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Multi-Objective Intelligent Optimization of Arrival and Approach Procedure Design

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ABSTRACT: With the sustained growth of air traffic flow, aviation noise problems of arrival aircraft are growing more and more severely. It puts forward higher requirements to optimize the trajectory of arrival and approach segment. The technique of Performance Based Navigation makes flexible flight procedure design possible, also safety, noise effect, efficiency, simplicity of flight procedure should be taken into consideration when designing flight procedure. In this paper, multi-objective optimization model of arrival and approach procedure design is established which selects safety and noise constraints as the limits, efficiency and simplicity as the optimization targets, then improved ant colony algorithm is designed to solve the problem. Finally, taking Lanzhou terminal airspace as design background, the arrival and approach procedures are designed. Analysis verifies the feasibility and validity of the optimization model and solution algorithm.

KEYWORDS: Noise abatement; Multi-objective optimization; Pareto ant colony algorithm; Flight procedure design.

INTRODUCTION

With the rapidly increasing of air traffic flow, aviation noise nuisance problems become more and more severely. As an important part of the airspace planning, reasonable procedure is useful for the terminal area operating safely, efficiently and orderly. Contemporarily, flight procedure design is primarily based on FAA TERPS, FAA Order 8260.58, ICAO Doc9905 and ICAO Doc8168 [1], which sets the program safety protection zone through obtaining the position and height information of the ground obstacle to ensure the corresponding obstacles conform to the redundancy between the aircraft and ground barrier. The traditional method can hardly meet the traditional program and PBN program design concerning the safety and economy, simplicity and noise requirement. For years, the related research about flight program is limited to computer aided procedure design and there are few research results about direct flight program design [2]. 2011, the instrument flight procedures three-dimensional rendering system was developed to improve the efficiency of safety assessment , but the system is only used for the traditional instrument procedures, not suitable for the Performance Based Navigation (Performance Based Navigation, PBN) procedure [3]. 2012, based on Google Earth, a set of instrument flight procedure design system was developed through the introduction of runway configurations, navigation station and protected areas,which used AutoCAD software module to complete the program to realize auxiliary design [4]. 2012, KML language was used to generate space track set,which provided the good method to simplify the design [5]. 2012,World Wind platform was used to achieve three-dimensional visualization of flight procedures, which provided a new way of PBN program for the rapid assessment of the safety [6]. These methods aimed at reducing the influence of noise and the operating cost as the optimization objective, a set of decision variables and optimization function differential equations are built, and then the decisive variables and state variables are optimized to obtain the optimal path. 2009, Khardis described a method to optimize the approach procedure in terms of fuel efficiency. Assuming constant acceleration and point mass model, the total fuel consumption is calculated. Optimization is conducted with constraints imposed upon flight procedure design by using genetic algorithm [7]. 2013, an optimization model of flight path is put forward with a target function of minimizing aircraft noise around airports. The vertical plan and the space cases have been solved by using two approaches, one direct and one indirect. The three-segment approach procedure has been obtained as an optimized flight path which can substantially reduce noise levels. However, the method needs a good guess for the initial solution [8].In the comprehensive consideration of flight procedures, 2008, a index system for evaluating the flight procedures was firstly constructed, among the system, a multi hierarchy fuzzy comprehensive evaluation model of flight procedures was established, but the model emphatically to rely on expert scoring qualitative analysis,which is easily affected by subjective factors and the lack of reliable mathematical foundation [9]. 2012, Wang developed flight

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procedure simulation and analysis platform based on Delphi tools, operation safety, economic, regulatory applicability and pollution gas emissions were carried out through simulation analysis and evaluation [10]. 2012, the evaluation model of PBN flight program was constructed, which could make full use of the decision information and effectively solve the optimization problem of the PBN procedure design [11]. 2012, a procedure design example was described, which started from the PBN procedures standards and summarized the methods and ideas of the small airport flight program adjustments, the method could improve the terminal area capacity and controllers efficiency [12].2014, due to the PBN and ATFM technology were independently providing benefits to flight operation, then a method of combining the two technologies to increase the operating capacity, which exploring the application prospects [13].

