DESIGN OF DUAL-FUSELAGE FLIGHT PLATFORM FOR JET CONTROL FUNCTION VERIFICATION

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Abstract

Aiming at the integration problem of jet flow control system, a dual-fuselage flight platform scheme with large space and large load capacity is proposed, based on the jet control of trailing edge flap flow separation. A replaceable large-scale test wing section is installed between the fuselages, and the jet air source and pipeline system are loaded inside the fuselage. Five small jet controllers are arranged at the deflection of the trailing edge flap. The control ability of jet flow to the separation flow field under different total pressures was analyzed by numerical simulation. Considering the lift increase and flow demand, the total pressure of the jet controller plenum chamber is determined to be 0.3MPa and the mass flow rate is 0.03kg/s. According to the requirements of the front end of the jet controller, the design of the air supply system based on the high pressure air source is completed. The flight test results show that: the jet air supply system can provide a high-pressure air flow with a total pressure of 0.3MPa and a duration of more than 30s, and the developed jet control system can effectively suppress the flow separation of the trailing edge flap.

Keywords: dual-fuselage flight platform, trailing edge flap, jet control, flight test

1. Introduction

Flow separation not only increases flight drag, but also causes flight instability, which is one of the main problems affecting the flight performance of aircraft. Jet control, which can effectively inhibit the separation flow by injecting high energy air into the flow field, has become the focus of future civil aircraft key technology research in recent years.

According to the way of jet formation, it can be divided into two categories : active jet and passive jet. The active jet can be subdivided into pulse jet[1] and oscillating jet[2]. Passive jet includes synthetic jet[3], co-flow jet[4] and so on. In recent years, there have been many studies on the new jet controller and its application. The efficiency of jet control has been greatly improved, and the application scenarios of jet control have been continuously expanded, including external flow such as wing[5] and vertical tail[6] and internal flow such as inlet[7] and turbine blade[8]. After verifying the feasibility of the application of jet control in various separated flow control by means of numerical simulation and wind tunnel test, the research focus has been extended to the integration and flight test of jet control system[9-10], and The function of the jet control system is verified by flight platform integration and flight test. Compared with numerical simulation and wind tunnel test, the integration of jet control system combined with flight platform will not only increase the complexity and risk, but also multiply the research cost.

As a complex system, active jet flow control not only needs actuators to produce high-speed jet, but also needs high-pressure air source and pipeline system to provide continuous energy. At present, the numerical simulation and wind tunnel test methods used in the study of jet control mechanism are relatively mature, but the means for systematic verification are generally lacking. In order to meet the requirements of functional verification and ensure the controllable cost, this paper proposes a low-cost dual-fuselage flight platform that can carry out flexible test. The jet control system was developed, and the jet control flight test was carried out on the background of low-speed separation flow of trailing edge flap.

2. Dual fuselage flight platform scheme

With the background of jet control of flap flow separation at the wing trailing edge, a dual-fuselage flight platform scheme with large space and load capacity is proposed (Figure 1). A large replaceable test wing section is installed between the fuselage, the jet air source and pipeline system are installed inside the fuselage, and a set of propeller power units are installed at the front of the left and right fuselage. In order to ensure normal flight, a straight wing is installed on the outside of the fuselage, and the horizontal tail and vertical tail are connected at the aft fuselage to form a π-shaped tail.

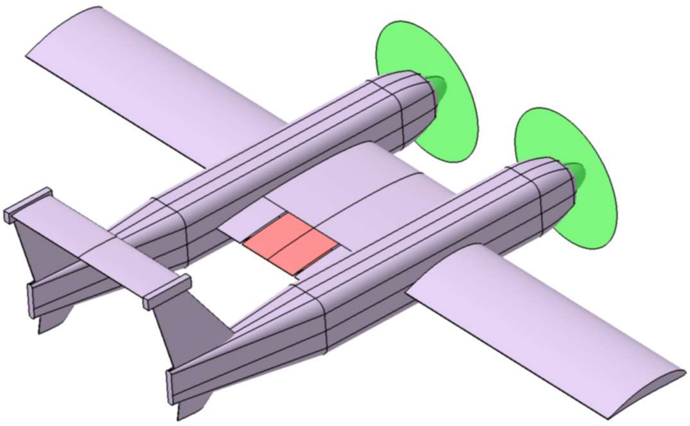


Figure 1 – A dual-fuselage flight platform scheme.

