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An Aircraft Carbon Emission Calculation Model Using Point Merge Procedure

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Abstract. Based on the current development trend of China's civil aviation industry, the rapid growth of flight volume causes excessive pollutant emissions. Aiming at decreasing the carbon emissions of aircraft operation, in this paper, a flight procedure namely point merge procedure is firstly introduced. Meanwhile, we improves the carbon emission calculation model under the point merge procedure. Finally, a case study of Shanghai Pudong Airport shows that the operational capacity has increased 5% in peak-hour under point merge procedure, while the total carbon emissions has reduced 309.3064g.

Keywords: carbon emission, aircraft, point merge, operational capacity

1. Introduction

In recent years, the rapid development of the aviation industry has brought convenience to people's travel and cargo transportation, but also has a huge impact on the airline and the ecological environment. Aviation carbon emissions mainly come from pollutants such as CO2, SO2, CO, NO_x, UHC, AIC that are emitted after aviation fuel is mixed with air during combustion[1], which not only affect air quality but also cause greenhouse effect. From 2013 to 2019, the global aviation carbon emissions have exceeded 70% of the predicted values of the International Civil Aviation Organization. If left unchecked, 25% of the world's carbon emissions will come from the aviation industry by 2050. Therefore, the necessity and urgency of reducing carbon emissions in the aviation industry are very prominent[2]. Internationally, by the end of 2020, 193 countries or regions that account for more than 65% of global CO2 emissions and 70% of the world economy have put forward their commitment to carbon neutrality[3]. And China has also put forward dual carbon goals in 2020, urging China's entire industry to actively explore emission reduction paths.

Due to the impact of carbon emissions, scholars and units have carried out research on their influencing factors. The research shows that the most important factor affecting carbon emissions is the fuel consumption of the voyage in flight, and the fuel consumption of the voyage is mainly determined by the two factors of route and flight sorties[4][5]. The Global Greenhouse Gas Protocol[3] is the most widely used international accounting calculator at present. At the same time, each unit also began to change the traditional step-down approach to optimize and improve the flight approach procedure according to the influence factors of carbon emissions. Pagoni and Psaraki-Kalouptsidi[6] determined the fuel combustion and carbon dioxide emissions during aircraft flight based on clustering and landmark registration techniques, as well as BADA performance models. Eurocontrol released the Point Merge Implementation[7] in 2006, introducing the point merge procedure and its design method for the first time. R. Christien et al.[8] analyze the extensibility of the flight scheduling method in major European airports. CDA can improve the unfavorable situation of low efficiency and poor environmental protection in civil aviation transportation. Lowther[10] analyzed the key factors that constrain the large-scale application of CDA. B Favennec et al.[9] describes the applicability of point merge procedure to the scheduling of peak-hour of approach flights at Paris Charles de Gaulle Airport.

At present, the flight procedure design of each unit is mainly to ensure the safety of the route and comply with the requirements of laws and regulations, but there is no procedure design for emission reduction.

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Therefore, Boursier first proposed a point merge procedure. When the flight volume is low, the aircraft can directly fly to the merging point after entering the procedure, without the need for additional waiting on the sequencing track, improving operational efficiency. As the flight flow increases, the sequencing track gradually exerts its flight capacity and increases the entry capacity. Hong et al.[11] optimized the entry sorting with the goal of running time and number of sequence changes while the point merge procedure was running.

The structure of the paper is followed. Section 2 introduces the basic principle of point merge procedure. In Section 3, it constructs carbon emissions model under the point merge procedure. A real scenario Shanghai Pudong Airport was used to show the operation performance of point merge procedure. Conclusion is drawn in Section 5.

2. Point Merge Procedure

At present, both China's traditional approach procedures will lead to the delay and the increase of fuel consumption under the condition of large flow operation. Therefore, the point merge approach procedure is introduced to guide and sequence aircraft approaching in different directions in the horizontal direction, thoroughly improve the limitations of the regional navigation procedure under the condition of high density traffic flow, while providing perfect implementation conditions for the continuous descent approach.

The route structure of the point merge approach procedure is different from the area navigation, the required performance navigation and the radar guidance procedure. It is mainly composed of three parts: the sequencing track, the fix, and the merging point. The typical route structure of point merge approach procedure is shown in Fig. 1.