On the basis of the above study, a method using the improved simulated annealing algorithm to optimize the design of the departure procedure is proposed in the paper. The results illustrated that the multi-optimization objectives cannot achieve the optimization at the same time. There are some problems of existing research: Firstly, in allusion to optimization and adjustment of flight program, the research on the automatic design of optimal flight program has not yet been seen; Secondly, owing to the single index of flight program design, the comprehensive consideration of the safety, economy, simplicity and noise of the flight program, under the traffic flow condition, have not been included in the procedure design system, and quantitative indicators and procedure optimization design model are incomplete. Therefore, in this paper, the optimization model of flight procedure is constructed, which is used the safety and noise of flight program as the constraint condition, selecting the economy and simplicity of the flight procedure as the optimization objective. The multi-objective optimization design model is designed. The improved multi-objective ant colony algorithm is used to solve the model. Finally, based on the background of Lanzhou terminal airspace, this approach is optimized for Lanzhou's approach to the design of this field. The feasibility and effectiveness of the model and the algorithm are verified.

METHOD DESCRIPTION

During the design of flight program, factors need to be considered are as followed: terrain and obstacle relevant features, terminal area airspace, the airway and route link to each other, the influence of aircraft operation on urban planning and construction, aircraft category, flight performance, airborne electronic equipment, airport facilities, equipment support conditions, navigation station layout. During the design of flight program, the requirements need to be satisfied are as followed: to ensure that the aircraft can safely fly over obstacles, to improve the operation efficiency of the aircraft, to enhance the airport and terminal airspace capacity, to benefit the air traffic control services, to help the pilots to control the aircraft, to reduce the noise effect and environmental protection.

Considering the requirement of the safety, economy, simplicity and noise, during the design of flight program, the premise is ensuring the safety of flight procedures, that is to say, the requirement of corresponding barrier should be satisfied when procedures is near obstacles; The limits of acceptable noise levels in the surrounding areas of the airport must be met, i.e., the implementation effect of noise sensor cannot exceed the limit requirements; and other performances of aircraft flight constraints, namely turning angle, minimum distance, climb and descent gradient, were saw as constraints. Furthermore, the flight program optimization design model is constructed with the optimization target of efficiency and simplicity.

OPTIMAL TARGETS

(1) Economic objectives

As to economy index of flight program, the cost of fuel and time of all aircraft operating, under the condition of traffic flow, should be better reflected. CI (Cost Index) is the ratio of the time cost and fuel cost which is relevant with the flight time. Assuming the same type of flight of the CI which sets in the management computer are the same. Categories are divided into class. Hence, the definition of economic function of the flight program is defined as follow:

$$EC = \sum_{i=1}^{n} N_i \cdot (1+100CI_i) \cdot T_i \cdot Flow_i . \quad \text{* MERGEFORMAT (1)}$$

Where N_i the operated flight is number of type i in a unit time; T_i is the flight time of the type i ; $Flow_i$ is the fuel ratio of type i ; CI_i is the cost index of type i .

The BADA model can be used to analyze the performance of the full-flight phase, including the fuel flow rate of the aircraft climbing, descending, and cruising [14]. The flight procedure is divided into climbing, descending and cruising stage descending, supposing that there are climbing stages, descending stages, cruising stages, and is the flight distance of stage, the corresponding true airspeed is , fuel flow rate keeps constantly during the stages of ascending, descending and cruising, in that economic functions of the flight program could be represented as follows:

$$EC = \sum_{i=1}^{n} N_i \cdot (1+100CI_i) \cdot N_e{}^i \cdot (\sum_{j=1}^{m_1} \frac{DIS_j}{TAS_j} \cdot f_{climb}{}^i + \sum_{j=1}^{m_2} \frac{DIS_j}{TAS_j} \cdot f_{des}{}^i + \sum_{j=1}^{m_3} \frac{DIS_j}{TAS_j} \cdot f_{cr}{}^i).$$

* MERGEFORMAT (2)

Where $N_e{}^i$ is the engine number of type i, $f_{climb}{}^i$ is the single engine fuel flow rate in the stage of climbing of type i, $f_{des}{}^i$ is the single engine fuel flow rate in the stage of descending of type i, $f_{cr}{}^i$ is the single engine fuel flow rate in the stage of cruising of type i.

