

Research on the Optimization Strategy of Center of Mass Balance of Aircraft

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Abstract. Aiming at the problem of centroid deviation of aircraft carrying multiple fuel tanks under different fuel supply strategies, the time discretization, coordinate transformation and vector synthesis methods are used to obtain the centroid change curve, and the centroid change problem caused by the change of pitch attitude of the aircraft is studied. The Euclidean distance between the aircraft centroid and the ideal centroid is minimized as the objective function, and the optimization model is established. The fuel supply rate of each tank is obtained by particle swarm optimization algorithm, and the centroid optimization strategy is finally obtained. Simulation results show that the proposed strategy can effectively find the optimal fuel supply strategy for aircraft, which provides important reference value for aircraft design.

Keywords: Center of mass balance, optimization, Particle swarm optimization.

1. Introduction

With the progress of science and technology, aircraft [1] are more and more widely used in military and civil fields. During the flight of aircraft, its center of mass balance is very important for the stable flight and control of aircraft. The control problem of aircraft has been concerned by researchers at home and abroad [2-4].

A certain type of aircraft carries multiple fuel tanks [5, 6]. During the flight, several fuel tanks are combined to supply fuel to meet the requirements of flight mission and engine work. In the process of mission execution, the change of the center of mass of the aircraft has an important impact on the control of the aircraft. The distribution of oil in each tank and the fuel supply strategy will lead to the change of the center of mass of the aircraft, and then affect the control of the aircraft. Therefore, the formulation of the fuel supply strategy for each tank is an important task for the control of this type of vehicle [7, 8].

2. Problem Description

A certain aircraft uses fuel oil as fuel. The aircraft has multiple fuel tanks, which are distributed in different positions of the aircraft. Due to the limitation of pipeline design, some fuel tanks are main fuel tanks, which can directly supply oil to the engine, and some fuel tanks are backup fuel tanks, which generally only supply oil to a main fuel tank and cannot directly supply oil to the engine. There will be limits to how long the fuel can last and how fast it can be supplied. During the flight of the aircraft, the pitch and yaw of the aircraft will cause the attitude of each fuel tank to tilt relative to the ground. Under the action of gravity, the fuel distribution of the fuel tank will also change, so that the center of mass of the aircraft will shift. Therefore, in order to keep the aircraft balanced, it is necessary to develop a reasonable fuel supply strategy.

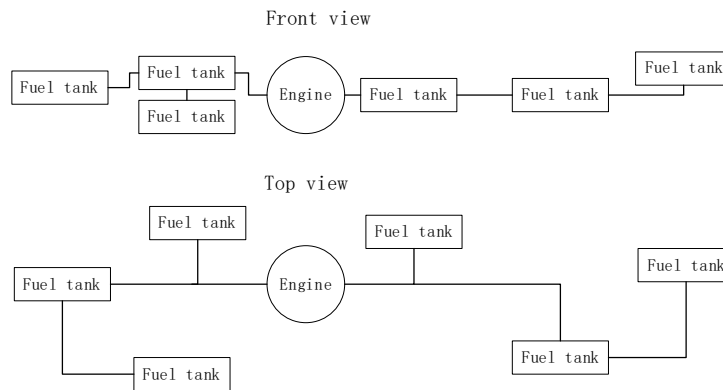


Figure 1. Tank distribution diagram

3. The Centroid Solution Method

The involved coordinate systems mainly include the aircraft coordinate system and the fuel tank coordinate system [9, 10]. The aircraft coordinate system is $O(t) - X(t)Y(t)Z(t)$, and the inertial fixed coordinate system takes the origin of the aircraft coordinate system as the origin, and the three axes are parallel to the inertial coordinate system. The three axes of the fuel tank coordinate system are parallel to the aircraft coordinate system, and the origin is the center point of each fuel tank. The transformation relationship between the aircraft coordinate system $O(t) - X(t)Y(t)Z(t)$ and the inertial fixed coordinate system $O^{(1)}(t) - X^{(1)}(t)Y^{(1)}(t)Z^{(1)}(t)$ is as:

$$\begin{bmatrix} X^{(1)} \\ Z^{(1)} \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} X \\ Z \end{bmatrix} \quad (1)$$

There is a translation relationship between the fuel tank coordinate system $O^{(2)}(t) - X^{(2)}(t)Y^{(2)}(t)Z^{(2)}(t)$ and the aircraft coordinate system $O(t) - X(t)Y(t)Z(t)$, namely:

$$\begin{cases} X = X^{(2)} + x \\ Y = Y^{(2)} + y \\ Z = Z^{(2)} + z \end{cases} \quad (2)$$

Where, x, y, z is the coordinate of the origin of the fuel tank coordinate system in the aircraft coordinate system.

