	DH8D	MD83	H25B	PAY2	
	C5		B737	E135	MD87	LJ31	PA31	
			B738	E145	MD88	LJ35	PC12	
			B739	E170	MD90	LJ45	SR22	
			B752	E75L	SB20	LJ55	SW3	
			B753	E75S	SF34	LJ60		
			C130	E190		SH36		
			C30J	E45X		SW4		

Table 4. FAA'S RADAR SEPARATION - ON APPROACH

Lead Aircraft	**Trailing Aircraft**						
	A	B	C	D	E	F	G
A		4.5	6	7	7	8	7
B		3	4	5	5	6	7
C				3.5	5	6	7
D						4	7
E							7
F							7
G	7	7	7	7	7	7	7

3. Methodology

The terminal area flight sequencing problem is to meet the operational constraints and meet the operational constraints while properly and efficiently arranging the landing sequence of the incoming flight to improve the runway capacity, reduce delays and relieve the controller workload. The purpose is also one of the difficulties faced by the controller. The solution to the problem needs to meet the airspace capacity and the minimum separation standard required by the regulations. Under the load that the controller can bear, increase the number of flights in the airspace and reduce flight delays. Airport traffic, passenger satisfaction, and reduced airline losses. The aircraft enters the approach area from the route through the corridor entrance, and the controller of the corresponding sector will give instructions to the captain to guide the aircraft to land along a specific flight procedure, or to hover, waiting for different flights to be arranged at this time. Maintain the intervals required by the regulations. Different orders can affect the waiting time of the flight and thus determine whether the flight is delayed. Therefore, reasonable sorting of flights can effectively improve efficiency. This paper focuses on the effort of the wake turbulence separation, so a mathematical model is now established based on the above two wake turbulence standards within the

FCFS algorithm which is also the most appropriate to the actual situation in China's ATCC because it is the easiest way to deal with.

We first sort the flights by the position of the aircraft so we can deal with it easily.

$$d_i < d_{i+1}, \forall i \in \{1, 2, 3, ..., n-1\} \qquad (1)$$

where d_i is the distance between the i -th aircraft and the 1st aircraft, obviously $d_1 = 0$.

To ensure safety, the trailing aircraft should keep the minimum wake turbulence separation in the orders:

$$d_{i+1} = d_i + w_{i,i+1}, \forall i \in \{2, 3, 4, ..., n\} \qquad (2)$$

where $w_{i,i+1}$ is the minimum wake turbulence separation in the orders define in section II.

From (1) and (2) and the two different minimum wake turbulence separation, we can get the model of the FCFS model:

$$\begin{cases} d_1 = d_1^{'} = 0 \\ d_{i+1} = d_i + w_{i,i+1}, \forall i \in \{1, 3, 4, ..., n-1\} \\ d_{i+1}^{'} = d_i^{'} + w_{i,i+1}^{'}, \forall i \in \{1, 3, 4, ..., n-1\} \end{cases} \qquad (3)$$

where d_i represents the distance between the *i*-th aircraft and 1st aircraft in CAAC's standards and $d_i^{'}$ represents the distance between the *i*-th aircraft and 1st aircraft in in FAA's standards. $w_{i,i+1}$ represents the minimum wake turbulence separation between the *i*-th aircraft and $w_{i,i+1}^{'}$ represents *i+1*-th aircraft in CAAC's standards and represents the distance of the *i*-th aircraft and *i+1*-th aircraft in FAA's standards.

4. Simulation Results

This paper collects the real flights data from particular airports in particular time, but only use this data for research, so the types of the aircrafts and the order of they on the routes are needed. The specific data is as shown in Table 5.

Table 5. Flights Data

Flights id	***Aircraft's ICAO code***	***CAAC's Category***	***FAA's Subhead***
1	A320	M	D
2	A320	M	D
3	A320	M	D
4	A321	M	D
5	A320	M	D
6	A321	M	D
7	A332	H	B
8	A321	M	D
9	A320	M	D
10	A321	M	D
11	A332	H	B
12	A321	M	D
13	A319	M	D
14	A321	M	D
15	A320	M	D
16	A321	M	D
17	A320	M	D
18	A332	H	B

Flights id	*Aircraft's ICAO code*	*CAAC's Category*	*FAA's Subhead*
19	A321	M	D
20	B77W	H	B
21	A320	M	D
22	B738	M	D
23	A320	M	D
24	A321	M	D
25	A321	M	D
26	A332	H	B
27	A320	M	D
28	A333	H	B
29	A333	H	B
30	A333	H	B

Using the FCFS model under these two standards to simulate. The distance of each aircraft is shown in Fig.1. As shown in the Fig.1, the total distance increased with the flights number increasing, all 30 flights need at least 88 nautical miles in CAAC's standards and 75 nautical miles under RECAT standards.

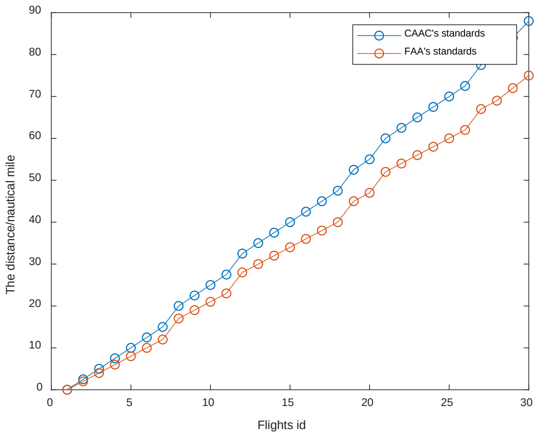

Figure 1. The results of the simulation

5. Conclusion

From the simulation results, the RECAT wake turbulence separation standards are more efficient than CAAC's standards which increase capacity of terminal airspace by 17% which make great efforts to the capacity of the airspace, reduce delays.

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