(2) The simplicity objective

There is no specific methods and standards for the simplicity of flight procedure. Thus, this paper introduces the dynamic density (Dynamic Density, DD) parameter which is characterize the air traffic complexity to characterize the simplicity [15]. Dynamic factors, aircraft density factors and conflict factors are defined as the key factors to characterize the air traffic complexity. Namely, the dynamic factors can be divided into two factors, including the change of aircraft height and the speed of the aircraft; the density factors indicates whether the corresponding horizontal or vertical interval is satisfied. The conflict factors indicates whether there is a potential conflict between the aircraft in the airspace. Toward flight program, the major factor of effecting simplicity is the DD factor, height changing factor and speed changing factor and direction changing factor associated with the segment structure and the flight number. Assuming is the number of the operated flights per time; is the number of times that attitude changes; is the number of times that definition changes; is the number of times that speed changes; eventually, simplicity function of the flight program is represented as follows:

$$SC = N(t) \cdot (W_{ac}A(t) + W_{hc}H(t) + W_{sc}S(t)).$$ * MERGEFORMAT (3)

Where W_{AC} is the weight of attitude changing, with the attitude changing less than 750 ft; W_{HC} is the weight of direction changing factors, with the heading changing more than 15°; W_{SC} is the weight of speed changing factors, with the heading changing more than 10kt or 0.02 Mach.

CONSTRAINT CONDITIONS

(1) Security constraints

The procedure security constraints can base on the security zone which defined by the ICAO DOC8168 FAA and TERPS. This paper selects the RNP standards that the DOC8168 of ICAO provides the flight program safety standards. For the straight leg with the RNPi standard, the obstacle point set is assumed as $O_i(x^j_{obs}, y^j_{obs}, h^j_{obs})$, then the track point set $F_k(x^k_{plane}, y^k_{plane}, h^k_{plane})$ should be met the constraints as follows:

$$\begin{cases} h^k_{plane} > h^j_{obs} + MOC_i & if \quad (x^j_{obs} - x^k_{plane})^2 + (y^j_{obs} - y^k_{plane})^2 \le 0.0625AW_i{}^2 \\ h^k_{plane} > h^j_{obs} + MOC'_i & if \quad 0.0625AW_i{}^2 < (x^j_{obs} - x^k_{plane})^2 + (y^j_{obs} - y^k_{plane})^2 \le 0.25AW_i{}^2 \end{cases}.$$

* MERGEFORMAT (4)

Where AW_i is the half width of the protection zone with the reference to the straight leg; MOC_i is the obstacle clearance with the reference to the straight leg.

The turning leg of PBN procedures is divided into turning with fly-by and turning with fly-over, mainly considering the effect of the omnidirectional wind on the turning of the aircraft. For point set $F_k(x^k_{plane}, y^k_{plane}, h^k_{plane})$ of the turning with fly-by and the track should be satisfied as follows:

$$h_{plane}^{k} > h_{obs}^{j} + MOC_i \ ,if \ \ (x_{obs}^{j} - x_t)^2 + (y_{obs}^{j} - y_t)^2 \le (r + \frac{W}{R}\theta_e)^2.$$

* MERGEFORMAT (5)

For point set $F_k(x_{plane}^k, y_{plane}^k, h_{plane}^k)$ of the turning with fly-over and the track should be satisfied as follows:

$$h_{plane}^{k} > h_{obs}^{j} + MOC_i \ ,if \ \ (x_{obs}^{j} - x_t)^2 + (y_{obs}^{j} - y_t)^2 \le (r + \frac{W}{R}(\theta_e + 30^\circ))^2.$$

* MERGEFORMAT (6)

Where r is the turning radius; θ_e is the turning angle, R is turning ration; (x_t, y_t) is turning center point which is determined by turning radius.