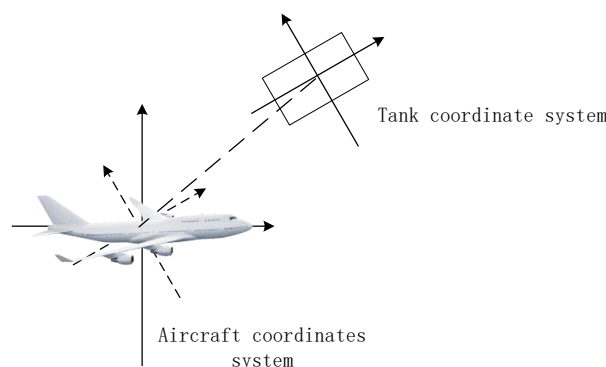


Figure 2. Coordinate system definition

For a single continuous object, that is, the fuel in each tank, the center of mass is:

$$\begin{cases} \bar{x} = \frac{\iint_D x\rho(x,y)d\sigma}{\iint_D \rho(x,y)d\sigma} \\ \bar{y} = \frac{\iint_D y\rho(x,y)d\sigma}{\iint_D \rho(x,y)d\sigma} \end{cases} \quad (3)$$

Where ρ is the object density and σ is the object micro element. For multiple particles, the centroids are as follows.

$$\bar{x} = \frac{\sum_{k=1}^n x_k m_k}{\sum_{k=1}^n m_k}, \bar{y} = \frac{\sum_{k=1}^n y_k m_k}{\sum_{k=1}^n m_k}, \bar{z} = \frac{\sum_{k=1}^n z_k m_k}{\sum_{k=1}^n m_k} \quad (4)$$

4. Centroid Optimization Strategy

We treat each second as a computational unit, and due to fuel consumption, the center of mass is affected by the fuel mass:

$$c_1 = \left[\frac{\sum_{k=1}^6 x_k m_k}{\sum_{k=1}^6 m_k + M_0}, \frac{\sum_{k=1}^6 y_k m_k}{\sum_{k=1}^6 m_k + M_0}, \frac{\sum_{k=1}^6 z_k m_k}{\sum_{k=1}^6 m_k + M_0} \right] \quad (5)$$

The objective function of the optimization model is to minimize the Euclidean distance between the centroid of each second and the ideal centroid. Therefore, the optimization model can be summarized as follows.

For t in T

$$\min f(u_t) = \|c_1(u_t) - c_2\|_2$$

$$s.t. \begin{cases} u_{i,t} > 0 \\ \prod_t^{t>60} u_t > 0 \\ sum(flag(u_1, u_2, u_3, u_4, u_5, u_6)) \leq 3 \\ sum(u_i) \geq u_{need} \\ V_{oi}(t) \geq 0 \end{cases} \quad (6)$$

$$t = t + 1$$

...

The constraints are as follows: 1. Make the oil supply of the oil supply tank greater than 0; 2. Continuous oil supply time needs to be greater than 60s; 3. Only 3 fuel tanks at most; 4. The oil supply of the main fuel tank should be greater than the oil required by the aircraft; 5. The remaining oil in the tank cannot be less than 0.

In this paper, PSO (particle Swarm Optimization algorithm)^[11, 12] is used to optimize the model. For discontinuous and nonlinear problems, PSO has certain advantages. The variable to be optimized in this paper is the amount of oil supply at the current moment. First, we set the maximum number of iterations, in this case, the maximum number of iterations is set to 1000, and the number of independent variables of the objective function is the number of tanks used.

According to the formula of population velocity and position, iterative operation was carried out continuously until the set number of iterations was reached or the difference between generations

satisfied the minimum bound, the algorithm stopped operation. The iterative formula of the standard PSO algorithm is as follows.

