Hindawi
Journal of Applied Mathematics
Volume 2022, Article ID 8306216, 16 pages
https://doi.org/10.1155/2022/8306216

Research Article

Mechanical Structure Design of the Aircraft ASD Control Isolation Control

Qiongyan Shi and Jianghua Zhang

College of Mechanical Engineering, Changzhou Vocational Institute of Mechatronic Technology, Changzhou 213164, China

Correspondence should be addressed to Qiongyan Shi; sqy20220122@163.com

Received 23 August 2022; Revised 11 October 2022; Accepted 29 October 2022; Published 16 November 2022

Academic Editor: Qiankun Song

Aircraft control system is of key importance for flight attitude control of aircrafts. Its normal function directly determines whether the aircraft flies safely, flight delay, and dispatch reliability. Therefore, this paper designs the mechanical structure of the aircraft ASD control isolation control. Firstly, the mechanical control principle of the driving rod system is analyzed, and the isolation mechanism of pitch and roll control is designed; secondly, the control lines are classified, the transmission characteristic requirements of the aircraft control isolation system are given, the transmission ratio distribution and calculation of the aircraft control isolation system are given, and finally, the mechanism design of the aircraft ASD control isolation system is realized.

1. Introduction

The aircraft control isolation system, also known as the aircraft control system, is used to transmit the pilot's control command, make each control surface of the aircraft deflect according to the law of the command, generate pneumatic control force and torque, and realize the stable control of various flight attitudes [1]. Therefore, it affects the flight performance and flight safety of an aircraft to a great extent. According to the command source, the manual control system can be divided into two parts [2]. Manual control system is divided into main control and auxiliary control. The main control system refers to the stability and maneuver control of pitch, roll, and yaw; auxiliary control refers to the control of increasing lift, increasing resistance, and equal distribution. Manual control system can be divided into simple mechanical control system and power-assisted control system [3]. With the birth of aircraft, the aircraft control isolation system has mainly experienced the following development stages. The control system of early aircraft directly controlled the rudder surface with the help of steel cable or pull rod. The pilot directly felt the change of aerodynamic force on the rudder surface through rod force and rod displacement to control the movement of the aircraft. This control system is called simple mechanical control system. Traditionally, simple mechanical control systems are divided into soft, hard, and hybrid. In recent years, with the rise of general aviation, mechanical control systems with push cables as the main transmission components have been widely used in light/ultralight aircraft [4]. With the improvement of flight speed and the increase of aircraft size and weight, it is difficult to operate the aircraft by the pilot's physical strength. Therefore, a hydraulic booster that uses hydraulic energy to load and start the rudder deflection is proposed [5]. On high-speed and heavy aircraft, the reversible power-assisted control system is first adopted. Most of the aerodynamic loads on the control surface are overcome by boosters, and only a small part is transmitted to the cockpit, so that the pilot has the feeling of control [6]. In the 1970s, the requirements of aircraft performance were higher and higher, and the control and stabilization system with mechanical control as the theme could not meet the requirements. The rapid development of computer and the development of modern control theory and redundancy technology have created conditions for the full authority fly by wire control system. Flight control, aerodynamics, structure, and

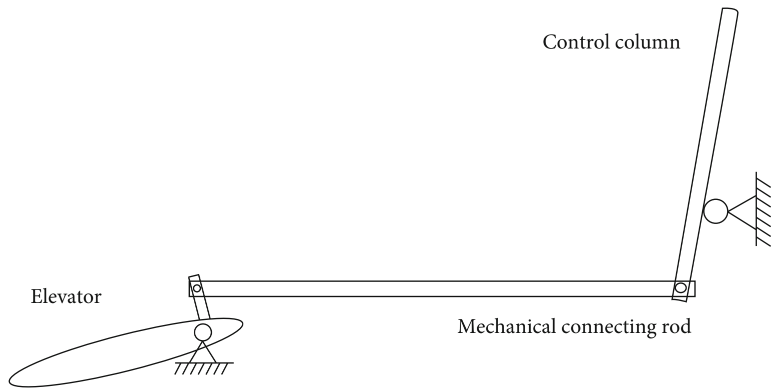


Figure 1: Working principle of mechanical control.