The dual-fuselage flight platform has a fuselage length of 2m, a wingspan of 3.44m, and a wing area of 1.38m^2. The chord length of the test wing segment is 0.8m, the wingspan of the test wing segment is 0.6m, and the chord length of the trailing edge flap of the test wing segment is 0.24m, the width of that is 0.3m. Based on available power constraints, the estimated maximum take-off weight does not less than 30kg.

3. Jet flow control conceptual design and aerodynamic characteristics analysis

In order to realize the separation control of the flap at the test wing segment trailing edge, five small jet controllers are arranged at the flap front end (Figure 2). The jet outlet is close to the trailing edge flap wall. The shape of the jet outlet is a rectangle with a width-to-height ratio of 3. The angle between the outlet jet direction and the trailing edge flap surface is 10°. The span wise width of a single jet controller is 0.03 of the width of the trailing edge flap. The step height of the end face of the jet controller is 0.02 of the length of the trailing edge flap. The height of the jet outlet is 0.6 of the height of the end face step. For the selected jet controller array, the total area of the jet outlet is about 165mm^2.

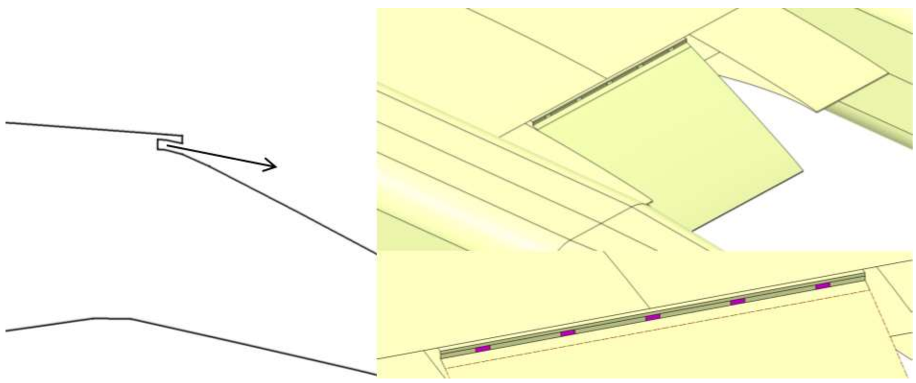


Figure 2 – The arrangement of trailing edge flap jet controller array.

The control ability of different total pressures on the separation flow field is analyzed by numerical simulation method. The governing equation used is the three-dimensional steady N-S equation, which is discretized by the finite volume method. The selected turbulence model is Menter 's SST model. The aircraft surface adopts non-slip boundary condition, and the far-field boundary is determined by the local one-dimensional Riemann invariant. Unstructured mesh were used in the calculation. In order to ensure that the flow characteristics in the boundary layer can be simulated, a prismatic layer mesh was generated near the wall surface. The height of the first layer mesh is 10^{-6} of the reference length. The whole model was used for numerical simulation, and the calculated mesh size is about 10 million.

The simulation state is that the flight height is 50m, the flight speed is 30 m/s, the flight angle of attack is 5-10°, and the total pressure range of the front inlet of the jet controller is 0.1~0.5MPa.

The lift coefficient variation curve of the test wing section under different total pressure conditions is shown in Figure 3. For the cases where the inlet total pressure is greater than the incoming flow pressure(P0=0.1MPa), the lift coefficient increases with the increase of the inlet total pressure at different angles of attack. However, when the inlet total pressure exceeds 0.4MPa, the increasing amplitude is reduced. When the inlet total pressure changes in the range of 0.2~0.4MPa, with the increase of the inlet total pressure, the lift coefficient increment at different angles of attack is about 0.19/MPa. When the inlet total pressure is 0.3 MPa, the jet control increases the lift coefficient by 12%, 10% and 8% for the angles of attack of 5°, 7° and 10°, respectively.

