Research on Air Flight Simulation Control Law of Large Aircraft

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Abstract. The air flight simulator, also known as the variable stability aircraft, can make the dynamic characteristics of the machine change or simulate the response characteristics of different objects in a large range through the variable stability telex system. This paper is devoted to the research of the air flight simulation control law of large aircraft, and designs the five degree of freedom variable stability control law: to control the elevator, rudder and aileron of the basic aircraft, and to design the three-degrees-of-freedom variable stability control law. The control of the direct lift surface and the automatic throttle was added, and the five-degree-of-freedom variable stability control law was designed to simulate the trajectory characteristics and velocity characteristics. Finally, the variable stability control law is verified based on the target aircraft simulator.

1. Introduction
Air flight simulator is also known as Variable Stability Aircraft (Variable Stability Aircraft, VSA) for short, which is a kind of wide application, high efficiency and low cost of experimental study on the plane, its essence is through the Variable Stability control law to control surface deflection generate additional force and moment. So as to achieve the aim of changing the plane stability, it can become stable by telex system guarantee under the condition of constant state of flight, so that the dynamic characteristic of the machine and its control system in large range change, thus and studied the response of the Aircraft [1]. When the pilot steers the stabilized aircraft, he can feel the motion state and flight control quality of the simulated aircraft in the real flight environment, so as to obtain a more realistic simulation effect than the ground flight simulator [2].

2. basic principle of variable stability
At present, there are two basic methods for the control law of variable stability aircraft, namely response the method of feedback and model tracking.

The principle of response feedback is to feedback the corresponding aircraft response to the aircraft control surface, so as to change the aircraft response to the actual disturbance and the pilot control, which is equivalent to the pilot operating an aircraft that makes the basic derivative changed. This principle is the same as the conventional aircraft stabilization system, but its purpose, function and scope are different.

The advantages of the response feedback method are that the simulation frequency band is high and the system delay is small. The disadvantage is that control is too complex to simulate a large disturbance, and even situations such as adding or reducing equipment or aircrew require resetting the control law. Therefore, a large number of air calibration test flights are required when response feedback is used [3].
The method of model tracking control. Namely, closed-loop model tracking control. It is based on forming an ideal tracking loop with the corresponding control system to track the model output. The closed-loop tracking control law minimizes the difference between the response of the machine and the simulated object.

The advantage of the model tracking method is that the tracking loop composed of the unit can maintain a tracking with good quality during a large disturbance or when some parameters of the unit change with a small change of the control law, so as to obtain satisfactory flight simulation results. Model tracking can overcome the influence of local parameter variation to a certain extent and reproduce simulated aircraft characteristics realistically. However, its disadvantages are also quite obvious. It cannot simulate the model with high frequency, otherwise the frequency band of the ring of tracking is too high [4].

As theoretical research, this paper adopts the combination of the two methods as the control method. Response feedback is used as the inner loop loop of controlling the variable stability, and the model of tracking is used as the outer loop loop. The structure of law control is shown in Figure 1.

3. Establishment of research object model

3.1. Selection of research objects
In this paper, a regional airliner is selected as the prototype, and a trunk airliner is taken as the model of tracking object, that is, the simulation object, which is called X aircraft. Compared with X aircraft, the platform size of the prototype aircraft is obviously different from that of the X aircraft. Therefore, the model tracking control law designed in this paper can further prove the applicability of this method.

The purpose of this paper is to study the control law of air flight simulation of large aircraft. As theoretical research, in order to verify a range of abilities in the flight envelope, three flight configurations of take-off, cruise and landing are selected as the state points of this study.

According to the train of thought in this paper, the control law of the approach and the landing stage of large aircraft is taken as the focus of the study. The following three flight states are selected as the simulated state points, and the details are shown in Table 1.

| Serial number | configuration | Mach number | Pressure height (m) | The landing gear | Flaps (degree) |
|---------------|---------------|-------------|---------------------|------------------|----------------|
|               |               |             |                     |                  | Native machine | X plane        |
| 1             | Take off      | 0.19        | 400                 | Lay down         | 15             | 25             |
| 2             | cruise        | 0.3         | 1000                | Pack up          | 0              | 0              |
| 3             | landing       | 0.19        | 400                 | Lay down         | 30             | 40             |
3.2. Establishment of aircraft model
For the aircraft prototype, the six degrees of freedom motion equation are used to solve the aircraft response. The target model is linearized and the simplified model is established. For simplification, the control law only retains the master control mode control stability augmentation control law. Taking longitudinal control law as an example, the method of instruction overload is adopted to control, including the forward channel, proportional channel and integral channel.

3.3. Comparison of aircraft models
After the establishment of the local model and the mathematical model of Plane X, the response and stability of the two aircraft are compared. We can compare the responses of the two types of aircraft with the same input. In the cruising configuration of 1000m and 0.3mA, the responses of the two models with longitudinal step input are shown in Figure 2.