engine have become the four basic elements of the new aircraft design. This paper takes the mechanical structure design of the aircraft ASD control system as an example to design the corresponding human sensory system. According to the different actuators of the afterburner system, the afterburner system can be divided into the afterburner system based on the hydraulic servo system and the afterburner system based on the torque motor. The pitch and roll control isolation mechanism is designed. In the flight control system, the central control mechanism is connected with the control surface through a mechanical transmission chain to realize the transmission of control force and control displacement. The required system control characteristics are realized by the transmission characteristics and selected functional components to meet the requirements of control quality. The control circuit can be divided into soft control and hard control according to the transmission components used. Assign and calculate the transmission ratio of aircraft control and vibration isolation system, draw the system transmission diagram, and calculate the transmission characteristics of control and isolation system. Optimize the aircraft control isolation mechanism. The design effect of this method is verified.

2. Research on Control Circuit

2.1. Mechanical Control Principle of Driving Rod System. In the mechanical control system, the pilot directly controls the joystick and drives the movement of the aircraft rudder through the mechanical link, so as to realize the corresponding flight attitude. The principle of mechanical manipulation is shown in Figure 1.

In the traditional mechanical control system, after the pilot controls the steering rod to rotate, the rudder surface of the aircraft is driven to rotate through the mechanical connecting rod, and the aerodynamic force acting on the rudder surface is transmitted to the pilot through the mechanical connecting rod. The current aircraft control system is no longer directly connected with the control surface of the aircraft. In order to make the pilot feel like operating the aircraft, certain methods need to be adopted to simulate this force feeling; that is, the corresponding human feeling system needs to be designed [7]. The human sense system is also the force loading system that realizes the force feedback to the driver. For the side bar device, PSS uses the spring to load the force and uses the servo hydraulic system or motor to load the force. The force loading system of as needs to have good simulation fidelity for the sense of control force and can simulate the force that the pilot should feel in different flight states in real time [8, 9]. According to the different actuators of as force loading system, the force loading system can be divided into force loading system based on hydraulic servo system and force loading system based on torque motor. The former uses hydraulic cylinder as actuator, and the latter uses torque motor as actuator.

The force loading system of PSS has only one function, that is, to provide the driver with a single feedback force with force displacement characteristics, while the force loading system of pass has two functions: on the one hand, when the aircraft works in autopilot mode, drag the handle to rotate, so as to provide the driver with visual signal indication; on the other hand, in the pilot's manual driving mode, it provides the driver with the feedback force whose force displacement characteristics change with the flight state of the aircraft. In these two functions, the former is position servo and the latter is force servo.

2.2. Design of Isolation Mechanism for Pitch and Roll Control. The pilot can control the two actions of pitch and roll of the aircraft by controlling the driving rod device. How to isolate the pitch control and roll control within the limited volume of the driving rod device, the driving rod isolation mechanism is the key of structural design [10]. The aircraft attitude control system can be simply described in Figure 2.

θ and γ in Figure 2 are the pitch angle and roll angle of the aircraft, respectively. The two degree of freedom gyroscope is a feedback device, which can be used to measure and indicate the pitch angle and tilt angle of the aircraft [11]. When the pilot exerts force on the pitch and roll control mechanism of the driving rod, the driving rod device outputs an electrical signal to the pitch and roll attitude controller. The controller outputs the corresponding electrical command according to the input electrical signal to control the pitch and roll of the aircraft. The two degree of freedom

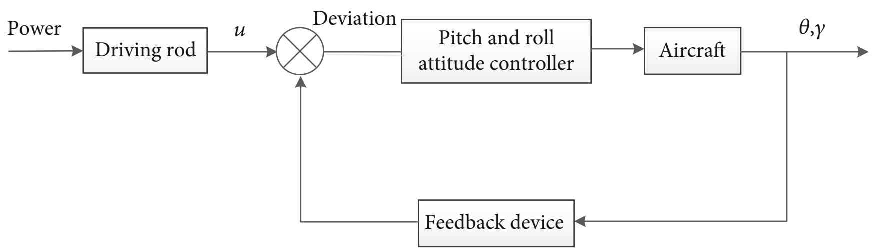


Figure 2: Aircraft attitude control system.