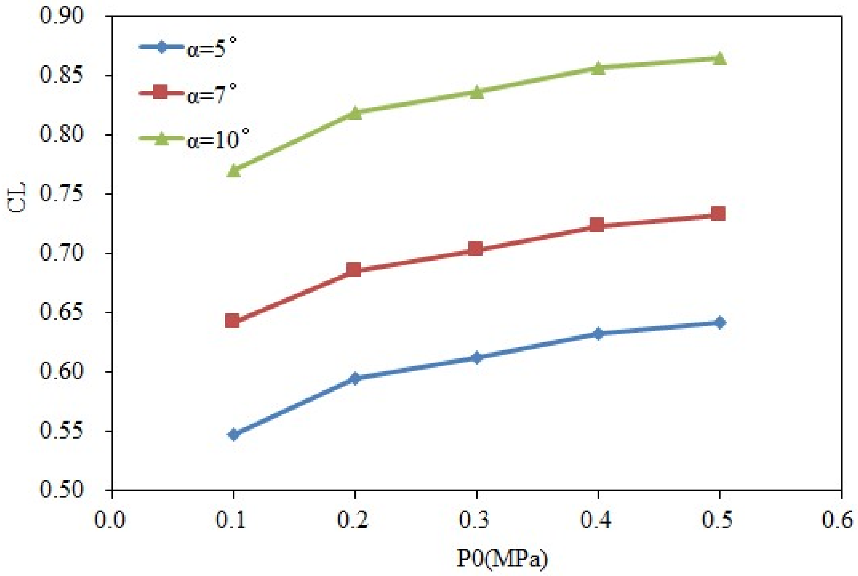


Figure 3 – The lift coefficient variation curve of the test wing section under different total pressure conditions.

The mass flow rate variation curve of the jet controller is shown in Figure 4. The mass flow rate of the jet is only linearly related to the total inlet pressure and is not affected by the change of the angle of attack. When the inlet total pressure changes in the range of 0.2 ~ 0.5MPa, with the increase of the inlet total pressure, the jet mass flow increment is about 0.1kg/MPa. When the inlet total pressure is 0.3MPa, the mass flow rate of the corresponding jet control system is 0.03kg/s.

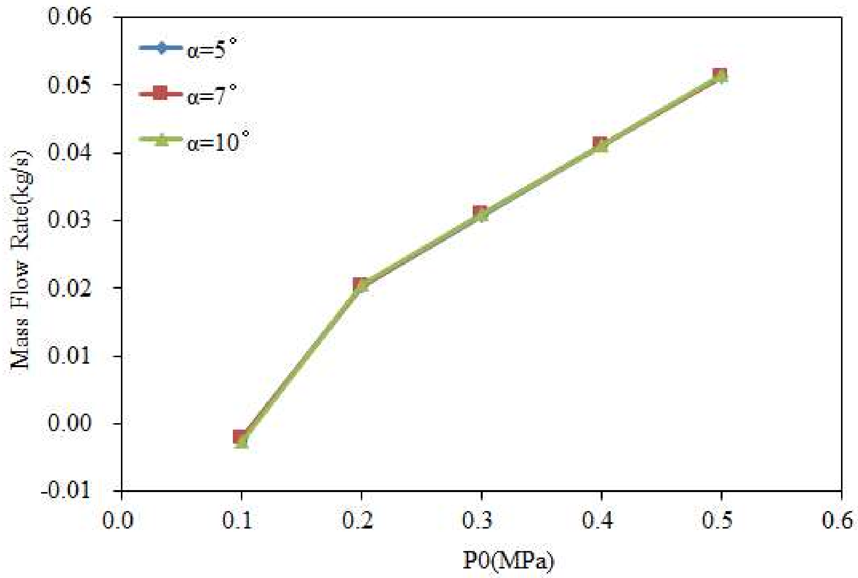
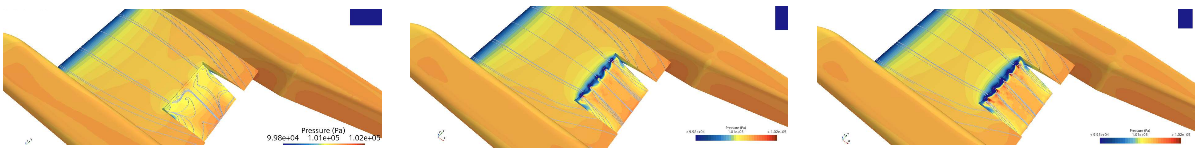


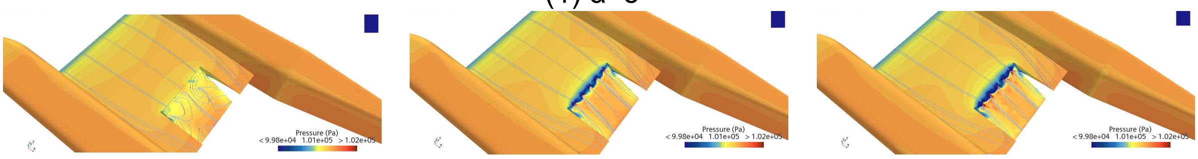
Figure 4 – The mass flow rate variation curve of the jet controller under different total pressure conditions.