(2) Limitation of noise constraints

The boundary surface of noise limited region can be accurately represented as surface equation of egg circle using the least square method. Assuming the $N_k(x_{noise}^k, y_{noise}^k, z_{noise}^k)$ is the set of limitation of noise which is determined by surface equation of fitting boundary. The procedures of each flight leg are not through the restricted area, so we should satisfy the procedure of track sets and restricted area without any intersection. The relevant constraint equation is as follows:

$$F_k \cap N_k = 0, \left\{ N_k(x_{noise}^k, y_{noise}^k, z_{noise}^k) \middle| (x_{noise}^k)^2 + (y_{noise}^k)^2 \le r^2, r = f(z_{noise}^k) \right\}.$$

* MERGEFORMAT (7)

(3) The flight performance constraints

For the minimum segment distance, the stable minimum distance must be satisfied between before and after the waypoint. The minimum stable distance d_{seg} is determined by the type of the front and back waypoints, so the minimum segment distance constraint is defined as follows:

$$L(f_i, f_{i+1}) \ge d_{seg}, \forall f_i, f_{i+1} \in WP.$$

* MERGEFORMAT (8)

The turning angle refers to the heading change during flight operating. Associating with the design of procedure and the actual operation of radar control, the maximum change in the course of an aircraft, owing to the safety of terminal area, should not be more than 90 degree, continuous turning not considered, so the turning angle constraints is defined as follows:

$$\angle f_k, f_{k+1}, f_{k+2} \le 90^\circ, \forall f_k, f_{k+1}, f_{k+2} \in F_K.$$

* MERGEFORMAT (9)

The climbing and descending gradient indicates the ratio of height of flight increasing or decreasing and corresponding horizontal distance when the aircraft is flying along the flight path. During the design of procedure, actually, the gradient also selects less than 10 per cent, so climbing and descending gradient can be defined as follows:

$$\left| G(f_k, f_{k+1}) \right| \le 0.1, \forall f_k, f_{k+1} \in F_K.$$

* MERGEFORMAT (10)

Where WP the route point is set of PBN procedure; F_K is the track point set.

(4) Approach segment constrains

Initial Approach segment is form the IAF (Initial Approach Fix) to the IF (Intermediate Approach Fix), stipulates the best allowable downward gravity is 8%. Segment length is determined jointly by the falling height and falling gradient. Therefore define downward gravity and segment length of initial approach segment constraints equations as follows:

$$L_{\text{IAF-IF}} = \frac{H_{\text{IAF}} - H_{\text{IF}}}{G_{\text{IAF-IF}}} \ge 12.5(H_{\text{IAF}} - H_{\text{IF}}), G_{\text{IAF-IF}} \le 8\%.$$

* MERGEFORMAT (11)

Middle Approach segment is form the IF to FAF (Final Approach Fix), stipulates the best allowable downward gravity is 5.2%, and must provide a level flight segment in front of the FAF, the minimum length of level flight segment was determined by model classification. Segment length should be not less than 9.3 Km and not greater than 28 Km. Therefore define downward gravity and segment length of middle approach segment constraints equations as follows:

$$9.3 \le L_{\text{IF-FAF}} = \frac{H_{\text{IF}} - H_{\text{FAF}}}{G_{\text{IF-FAF}}} + L_{cru} \le 28, G_{\text{IAF-IF}} \le 5.2\%,$$
$$L_{cru} \ge 1.9(\text{Category A/B}) \text{ or } 2.8(\text{Category C/D}).$$
* MERGEFORMAT (12)

The final Approach segment is form the FAF to MAPt (Missed Approach Point), stipulates the best allowable downward gravity: A/B type is 6.5%, the C/D class is 6.1%.From the runway threshold, the minimum length of final approach segment is 5.6 Km, the maximum is 19 Km. Therefore define downward gravity and segment length of final approach segment constraints equations as follows:

$$5.6 \le L_{\text{FAF-THR}} = \frac{H_{\text{FAF}} - 15}{G_{\text{FAF-THR}}} \le 19,$$
$$G_{\text{FAF-THR}} \le 6.5\%(\text{Category A/B}) \text{ or } 6.1\%(\text{Category C/D}).$$
* MERGEFORMAT (13)

THE MULTI-OBJECTIVE INTELLIGENT OPTIMIZATION ALGORITHM FOR PROCEDURE DESIGN

According to the basic ant colony optimization algorithm and multi-objective Pareto optimization theory, combined the flight program design problem, taking the idea of path planning for reference, the PACA is used to solve optimization model of the flight program design.