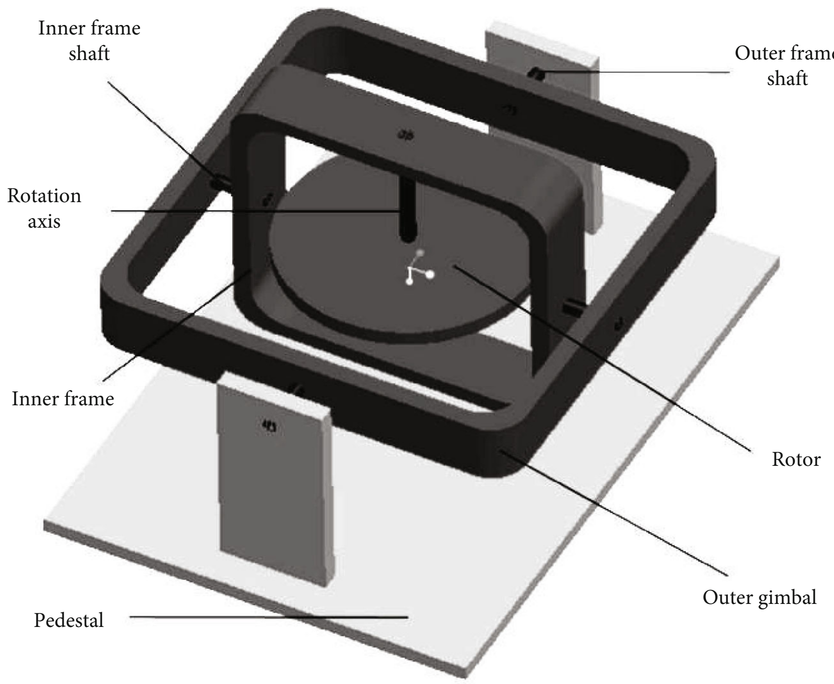


Figure 3: Structural diagram of two degree of freedom gyroscope frame.

gyroscope detects the pitch angle and roll angle of the aircraft and feeds back the signal to the attitude controller, so as to form a closed-loop control system of the aircraft attitude.

The frame structure of two degree of freedom gyroscope is shown in Figure 3, which is composed of outer frame, inner frame, outer frame shaft, inner frame shaft, rotation shaft, rotor, and base. The outer frame is installed on the base through the outer frame shaft, the inner frame is installed on the outer frame through the inner frame shaft, the outer frame shaft and inner frame shaft are perpendicular to each other, and the rotor is installed on the inner frame through the rotation shaft [12]. The rotor and the inner frame can rotate around the inner frame axis, and the inner frame and the outer frame can rotate around the outer frame axis, so the rotation axis has two precession degrees of freedom perpendicular to each other. Therefore, the two degree of freedom gyroscope can realize that the rotation axis can point to any inertial space [13].

Because the two degree of freedom gyroscope has two mutually perpendicular rotational degrees of freedom, and it is thought that the isolation mechanism of pitch and roll control to be designed also needs two mutually perpendicular actions, this paper designs the isolation mechanism of pitch and roll control based on the structural principle of the two degree of freedom gyroscope frame. The three-dimensional solid model of the isolation mechanism is shown in Figure 4.

The rolling rotor of the isolation mechanism in Figure 4 is regarded as the inner frame in the two degree of freedom gyroscope, structure 1 is regarded as the outer frame in the two degree of freedom gyroscope, and the handle connecting frame is regarded as the rotor in the two degree of freedom gyroscope [14]. The handle is fixedly connected with the handle connecting frame, the handle connecting frame is connected with the rolling rotor through the pin shaft, and the rolling rotor is also connected with the rolling shaft through the pin shaft. When the driver operates the handle along the pitching direction to drive the pitching axis to rotate, the roller does not rotate; when the driver operates the handle along the rolling direction and drives the rolling shaft to rotate through the rolling rotor, the pitching shaft does not rotate, so as to realize the control isolation between the pitching direction and the rolling direction.