The the trailing edge flap flow field of the test wing section under typical total pressure conditions is shown in Figure 5. At different angles of attack, when the inlet total pressure is 0.1 MPa, there is almost no jet ejection, and the flow field near trailing edge flap is completely separated. When the inlet total pressure reaches 0.3 MPa, the jet flow eliminates the separation flow near the trailing edge flap. When the inlet total pressure is further increased to 0.5 MPa, the flow structure is similar to that of 0.3 MPa.



P0=0.1MPa P0=0.3MPa P0=0.5MPa

(1) α=5°



P0=0.1MPa P0=0.3MPa P0=0.5MPa

(2) α=10°

Figure 5 – The trailing edge flap flow field of the test wing section under typical total pressure conditions.

Based on the above analysis, the total pressure at the front entrance of the jet controller is preliminarily determined to be 0.3 MPa, and the scheme design of the jet air supply system is carried out by taking this as the input.

4. Air supply system based on high pressure air source

According to the requirements of the front end of the jet controller, the design of the air supply system based on the high pressure air source is completed, including the high pressure vessel, joint, pressure reducing valve, high pressure pipeline, low pressure pipeline, electro-valve, etc.

The preliminary layout of the air supply system is shown in Figure 6. Combined with the characteristics of the dual fuselage, a set of high-pressure vessels and a decompression system are arranged on the left and right fuselages. The maximum pressure of the vessel is 15 MPa. With the help of the pressure reducing valve, the end air supply pressure is 0.3 MPa, and the effective gas supply time is not less than 20 s. According to the demand of air supply flow, the diameter of low pressure pipeline is determined to be 8mm. In order to ensure the safety of the air supply system, a three-way electro-valve with a small vent is added after the pressure reducing valve. During the flight test, the vent continues to deflate. Even if the platform or air supply system is out of control, it can still exhaust the high-pressure gas inside the vessel after enough time. The air on the left and right sides of the vessel converges through a five-way connector after the three-way electro-valve and enters the jet controller in three ways.

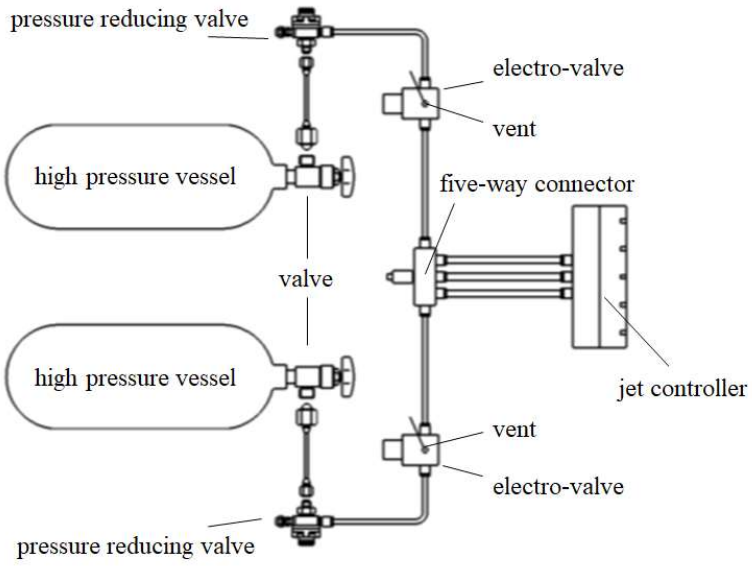


Figure 6 – The preliminary layout of the air supply system.

5. The structure scheme of double fuselage flight platform

The structure scheme of the dual-fuselage platform includes body structure, equipment system, air source system, jet actuator and so on (Figure 7). The body structure is mainly assembled by light wood, and the load-bearing structures such as the wing girder are strengthened by carbon fiber rods. The power and control units of the equipment system are arranged at the front end of the double fuselage, and the fixed landing gear similar to the last three points is adopted. The high-pressure vessel and decompression system of the air source system are arranged in the double fuselage, which are loaded and unloaded through the fuselage cover. The low-pressure gas after decompression is connected to the front end of the jet controller through the air hose.