(1) The description of space environment

The abstract method of the space environment of flight program design is as follows: Firstly, the terminal planning space is determined during the program designing, which is mainly determined by the position of the moving point, the position of the navigation station and the airport runway. Secondly, the three-dimensional of space is established, which puts the runway center as a spatial planning origin of coordinate, without considering the effect of magnetic deviation. The X axis positive direction represents east direction; The Y axis positive direction represents north direction; The Z axis positive direction represents the upward which is perpendicular to the ground. Finally, the method of equidistant partition method to discretize the space grid point that flight procedure designing required is adopted. Then the three-dimensional planning space is discretized as a 3D point set, namely the serial number coordinate represented by $a^1(i,j,k)(i=0,1,2,...n, j=0,1,2,...m, k=0,1,2,...l)$ and the position coordinate represented by $a^2(x_i, y_i, z_i)$, where i,j,k is the division number along the X axis, Y axis and Z axis direction separately.

(2) Visual search space

In order to reduce the complexity of path planning, it is ruled that the ant can only reach the next node from the current node, and cannot cross the middle node, that is, the visual area existed, at any point. $L_{x\,max}$ is the maximum distance of forward movement along X axis at a time; $L_{y\,max}$ is the maximum distance of lateral movement along Y axis at a time; $L_{z\,max}$ is the maximum distance of vertical movement along Z axis at a time. Consequently, the horizontal plane, assuming that the velocity speed of ants, in the current flight path point O, is along the normal direction of the X axis, and the turning point of the program design is considered, then the ants may search the number of the node from the next level is less than 5, respectively, points A, points B, points C, points D, points E; Similarly in vertical plane, assuming that the velocity speed of ants, in the current flight path point O, is along the normal direction of the Y axis, and the turning point of the program design is considered, then the ants may search the number of the node from the next level is less than 3, respectively, points M, points N, points T.

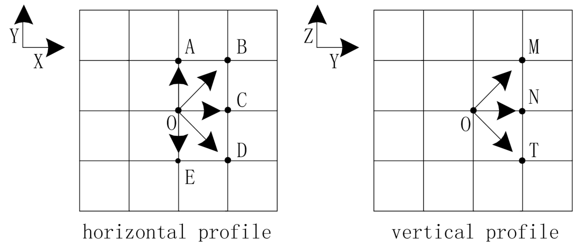

Figure 1. Visual area sketch map of ant search.

(3) Pheromone updating

PACA belongs to the multi-objective single population ant colony algorithm, for the model, the k Pheromone is set by the k optimization objective. Consequently, the pheromone vector is represented by $\tau^k(i,j)$. In the stage of constructing the initial feasible solution, the k target's weight p_k is divided by using the stochastic method and it must satisfy the condition as follows:

$$0 \le p_k \le 1 \, , \sum_{k=1}^{K} p_k = 1. \quad \text{* MERGEFORMAT (14)}$$

The pheromone is set in the flight path segment which is constituted by any two discrete air path points, updated after each ant having passed by. The update of pheromone vector includes local and global updating, the pheromone vector updated when an ant completes a flight path search. The local update of the pheromone vector is shown as follows:

$$\tau^k(i,j) = (1-\rho_0)\cdot\tau^k(i,j). \quad \text{* MERGEFORMAT (15)}$$

Where ρ_0 indicates the volatile coefficient of pheromone vector and it should satisfy the equation: $0 < \rho_0 < 1$.

When all ants have completed a search, the current Pareto optimal path which is searched by all ants will be filtered out and only the value of the pheromone vector is increased on the optimal path. The global updating of pheromone vector is as follows:

$$\tau^k(i,j) = (1-\rho_1)\cdot\tau^k(i,j) + \rho_1\cdot\Delta\tau^k(i,j). \quad \text{* MERGEFORMAT (16)}$$

Where ρ_1 indicates the updating coefficient of pheromone vector and it should satisfy the equation $0 < \rho_1 < 1$. $\Delta\tau^k(i,j)$ is the value of pheromone vector.

The equation which indicates updating the only pheromone that the minimum value of the objective function corresponds to the pheromone on the search path in the current Pareto frontier is as follows:

$$\Delta\tau^k(i,j) = \frac{M}{\min(f_k)}. \quad \text{* MERGEFORMAT (17)}$$

Where the M is a constant and $\min(f_k)$ indicates the minimum value of the corresponding objective function after all ants have finished the paths search.