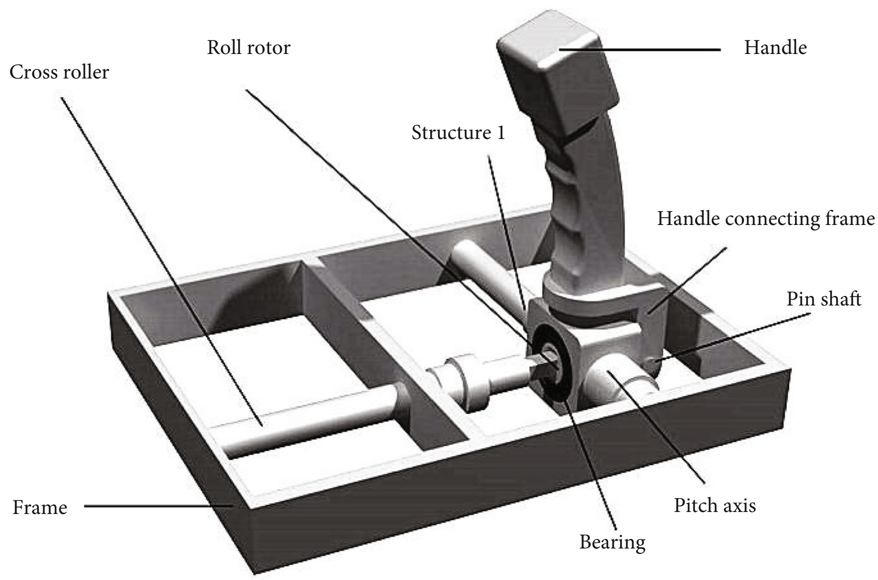


Figure 4: Pitch and roll control isolation mechanism.

2.3. Arrangement and Classification of Control Lines

2.3.1. Control Line Arrangement. In the flight control system, the central control mechanism and control surface are connected by mechanical transmission chain to realize the transmission of control force and control displacement, and the required system control characteristics are realized by transmission characteristics and selected functional components to meet the requirements of control quality. The control surface is arranged as far away from the center of gravity of the aircraft as possible, so as to reduce the area, aerodynamic load, and structural weight of the control surface on the premise of obtaining the required torque. Therefore, the control line will run through the whole aircraft [15]. The control line should also bear and move and have maintainability requirements. Therefore, the layout of the control line should be the shortest and most direct when the layout of the whole machine allows; obtain the strongest support of the body structure in the shelter; there is enough space to ensure the movement of components; keep away from pollution sources and heat sources; and it has good accessibility and is convenient for assembly, disassembly, and adjustment [16].

2.3.2. Classification of Control Lines. The control line can be divided into soft control and hard control according to the transmission components it can use. Early aircraft mostly used soft controls. With the improvement of aircraft performance, hard control is used in j-fighter aircraft. At present, all kinds of aircraft use soft, hard control, or hybrid, but after the booster line is hard control. The characteristics of the two control lines are shown in Table 1.

The above comparison is relatively good or bad, and some items can be reflected only when the line is long enough. In the design, corresponding measures can be taken to compensate for its shortcomings, so that all kinds of maneuvers can meet the requirements of maneuverability.

Table 1: Soft and hard control system.

Project	Soft control	Hard to manipulate
The system for clearance	Small	Big
System friction	Big	Small
The system stiffness	Poor	Good
For structural deformation and temperature change	Sensitive	Not sensitive
Weight	Lighter	Heavier
Maintainability	Different	Good
Cost	Lower	Higher
Production phase	Shorter	Longer

In the selection of scheme, soft control is generally selected for the system or area with long-distance, straight section transmission and less stress; the area with small structural deformation and temperature change; the line with open space and convenient maintenance, such as the flat tail and rudder control of light and explosive aircraft; the front section system of power flight control system; etc. In addition, the selection of control lines is also related to the traditional habits of the design unit.

With the continuous development of the aviation industry, the development of flight simulator has also made great progress, and has become an emerging discipline. As one of the important subsystems of flight simulator, the development of control load system has experienced three stages: simple mechanical loading and aircraft control system modification, analog computer force servo system, and modern all digital control load system. The characteristics of the development of control load system are as follows: it has high dynamic response and is difficult to realize; according to the design of specific aircraft control system, we can learn from each other in key technologies. The initial control load system adopts a simple mechanical loading mode, and the main components are spring, mechanical damping, etc.

Different force sensing simulations can be realized by using springs with different gradients, but its mechanical structure is similar to the real aircraft control mechanism, resulting in the complexity of the mechanism. If it is necessary to realize the force sensing simulation of other gradients, it can only be realized by replacing springs and other components. In 1950, the control load system developed by Redifon company and Curtiss-Wright company in the UK adopted the spring combined with the automatic adjustment mechanism of the electric force arm. Its principle is to change the transmission ratio between the control mechanism and the loader to obtain the changing control force.