![Comparison of response of longitudinal step input model](image)

The short-period characteristics of the two models are calculated. The pair of 1000m and 0.3mA cruise configurations are shown in Table 2:

| Model          | Short period frequency | Short period damping ratio | CAP  | Dutch roll frequency | Dutch roll damping ratio |
|----------------|------------------------|----------------------------|------|----------------------|-------------------------|
| X plane        | 1.99rad/s              | 0.99                       | 0.77 | 0.78rad/s            | 0.51                    |
| Native machine | 2.17rad/s              | 0.65                       | 0.94 | 1.36rad/s            | 0.25                    |

Model tracking control law design and numerical simulation

3.4. Design of three-degree-of-freedom variable stability control law
When conducting air flight simulation, the stability of the longitudinal short period is the first consideration, and the pitch angle rate is the parameter we want to track. The feedback quantity introduced laterally is roll rotation rate, and the state quantity tracked by the model is roll rotation rate. For the design of course control law, the feedback quantity is the yaw angle and yaw angular rate, and the state quantity tracked by the model is yaw angular rate.

3.5. Design of five degrees of freedom variable stability control law
The three degrees of freedom variable stabilization control with a good tracking effect on the pitch angle rate response, but the angle of attacking tracking effect is poor, and the deviation of velocity is small. However, with the increase of time, the deviation gradually increases. Due to the lack of longitudinal and normal force control, three degrees of freedom variable stability can not realize the
simulation of track and other characteristics, which is very necessary for some special approach task simulation.

This section will introduce a method for tracking the flight path of Aircraft X -- five degrees of freedom airborne stabilization. By definition, it can be known that the track angle is equal to the difference between the pitch angle and the angle of attack, and the pitch angle is the integral of the pitch angle rate over time, namely:

\[ \vartheta = \theta - \alpha = \int q \]

Among them, \( \vartheta \) is the track angle, \( \theta \) is the pitch angle, \( \alpha \) is the angle of attack, and \( q \) is the velocity of the pitch angle.

Therefore, as long as the plane's pitch angle rate and angle of track attacking the pitch angle rate and angle of attack of Plane X, the flight path angle of plane X can be considered to be tracked. In actual flight, tracking flight track angle alone cannot fully simulate the characteristics of aircraft approach and the landing stage, and speed is also an important evaluation index, so speed tracking should be added.

In the design of five degrees of freedom variable stability control law, the direct lift surface, namely flaps, is used to track the angle of attack. The state feedback quantity and the target tracked by the model is angles of attack. For the speed tracking, we choose the throttle input as the control quantity, the state feedback quantity and the target of the model tracking as the speed.

The basic structure diagram of the control law is shown in Figure 3.

![Figure 3 Basic structure of the five degrees of freedom variable stability control law](image)

The outer loop tracking loop design is based on the tracking accuracy and tracking performance of the system under the condition that the parameters of the inner loop have been determined. When only the model and the native state error is introduced for feedback, the steady-state error will be caused under the step input, so the steady-state error is eliminated by introducing the integral term. For an ideal tracking loop, the system is expected to show the characteristics of high frequency and large damping. If necessary, differential terms are introduced to make the tracking loop form to a PID tracking loop. By adding a tracking loop, a tracking effect of ideal can be achieved.

4. **Man-machine closed loop ground test verification**

Compared with numerical simulation, flight simulation in the simulator can intuitively experience the operating experience of the unstable aircraft, which is more valuable for the engineering application and practical significance compared with the operating experience of X aircraft. The tests performed in this chapter are based on the flight simulator of aircraft X.

In man-machine environment closed-loop ground test, through the three state points in selecting different input operation, can get steady simulation results, the control law through the manipulation of data contrast and the pilot experience, evaluation in this paper, the research variable stability control law, verify its correct or not, have stronger engineering application value. FIG. 4 shows longitudinal simulation curve in the cruising state.
Since the approach and landing stage require the pilot to accurately control the flight path, it is a relatively key link in the whole flight. Therefore, tracking the landing process of Aircraft X is a very meaningful work. The simulator test in this paper starts from state point 2, i.e. The altitude is 1000m, the speed is 0.3mA, and speed direction is 15° angle with the airport runway, the cruising configuration is started, and the landing is completed.

After the test, the pilot commented on the variable stability control law. The tracking condition of the whole stabilization system is relatively ideal, which is close to the flight quality of X aircraft. Especially near the selected state point, the control experience has a high similarity, which basically restores the control experience of X aircraft.

![FIG. 4 Results of longitudinal impulse input response](image)

5. Conclusion
This paper introduces the basic principle of variable stability aircraft, and established the basic plane six degrees of freedom (quantity model and simplified model was simulated aircraft, on the basis of three degrees of freedom model tracking to join to automatically throttle and direct lift control below, for X aircraft at five degrees of freedom was simulated, and platform for X aircraft simulator man-
machine closed-loop ground experiment system is established in this paper, the correctness of the
design of variable stability control law, which has a certain value in engineering application.

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