(4) The searching strategy

According to the different flight path pheromone, pseudo-random proportion rule is selected. Once the probability of choosing the path is determined, the roulette method is selected for the next flight path selection, according to selection probability of each path, that is, a constant $q_0 \in [0,1]$ should be set in advance and a random number q is generated on the [0,1] interval. If $q \le q_0$, then use the equation (15) for the next flight path selection or the equation (16) is used for the next flight path selection. Equation (15) (16) are as follows:

$$P_m(i,j)=\begin{cases}\arg\max\limits_{j\in L_m(i)}\left\{\left[\sum_{k=1}^{K}p_k\cdot\tau_m^k(i,j)\right]^{\alpha}\cdot\eta_j^{\beta}\right\} & q\le q_0,\ j\in L_m(i)\\ 0 & q\le q_0,\ j\notin L_m(i)\end{cases}. \quad \text{* MERGEFORMAT (18)}$$

$$P_m(i,j)=\begin{cases}\dfrac{\left[\sum_{k=1}^{K}p_k\cdot\tau_m^k(i,j)\right]^{\alpha}\cdot\eta_j^{\beta}}{\sum\limits_{h\in L_m(i)}\left(\left[\sum_{k=1}^{K}p_k\cdot\tau_m^k(i,h)\right]^{\alpha}\cdot\eta_h^{\beta}\right)} & q>q_0,\ j\in L_m(i)\\ 0 & q>q_0,\ j\notin L_m(i)\end{cases}. \quad \text{* MERGEFORMAT (19)}$$

Where $P_m(i,j)$ is the transition probability when the ant m selects the next path j at the point of the i, which is determined by the above-mentioned visual search space and the space point which is useless; $\tau_m^k(i,j)$ is the pheromone vector when the ant m selects the next path j at the point of the i; η_i is the visibility factor which can be calculated by $\eta_i = 1/d_{ie}$, where d_{ie} is the Euclidean distance between current node and final target node; α and β are the weight parameters of cumulative and heuristic information, which reflect the relative significance in the next path of route selection when the method is in the process of optimizing the above information.

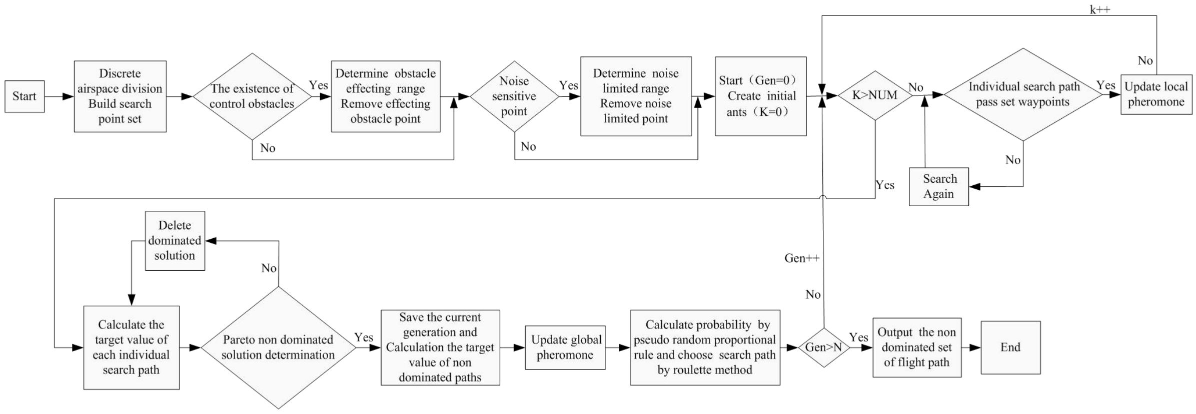

Figure 2. Flow chart of PACA.

SIMULATION AND ANALYSIS

Take the terminal airspace of Lanzhou Zhongchuan airport as object, the optimal design of the approach at the P242 direction is carried out. The related obstacles of the P242-ZGC direction and the noise sensitive point information are determined by reference to the Lanzhou airport surrounding topography and urban planning as shown in the Figure 3. In this case, while the intermediate and final approach fix are set in the program design, the ZGC001 and ZGC002 is set as the waypoint that must be passed by, which is based on the relative requirement.