3. Mechanical Structure Design of Aircraft ASD Control Isolation Control

3.1. Transmission Characteristic Requirements and Design of Aircraft Control Isolation System. The transmission ratio is a dimensionless parameter that describes the corresponding relationship between the control command objects of the flight control isolation system. The transmission coefficient is a dimensional quantity, such as the transmission relationship between the central control mechanism and the control surface, which is generally expressed in rad/m.

In the aircraft control isolation system, the average transmission coefficient between the control displacement of the joystick or pedal and the deflection of the control surface is

$$K = \frac{\delta}{D}. \tag{1}$$

According to the law of conservation of energy, regardless of the energy loss in the line system, the equation can be obtained:

$$F \cdot D = M_h \cdot \delta. \tag{2}$$

Then, there is a relation:

$$\frac{F}{M_h} = \frac{\delta}{D} = K, \tag{3}$$

where D represents the displacement of the control lever, δ represents the deflection of the control surface, K represents the average transmission coefficient of the control system, M_h represents the torque of the control hinge, and F represents the control force.

The ratio of the displacement of the central control mechanism to the input displacement of the rocker arm of the control surface is the transmission ratio of the aircraft control isolation system. The transmission ratio of the system is equal to the product of the transmission ratio of each transmission component in the transmission chain, that is,

$$n_0 = n_1 \cdot n_2 \cdot n_3 \cdots n_n. \tag{4}$$

The transmission ratio of the transmission component and transmission mechanism is the effective radius ratio or displacement ratio between its output and input, or the reciprocal of the load ratio, that is,

$$n_i = \frac{R_i}{R_{i-1}} = \frac{S_i}{S_{i-1}} = \frac{F_i}{F_{i-1}}. \tag{5}$$

According to the above equation, the relationship between the system transmission coefficient K and the system transmission ratio n is

$$K = \frac{n}{R}, \tag{6}$$

where R represents the distance between the rocker arm and the control surface.

From the control mechanism to the central components, it forms various functional sections of the transmission system, including the control chain to the central components. Some transmission sections have special transmission ratio requirements, so it is required to distribute the transmission ratio. The transmission ratio of each transmission section shall be determined according to the load, clearance, stiffness, friction, working stroke, and other factors of each functional component and component. Any functional component and transmission component require appropriate transmission ratio as the design basis, and each transmission section also has its corresponding transmission ratio requirements. The transmission ratio of the system is the product of the transmission ratio of each component and each section. When the transmission ratio of each section has been determined, the transmission ratio of the components should be changed and adjusted to meet the transmission ratio requirements of the whole system [17].

3.2. Distribution and Calculation of Transmission Ratio of Aircraft Control Isolation System

3.2.1. Allocation Procedure of Transmission Ratio

(1) When the total transmission ratio of the system is determined, first, meet the special transmission ratio requirements of some transmission sections or transmission components, and then, allocate the rest to other transmission sections or transmission components

(2) On the transmission line of the straight section, the guide part, follow-up rocker arm, and pulley ($n = 1$) are generally used, which do not participate in the distribution of transmission ratio

(3) For large transmission ratio or reversing transmission components with large load, they should be supported by stiffeners or easy to strengthen

(4) Small nonlinear transmission ratio should be concentrated on a few differential rocker arms

(5) In the soft control system, the transmission ratio is centrally set in the sector wheel or other hard transmission section

(6) After the system transmission ratio and component transmission ratio are preliminarily determined, the transmission calculation of the system can be carried out to determine the motion range of components and design load; put forward space requirements, structural support requirements, cover setting requirements, etc.; and complete the relevant coordination of the system in the sketch design stage

3.2.2. Drawing and Calculation of System Transmission Diagram

(1) Draw the transmission diagram: the transmission diagram is also known as the moving die line. On the steel plate or special gelatin plate, according to the accuracy requirements of the structural die line, first, draw the horizontal datum line, fuselage frame line, beam, and rib axis of the wing as the positioning data of the system components. The drawing of motion diagram generally starts from the central control mechanism and control surface and converges to the preset point. The drawing method of plane transmission is relatively simple. Spatial transmission can be described by projection geometry, or combined with calculation, projected onto the same plane, and then processed according to the principle of plane transmission. Finally, the parameters of the rocker arm group at the confluence point are adjusted to meet the requirements of the system transmission; change other component parameters if necessary. First, draw the mold line at the neutral position of the system, and then, draw the mold line at the front and rear movement limit positions. For the special parts, intermediate points can be added to check the movement relationship, the independence of movement in cross-linking control, the gap of space tight parts, etc. Through the drawing of motion diagram, the positioning size, structural parameters, motion range, transmission ratio, and other data of the whole system, mechanism, finished products, and transmission components are redetermined to form design documents, which are filed together with the drawing board for future reference