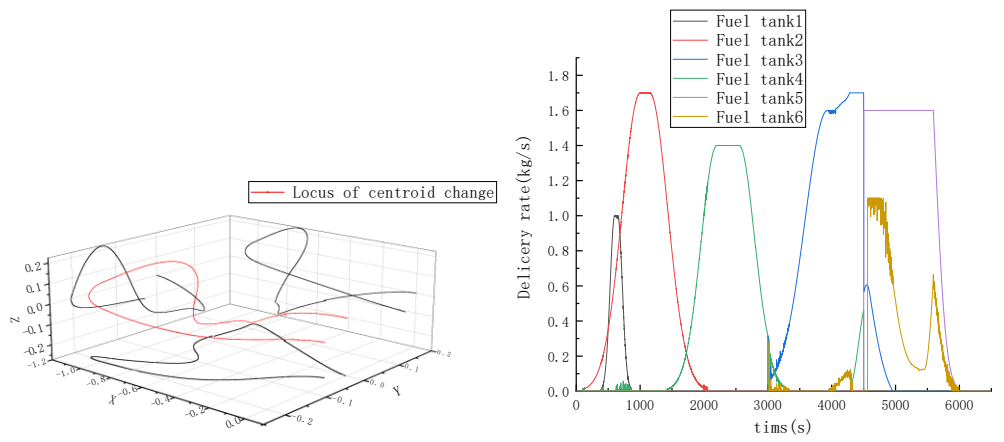
$$v_i^{k+1} = w \cdot v_i^{k+1} + c_1 \cdot r_1 \cdot (p_g^k - x_i^k) + c_2 \cdot r_2 \cdot (p_i^k - x_i^k) \quad (7)$$

$$x_i^k = x_i^k + v_i^{k+1} \quad (8)$$

Equation (6) is an iterative formula for the population velocity, and Equation (7) is an iterative formula for the population position.

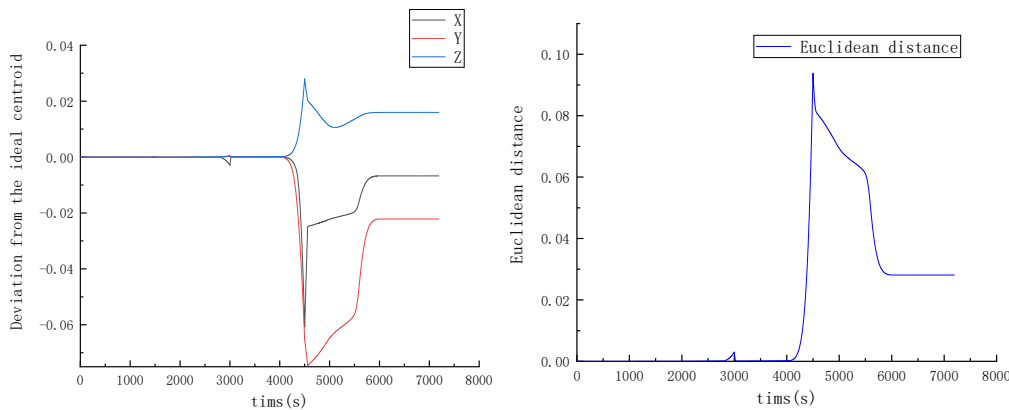
5. Simulation Results

Fig. 3 shows the simulation results, where (a) is the trajectory of a mission of the aircraft, under which the fuel supply strategy is obtained by using the above model planning, and (b) shows the respective fuel supply speed of six fuel tanks. It can be seen from the figure that the fuel supply of each fuel tank is basically very stable. The shape center of the aircraft is set as its ideal center of mass, and (c) is the comparison between the actual center of mass and the ideal center of mass. It can be seen that there is a certain error in the y axis and z axis, and the error in the x axis is very small. (d) shows the Euclidean distance between the ideal centroid and the actual centroid. It can be seen that the maximum error of each axis is no more than 0.08m, and the maximum Euclidean distance is only 0.09m, indicating the effectiveness of the algorithm.



(a) Trajectory of a flight mission

(b) Six tanks of their respective fuel supply speed curve



(c) The centroids in all directions deviate from the ideal centroid

(d) Euclidean distance

between the centroid and the ideal centroid

Figure 3. Simulation results

6. Conclusion

A certain type of aircraft carries multiple fuel tanks, and the amount of fuel remaining in the fuel tank affects the change of the center of mass of the aircraft during flight. Aiming at this problem, this paper establishes a coordinate system, analyzes the change law of the center of mass of the aircraft under the pitch and yaw motion, and establishes an optimization model by minimizing the Euclidean distance between the center of mass of the aircraft and the ideal center of mass. The fuel supply rate of each tank is obtained by particle swarm optimization algorithm, and the centroid optimization strategy is finally obtained. The simulation results show that the maximum Euclidean distance between the actual centroid and the ideal centroid of the aircraft is only 0.09 meters by using the proposed algorithm to solve the fuel supply strategy under a certain flight trajectory, which indicates the effectiveness of the proposed algorithm.

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