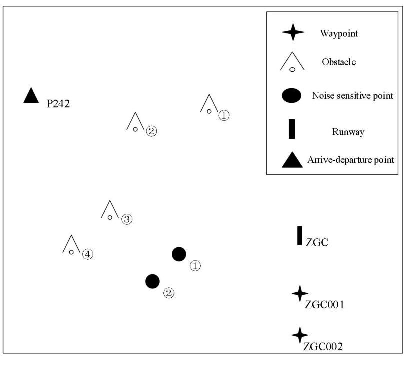

Figure 3. The schematic diagram of terminal airspace environment (P242-ZGC).

The right direction of flight take-off track which is perpendicular to the runway 36 is the positive direction of the axis X, the direction of aircraft take-off along the runway 36 being the positive direction of the axis Y, the direction which is perpendicular to the ground being the positive direction of the axis Z. Then the space rectangular coordinate system is constructed. Benchmarked against the elevation of the center point of the runway, the coordinates of the key points are determined by the conversion of the coordinates and the discrete simplification as shown in Table 1.

Table 1. The information and coordinate of key point.

Key point	Coordinate (KM)	Key point	Coordinate (KM)
Runway center point	(0,0,0)	Obstacle ②	(-40,40,0.6)
Waypoint ZGC001	(0,-20,0.6)	Obstacle ③	(-50,20,0.9)
Waypoint ZGC002	(0,-30,0.6)	Obstacle ④	(-60,-10,0.9)
Arrival point P242	(-70,50,2.7)	Noise point ①	(-30,-10,0)
Obstacle ①	(-20,50,2.1)	Noise point ②	(-40,-20,0)

(1) The parameters of safety protection zone

In the range of the low approach control sector, the entire program design airspace horizontal range is 100 km × 100 km and the vertical range is from 0 to 2700 meters. Considering the turning radius, climbing and descending rate, in this case, the horizontal range of X axis and Y axis direction is divided by 10 kilometers, and the vertical range of the Z axis is divided by 300 meters. The reference coordinate of the designing procedure is (0, 0, 0), and starting point coordinate of the approach procedure is (-7, 5, 9). According to the obstacle coordinate information in the Fig 1 and table 3, the obstacles ①, ②, ③ and ④ may become the approach control obstacles. In this case, the approach leg is based on standard of the RNP1, and the width of protection area is 6 nm. The width of the main protection area is controlled within less than 300m. The protection of IAA is controlled within 150 m. The width of the final approach leg is 1.6nm. Then in the main protection area, the MOC is controlled within 75m.

(2) The parameters of noise restricted area

Shown by Figure 3, the noise sensitive point ① and ② is mainly influenced by the noise of the approaching aircraft. According to the method, determining the noise restricted area boundary, the boundary equation of curved surface is determined, which is as follows:

$$C:\frac{x^2}{4550^2}+\frac{y^2}{4550^2}+\frac{(z-1745)^2}{(0.649(z-1745)+1192)^2}=1,\quad |x|,|y|\le 4550.$$

* MERGEFORMAT (20)

(3) The parameters of economic index

According to the empirical data, ignoring the influence of the flight speed, the ratio of the fuel flow rate, based on the B737 of climbing, cruising and descending, is approximately 6:2:1. Thus, the economic index of procedure can be simplified as follows:

$$EC = 6S_{climb} + 2S_{cru} + S_{des}.$$ * MERGEFORMAT (21)

Where S_{climb}, S_{cru} and S_{des} are represented respectively as the distance of climbing, cruising and descending in the process of the implementation of the procedure.

(4) The parameters of simplicity index

Lanzhou approach sector operation and control measures can be simulated by the operation simulation system of Lanzhou approach sector, which is developed by our research group. Combined with the simulation data, the parameters of simplicity index is determined by using regression analysis method. The simplicity index P242 direction approach procedure is shown as follows:

$$SC = 2.512A(t) + 1.867H(t) + 1.917S(t). \quad \text{* MERGEFORMAT (22)}$$

Where $A(t)$, $H(t)$ and $S(t)$ are the number of the aircraft attitude change, heading change and speed change respectively.