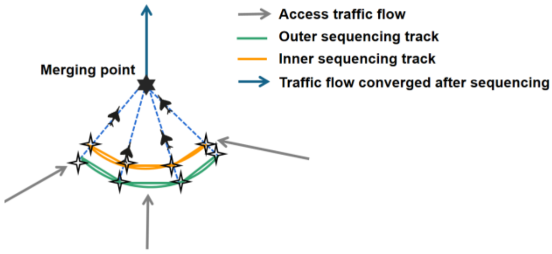

Fig. 1: Point merge system

In operation, due to the aircraft flying to the outer sequencing track will pass through the inner sequencing track during the direct flight to the merging point, in order to avoid flight conflict, the height of the inner should be higher than the outer in the design process to ensure there is sufficient vertical separation between the aircraft, as shown in Fig. 2.

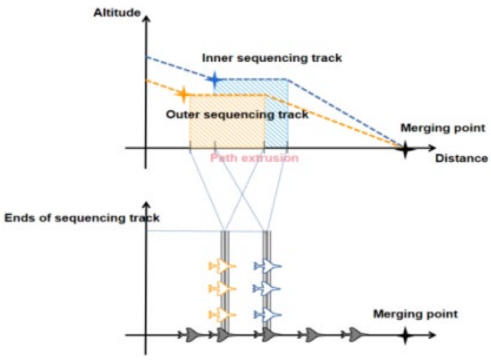

Fig. 2: Horizontal and vertical schematic diagram of point merge procedure.

The biggest feature of point merge procedure is that its structure simplifies the operation process and adopts more flexible methods (path extension/shortening) to delay or accelerate the aircraft operation. Compared with the traditional open-loop guided approach, it provides a structured and intuitive method for controllers to establish and maintain the aircraft air operation sequence[12]. Instead of the traditional horseshoe waiting procedure, which not only shortens the waiting time, improves the operation efficiency of the airport, but also reduces the aircraft carbon emissions. At the same time, although the height of the merging point in the point merge approach procedure is consistent with that in the conventional approach procedure, due to its low internal and external arc height, the gradient of the aircraft when flying to the merging point is small, so the aircraft using the point merge procedure during the approach is more stable, and the fuel consumption is less, thus reducing the total carbon emissions of the aircraft.

3. Aircraft Carbon Emissions Calculation Model

3.1. The conventional model

The specific calculation process of carbon emission is as follows:

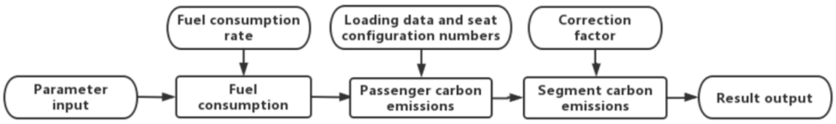

Fig. 3: Basic process of aviation carbon emission calculation.

The fuel consumption of an aircraft during a flight can be combined into two parts: the fuel consumption of the aircraft in the takeoff and landing phase (LTO) and the cruise phase (CCD). This paper mainly studies the approach process of the LTO. The calculation formula of fuel consumption rate in LTO stage is as follows:

$$F_{\mathrm{am}} = \frac{\sum_{j} K_j F_{\mathrm{jm}}}{A} \tag{1}$$

where, A is the total number of aircraft of type a; j represents the model of aircraft engine; K_j represents the total number of aircraft engines; F_{jm} is the fuel consumption rate of j engine at m setting ($kg \cdot s^{-1}$) . The calculation formula of fuel consumption in LTO stage is as follows:

$$B_{LTO} = \sum_{n} P_m \times C_n \times t_n \times F_{mn} \times N_m \tag{2}$$

where, B_{LTO} is the fuel consumption generated during LTO; P_m is the engine's standard thrust of the m-type aircraft (kg); C_n represents the thrust setting when the aircraft is in phase n; T_n represents the running time of phase n; F_{mn} is the rate of fuel consumption; N_m represents the number of engines of m-type aircraft; The value of n is 1,2,3,4, which represents the four stages of takeoff, climb, approach and taxiing.

According to the chemical formula of fuel combustion, the mathematical formula for calculating carbon emissions can be obtained:

$$C = BI \tag{3}$$

where, I is the coefficient of carbon oxide amount generated by unit fuel combustion.

It is learned from the above that in order to achieve the calculation of pollutant emissions, not only the fuel consumption but also the emission index of each pollutant should be known, and the pollutant emission index is also affected by various factors. In this paper, the carbon oxide emission index is modified by the parameter correction method according to the temperature condition.