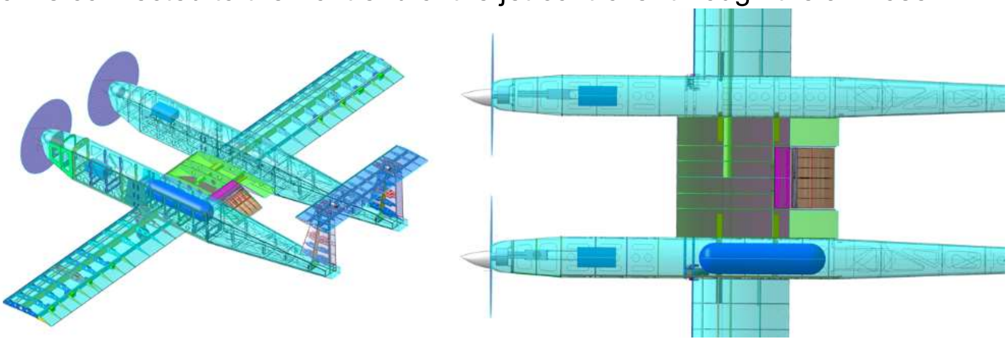


Figure 7 – The structure scheme of the dual-fuselage platform.

The jet controller is manufactured by metal 3D printing. Structurally, it is not only a part of the skin of the test wing section, but also serves as a restrainer for the deflection of the trailing edge flap (Figure 8). In order to ensure the air supply flow requirements, the front end of the controller adopts a three-way air supply scheme. The air converges after passing through the chamber and flows out through five jet outlets. The opening and closing of the jet is mainly controlled by the opening and closing of the electro-valve after the pressure reducing valve. There is no valve on the jet controller.

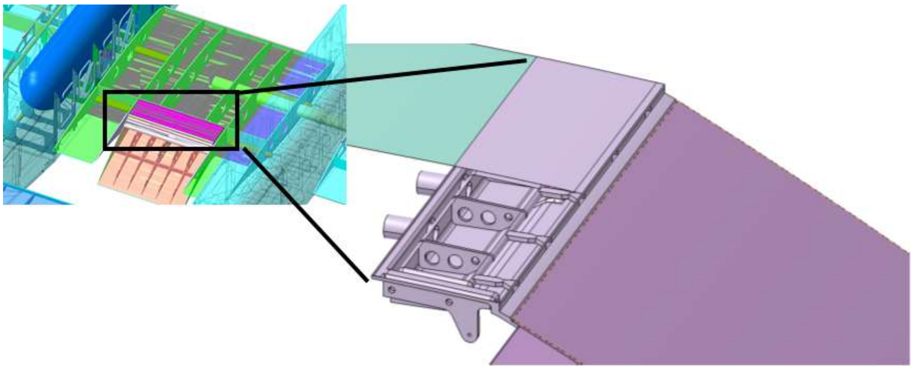


Figure 8 – The structure diagram of jet controller.

6. Flight test of trailing edge flap separation control

The functional verification of the jet control system is carried out by the flow separation control of the trailing edge flap surface. The jet control system, the flap actuation system and the data acquisition system are all controlled by the program. The selected flight speed is 30m/s, and flight height is 50m. The collected data are mainly the pressure of the high-pressure vessels end and the jet controller plenum chamber end. The data sampling frequency is 10 Hz, and the wing separation control effect is qualitatively analyzed by the wing surface wire. The schematic diagram of the ground and flight state of the dual-fuselage flight platform with jet control system is shown in Figure 9.

Figure 9 – The dual-fuselage flight platform in ground preparation and air flight.

The schematic diagram of the flight test route is shown in Figure 10. After taking off from the airport, the flight platform reaches the test state in the specified airspace through climbing acceleration and other operations. And then it is transferred to the level-flight state before the test, and the trailing edge flap is opened at point A, and the jet control system is further opened at point B for more than 20s. After the test, enter C point with recover the trailing edge flap and close the jet control system, re-into the level-flight state. After reaching the airspace near the airport, the flight platform descent, slows down, and finally lands on the runway.

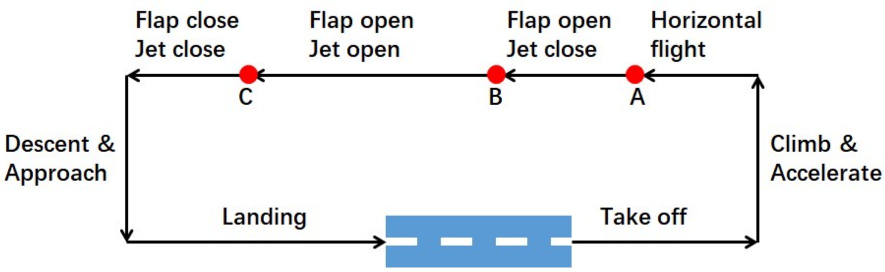


Figure 10 – The schematic diagram of flight test route.