The PACA, mentioned above, is applied to resolve the P242 approach procedure, and the calculation parameters are as follows: Colony size is $K = 20$; The initial pheromone of each path segment is set as 1; The ratio constant of pseudo random number is $q_0 = 0.5$; volatility coefficient is $\rho_0 = 0.1$; Update coefficient is $\rho_1 = 0.1$; the constant is $M = 1000$; The weight of cumulative information is $\alpha = 0.5$; The weight of heuristic information is $\beta = 0.5$; The number of iterations is $Gen = 100$. is used to calculate and analyze the distribution of optimal solution is shown in Fig 3, The distribution of the Pareto optimal solution is resolved and analyzed by using the MATLAB programming in Fig 4; The approach is shown in Fig 4 and Fig 5; The result is compared in the table 2.

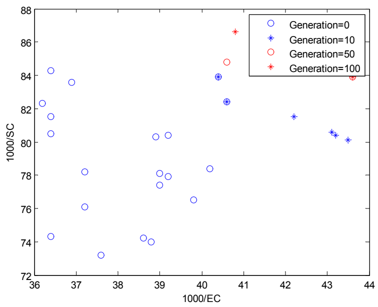

Figure 3. Optimal solution distribution of the Pareto.

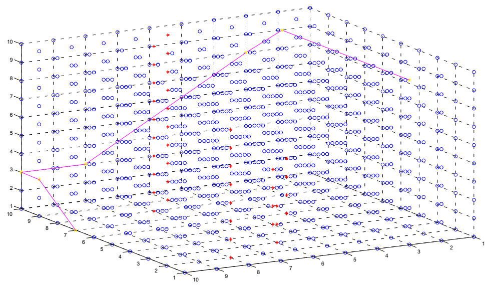

Figure 4. The approach procedure ①(P242-ZGC).

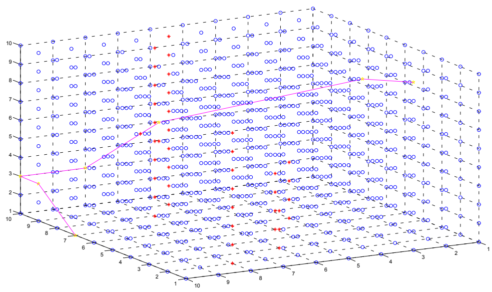

Figure 5. The approach procedure ②(P242-ZGC).

Table 2. The comparison of optimal index.

Number	EC	SC
①	24.5	11.5
②	22.9	11.9

According to the P242 direction of approach procedure, finally, two optimal solutions of the Pareto are generated, mainly owing to the noise sensitive point and obstacles effecting the aircraft to fly around the restricted area. Table 2 shows that the simplicity of procedure ① is optimal and intuitively the minimum number of aircraft heading changing, that is, the minimum number of aircraft turning; the economy of procedure ② is optimal and intuitively the procedure is the most short range of flying around the restricted area with the least time of it. Therefore, the two approaches case, mentioned above, economic and simplicity indexes have their own strong points and weaknesses. According to the actual airspace situation, pilots and regular ATC can make collaborative decision, and then select the appropriate procedure case.

CONCLUSION AND DISCUSSION

Concerning comprehensively the effect of safety, economy, simplicity and noise effect under the traffic flow, the article has presented a method of flight procedure design based on PACA. The optimal model of flight procedure is constructed based on the PACA method, with the limits of safety and noise effect, and set the economy and simplicity as the optimization target. The result demonstrates that the good diversity of Pareto optimal solution could be obtained by applying the PACA without prior knowledge and dimensionless process. Multiple sets of flight program scheme is helpful for collaborative decision-making between pilots and controllers, which can make scientific and rational decision under different indexes focusing.

Limited airspace resources limit the further growth of the amount of flight, as an important part of the airspace planning, scientific and reasonable flight procedures can be used to optimize the use of airspace resources. According to the requirements of safety, safety, economy, simplicity and noise effect of flight procedure design, design model of arrival and approach procedure is established and the introduction of intelligent algorithm is used to generate optimal procedures, which has important theoretical significance and application value in optimizing the airspace structure, increasing the airspace capacity and managing the flight flow. In the future research, the impact of aircraft gas emission will be considered to improve the flight programming model proposed in this paper.

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