$$I_{\mathrm{j}M} = \begin{cases} \dfrac{I_j \times \overline{\theta}^{3.3}}{\delta^{1.02}} & j = HC,\ CO \\ \dfrac{I_j}{\overline{\theta}^{0.3} \times \delta^{0.4} \times \phi} & j = NO_x \\ I_j & j = SO_2 \end{cases} \tag{4}$$

$$T = T_G - 0.006\times(h-h_R) \tag{5}$$

$$P = P_G - 0.1212\times(h-h_R) \tag{6}$$

$$\phi = e^{\left\{\frac{6.29-\exp[-0.00143\times(h-12900)]}{53.2}\right\}} \tag{7}$$

where I_{jM} is the corrected emission index of carbon oxides; I_j is the actual emission index of carbon oxides; θ represents the actual atmospheric temperature ratio; T_{ISA} is the sea level temperature under standard atmospheric conditions, 288.15K; T_G is the surface temperature; P is the actual atmospheric pressure; P_G is the surface air pressure; h is the actual operating altitude of the aircraft; θ is the ratio of the actual temperature to the international standard atmospheric temperature; δ is the ratio of the actual pressure to the international standard atmospheric pressure.

After correcting the pollutant emission index, the carbon oxide emission estimation model can be obtained as follows:

$$E_{\mathrm{j}} = I_{jM}\times Q \tag{8}$$

where, E_j is the emission of carbon oxides; Q is the total fuel consumption of the aircraft.

3.2. Novel model under point merge procedure

Under the operation state of the point fusion procedure, the distance and altitude of the aircraft in the approach phase have some changes compared with the traditional approach procedure. At the same time, the fuel consumption of the aircraft is also inextricably related to its operating altitude and distance. Therefore, under the point merge procedure, the horizontal distance d from the current position of the aircraft to the merging point and the current flight height h of the aircraft are calculated as follows:

$$d = \begin{cases} d_j & , v_1 \\ d_j - (t - t_{r,F_{ij}}) \times V_{TAS,F_{ij}}(V_{CAS,F_{ij}}) & , v_2/v_3 \end{cases} \tag{9}$$

$$h = \begin{cases} h_j & , v_1/v_2 \\ h_j - \sum_{r-t_{d,F_{ij}}}^{t} \frac{dh}{dt_r} & , v_3 \end{cases} \tag{10}$$

where, d_j is the horizontal distance (m) between the inner or outer sequencing track and the merging point; the value of j is 1, 2, representing the inner sequencing track and the outer sequencing track respectively; t is the current flight time of the aircraft; The value of v is 1,2,3, which represents the three phases of sequencing track flight, direct flight to merging point and descent.

The altitude difference from the sequencing track to the merging point in the point merge procedure is h_{des}. Since the aircraft F_{ij} (the aircraft i flying in the sequencing track j) has different descent gradients at different flight levels, the descent flight phase is divided into R segments, where each segment is represented by r, the values of segment r is 1, 2,..., R, the time interval between adjacent segments is 1s, and the descent gradient of segment r is calculated as follows:

$$\frac{dh}{dt_r} = \left[\frac{(T_{des}-D)\times V_{TAS,F_{ij}}(V_{CAS,F_{ij}})}{m_Z g}\right]\times f\{M\} \tag{11}$$

where, D is the resistance of the aircraft (N); m_z is the weight of the aircraft in segment r (kg); g=9.80665m/s^2; T_{des} is the thrust of the aircraft during the descent of segment r (N); $F\{M\}$ is the energy sharing coefficient allocated by the aircraft to climb.

4. Case Study

4.1. Experiment scenario and parameters setting

This paper selects Runway 16 of Shanghai Pudong Airport and designs a point merge approach procedure for the original route structure. It can be seen from the approach diagram that the three approaches, which are PONOT, DUMET and SHUYUAN, converging at the same place and conduct the final approach.

However, if the traffic flow is large and the safety interval cannot be achieved only by speed regulation, which needs aircraft to adopt the traditional waiting procedure (as shown in Fig. 4), which will inevitably lead to the increase of the workload of the controller and even the flight delay problem. At the same time, due to the long time of the waiting procedure, it will also aggravate the consumption of fuel and indirectly lead to the increase of pollutant emissions. In addition, the constant adjustment of the pilot's height and speed during the descending approach will have a certain impact.