(2) Calculation of transmission characteristics of control isolation system: although the system motion drawing is simple, intuitive, and accurate, which can meet the engineering requirements in most cases and check the coordination with the structure, this method is time-consuming, cumbersome, difficult to modify, and inconvenient to save the drawing board. With the popularization of computers, it provides a home change means for the calculation of transmission characteristics of the system. At present, subroutines for calculating transmission characteristics have been compiled for various typical components, mechanisms, finished products, and transmission components. Various subroutines can be selected according to the composition of the system, the arrangement order of components, and the installation position, and the program can be assigned and calculated according to the component parameters and the neutral state of the system. When the system characteristics meet the requirements, the whole program can be frozen as a system special program and archived

3.3. Mechanism Design of Aircraft Control Isolation System. The isolation mechanism plays an important role in the aircraft control system. Reasonable control mechanism plays an important role in improving the performance and reliability of aircraft control isolation system. In the design of aircraft control isolation system, both inheritance and development should be paid attention to the mechanism design. On the one hand, good mechanisms are widely used. For example, the six-bar nonlinear mechanism has been used in all kinds of aircraft for more than a century and is still widely used. The central control mechanism has a history of nearly one hundred years and is even still used in the fly by wire control system. On the other hand, the development of new institutions can not only expand the function of the system but also make the system simple and reliable. In the design of flight control system, the control mechanism of each link usually needs to be designed by itself, because the system transmission ratio, load, space condition, and installation form of various aircraft are different. Therefore, it is difficult to copy and use existing institutions. In addition, the application of the mechanism is very flexible, and the functions of the mechanism can be diverse. For example, there are more than ten functions of the spring barrel, and the mechanism can also be combined.

3.3.1. Design Requirements of Operating Mechanism. There may be some differences in the design requirements of the control mechanism for different types of aircraft, but the general design requirements remain unchanged, mainly including the following points:

(1) The mechanism shall meet the reliability requirements of the system and work reliably within the service life of the aircraft

(2) All components of the mechanism shall operate stably and continuously without obvious clearance and hysteresis

(3) Small friction and wear to ensure the performance requirements of the whole system

(4) Small inertia and large stiffness to ensure the requirements of weight index and follow-up

(5) High service life, requiring the same service life of the mechanism and the body

(6) Simple maintenance, no special maintenance, and no special maintenance of the equipment and tools

(7) In order to meet the requirements of authority and function transformation, hydraulic and electrical

energy and control elements such as hydraulic valves and switches can be introduced

3.3.2. Design Principle of Control Mechanism. The differential superposition mechanism is used to control the control surfaces at two symmetrical positions, complete the same direction or differential deflection at the same time, and realize the attitude control of two mutually perpendicular axes. The differential superposition mechanism adopts parallelogram mechanism, and uses the same motion of each point on the "t" rocker arm to realize the same direction control of the control surface.

When x_2 has displacement input, the output in the same direction is generated:

$$y_1 = y_2 = y_E = -n_2 x_2, \tag{7}$$

where n_1 represents the transmission ratio in the same direction.

When x_1 has displacement input, differential output is generated:

$$-y_1 = y_2 = n_1 x_1, \tag{8}$$

where n_2 is the differential transmission ratio.

3.3.3. Mechanism Design Steps. The mechanism design of aircraft control system shall follow the following steps and sequences:

(1) Determine the function: the function of the mechanism depends on the functional requirements of the flight control system, and the function of the system depends on the overall layout of the aircraft, the aerodynamic characteristics, and the functional requirements of the control axis

(2) Select the type: mechanisms that complete the same function can have different structural types, and different structures have their own characteristics. Therefore, the structural type should be selected according to the function, importance, and reliability requirements of the mechanism in the system. The selection principle should be to make the mechanism as simple and reliable as possible on the premise of meeting the performance requirements. One thing to note here is that in the control of completing key functions, the low pair mechanism should be preferred, because the low pair mechanism has the advantages of high precision, small wear, high reliability, simple maintenance, good manufacturability, and so on