Figure 11 shows the wire state on the flap surface recorded by the camera at different viewpoints of the aircraft during the typical flight phase of the flight test. It can be seen that, before the point A (the level-flight state), at this time, the trailing edge flap is retracted and the jet control system is closed, there is no flow separation on the surface of the flap, and the wire is close to the wall surface (Figure 11a). After that, the trailing edge flap is opened and the jet control system is kept closed, namely the A-B section. At this time, the wire state of the flap surface swings greatly, and the directions are different, indicating that the flow on the trailing edge flap surface is completely separated (Figure 11b). Subsequently, further open the jet control system, that is, B-C section, the wire thread on the surface of the flap is close to the wall, indicating that the jet control completely eliminates the separation of the wing surface (Figure 11c).

(a) The level-flight state with flap retracted and jet closed

(b) The level-flight state with flap opened and jet closed

(c) The level-flight state with flap opened and jet opened

Figure 11 – The wire state on the flap surface during the typical flight phase.

Take the point B on the flight test route when the jet control system is opened as the time of 0, after that, until the C point when the jet control system is closed. The pressure change curves of the high-pressure vessels end and the jet controller plenum chamber end with time during this time are shown in Figure 12. It can be seen that the initial pressure at the end of the high-pressure vessels is 2.27MPa, the pressure at the end of the test is 1.14MPa, and the cut-off pressure of the high-pressure vessels in which the jet air supply system works effectively is less than 1.1MPa. As the valve opens, the pressure at the high-pressure vessels end decreases linearly, while the total pressure at the jet controller plenum chamber end is approximately constant, basically maintained at about 0.3 MPa. As the valve closes, the pressure at the high-pressure vessels end immediately remains constant, and the pressure in the jet controller plenum chamber end is approximately 0Pa. After that, as the valve opens again, the pressure at the high-pressure vessels end decreases linearly. From the curves change, it can be seen that the jet air supply system adopted in this paper has better pressure reduction and flow control ability, and the effective air supply time is more than 30s, which meets the design requirements.

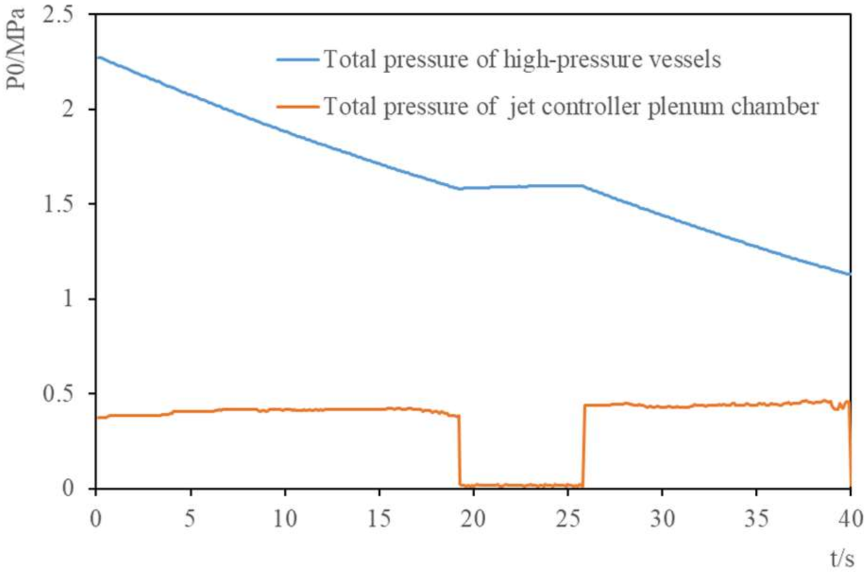


Figure 12 The pressure change curves of the high-pressure vessels end and the jet controller plenum chamber end with time during the flight test route B-C

7. Conclusions and Prospects

Based on the jet control of the separated flow of the trailing edge flap, a dual-fuselage flight platform with a fuselage length of 2m and a span of 3.88m is proposed. The available jet control wing section has a chord length of 0.8 m and a span of 0.6 m. The air supply system can provide a high-pressure air flow with a total outlet pressure of 0.3 MPa and a duration of more than 30 s. It can effectively support the function verification test of the jet control system.

As a general jet control verification platform, the integrated innovation research of jet control system can also be carried out by replacing the new jet controller in the future.

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9. Copyright Statement

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