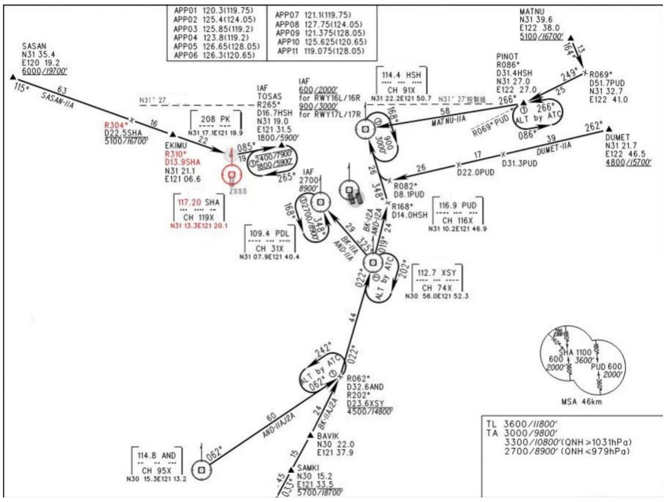

Fig. 4: Approach route structure of runway 16

Fig. 5 shows the designed structure of the point merge approach procedure at runway 16 of Shanghai Pudong Airport. From the original approach procedure, we can see that there are three main approach directions, which are located at three positioning points, PINOT, DUMET and SHUYUAN. On this basis, multiple fixes are set to obtain the inner sequencing track and the outer sequencing track. Finally, determine the merging point to form a complete point merge procedure.

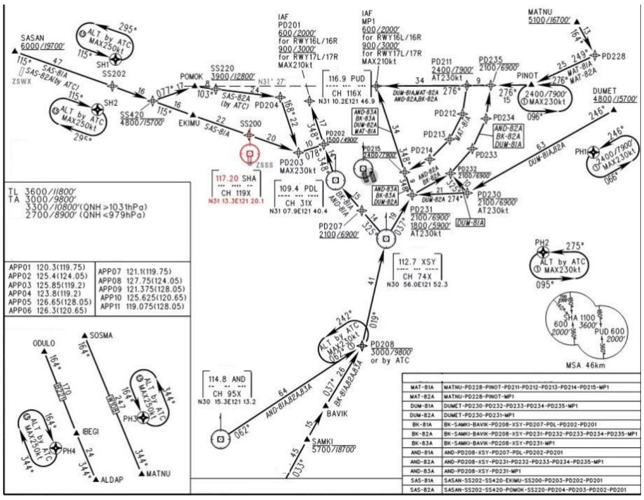

Fig. 5: Point merge approach procedure structure of runway 16

It is assumed that the aircraft type using this system is A320-232. The parameter standard of the point merge procedure of Shanghai Pudong Airport and the reference emission index of the aircraft engine under the standard LTO operating state are shown in Table 1.

Table 1: Relevant data

Symbol	Name of parameter	Numerical value
d_1	Inner sequencing track to merging point envelope	34km
d_2	Outer sequencing track to merging point envelope	43km
d_2-d_1	The horizontal interval between two sequencing tracks	9km
h_1	The height of the inner sequencing track	2400m
h_2	The height of the outer sequencing track	2100m
h_m	The height of the merging point	600m
——	Minimum standard for vortex separation under radar control	10km
h_2-h_1	The height difference between the two sequencing tracks	300m
V	Average approach velocity of aircraft	325*km/h*
T_{des}	Thrust setting during approach operation	30%
F	Fuel flow during approach operation	0.85*kg/sec*
I_{jm}	Carbon oxide emission index under approach operation condition	0.89*g/k*g

4.2. Results and analysis

The approach procedure based on point merge procedure can reasonably control the sequence of multiple aircraft approaching. The maximum static flow per unit time reflects the function of the procedure in saving time and fuel consumption. Through the analysis of the carbon oxide emission estimation model in Chapter 3, it is found that the carbon oxide emission is in direct proportion to the fuel consumption. Therefore, the evaluation results are shown in the following Table 2:

Table 2: Evaluation result

	Peak-hour sorties	Total carbon emissions	Peak-hour delay time
Conventional approach	80 aircraft/hour	2745.4342g	14.2min
Point merging approach	84 aircraft/hour	2436.1278g	13.8min

It can be seen that the number of aircraft sorties increased by 4 in the peak-hour after the point merge procedure was adopted, with an overall increase of 5%. At the same time, the increase of aircraft sorties in the peak-hour promoted the overall reduction of carbon emissions. Under the point merge procedure, the total carbon emissions decreased by 309.3064g, with an overall reduction rate of 11.27%, which successfully achieved the emission reduction effect of the point merge procedure. It improves the aircraft approach efficiency, saves fuel consumption in the waiting procedure, thus achieving the effect of green flight and energy-saving and low-carbon flight.

5. Conclusion

Based on the traditional carbon emission calculation model, this paper proposes a novel aircraft carbon emission calculation model under the point merge procedure. The operational capacity of Shanghai Pudong Airport can increase 5% in the peak-hour when using the point merge procedure. While the total carbon emissions in peak-hour decreased by 309.3064g, which is an reduction rate of 11.27% comparing with the traditional approach procedure. The point merge procedure achieved the increasement of operational capacity and the reducement of the total carbon emissions in the peak-hour. In the future, we will consider extending the efficiency evaluation of point merge system to the whole day at multi-runway airports.

6. References

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