(3) Determine the transmission ratio and range of motion: the transmission ratio includes mechanism transmission ratio and internal transmission ratio. The mechanism transmission ratio is distributed by the system transmission chain, and the input ratio of the mechanism shall meet the overall transmission requirements of the system. Transmission ratio is an important parameter in mechanism design. After the transmission ratio is given, the internal transmission ratio distribution is also an important link

(4) Selection of installation position: according to the functional requirements, various mechanisms shall be arranged in a certain order in the transmission chain. However, the installation position of the mechanism should also take into account the overall layout of the aircraft, the direction of the structure, the layout of stiffeners, the size of space, assembly, disassembly, and maintainability

(5) Structural design: the structural design shall be carried out after the selection of mechanism, the structural parameters of mechanism, and the installation position are determined. The structural design determines the installation form, connection size, assembly benchmark, special compensation, and positioning device of the mechanism. The structural design shall also ensure the strength, stiffness, transmission ratio, motion coordination, clearance requirements, design compensation, coordination, lubrication, and other requirements of the mechanism, as well as the normal and reliable operation of the mechanism within the whole working range

(6) Stress analysis: after the structure, transmission ratio, external load, and motion range of the mechanism are determined, the stress analysis shall be carried out. The design load of each component shall be determined according to the input load, and the support load required by the mechanism shall be determined. By adjusting the internal transmission ratio, the bearing shall be reasonable and the structural size and weight of parts shall be reduced

(7) Motion analysis: after the principle, structure, and structural size of the mechanism are determined, the motion analysis shall be carried out. The performance of the mechanism, the motion state of each component, the independence of multi-input control, whether the linear or nonlinear transmission meets the requirements, the isolation of fault state, the coordination of components within the whole motion range, and the guarantee of clearance between components are analyzed by analytical method or drawing method

(8) Dynamic analysis: since the mechanism of the flight control system works at low speed and reciprocating swing, the mass of the components is small. Inertia force has little influence, so generally, only static analysis is done, and dynamic analysis of the mechanism is carried out only when necessary

(9) Function conversion: for those mechanisms for function conversion, state indication, variable gain, clutch, variable brake, etc., it is necessary to select a

reasonable signal source to control energy and corresponding finished products and components, so as to ensure the accuracy and reliability of the required functions

(10) Test piece: important and complex mechanisms shall be inspected for function, motion coordination, installation, space coordination, manufacturability, and maintainability through test pieces, as well as component static test

4. Optimization of Aircraft Control Isolation Mechanism

According to engineering experience, properly reducing the mass of the constrained part of the structure can increase the natural frequency of the structure. For the two degree of freedom control isolation mechanism designed above, the constrained part is the place where the bearings are installed on the pitching shaft and roller. At the same time, considering that some dimensions of the designed control isolation mechanism cannot be changed, it is decided to drill the pitching shaft and roller first to observe the change of the natural frequency of the control isolation mechanism after drilling. First, for SolidWorks, there are three bearings with diameters of $\Phi 5$, and the diameters D1, D2 and D3 of the three holes are parameterized into DS_ D1, DS_ D2 and DS_ D3. The selected DS_ D1, DS_ D2, and DS_ D3 are used as the optimized design variables P_1, P_2, and P_3, respectively. The value range of the design variables is shown in Table 2. The first-order natural frequency in the frequency of the modal analysis result is selected as the optimization target P_4. In order to avoid resonance of the operating isolation mechanism, the minimum value of the optimization target P_4 is set to 50 Hz.

If the design variables $P_1 \sim P_3$ are recorded as vectors $X = [x_1, x_2, x_3]$, and the optimization objective P_4 is recorded as the objective function $f(X)$, the mathematical model of the optimization problem can be expressed as

$$\begin{aligned} &\max f(X), \\ &\text{s.t. } x_{i\,\min} \leq x_i \leq x_{i\,\max}, \quad i = 1, 2, 3, \end{aligned} \tag{9}$$

where $x_{i\,\min}$ and $x_{i\,\max}$ are the lower and upper bounds of design variable x_i, as shown in Table 3. Then, import the new model into the workbench and conduct the modal analysis again. Then, based on the modal analysis, select the optimization design module direct optimization to optimize the first-order natural frequency. According to the established optimization model, make relevant settings in the workbench, and list different test design points and their corresponding calculation results through solution and calculation, as shown in Table 3.

The optimal design points recommended in the workbench are DP1, DP2, and DP4. Considering the convenience of actual processing and manufacturing, the design point DP2 is taken as the final design point, and the values are approximated. Finally, $P_1 = 0$, $P_2 = 3$ mm, and $P_3 = 7$ mm.

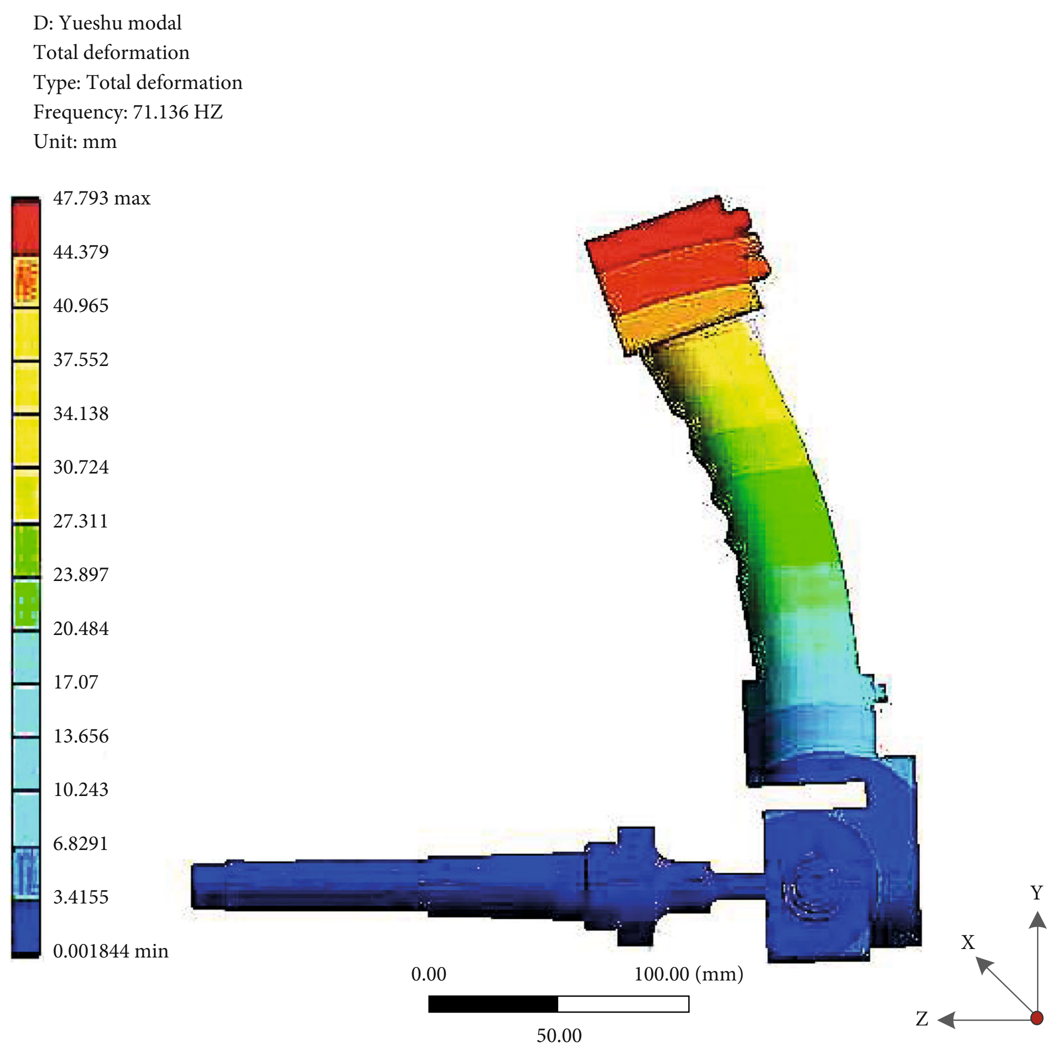
Table 2: Value range of design variables.

Design variables	Initial value (mm)	Lower bound (mm)	Upper bound (mm)
P_1	5	0	10
P_2	5	0	10
P_3	5	0	10

Table 3: Calculation results of different design variables.

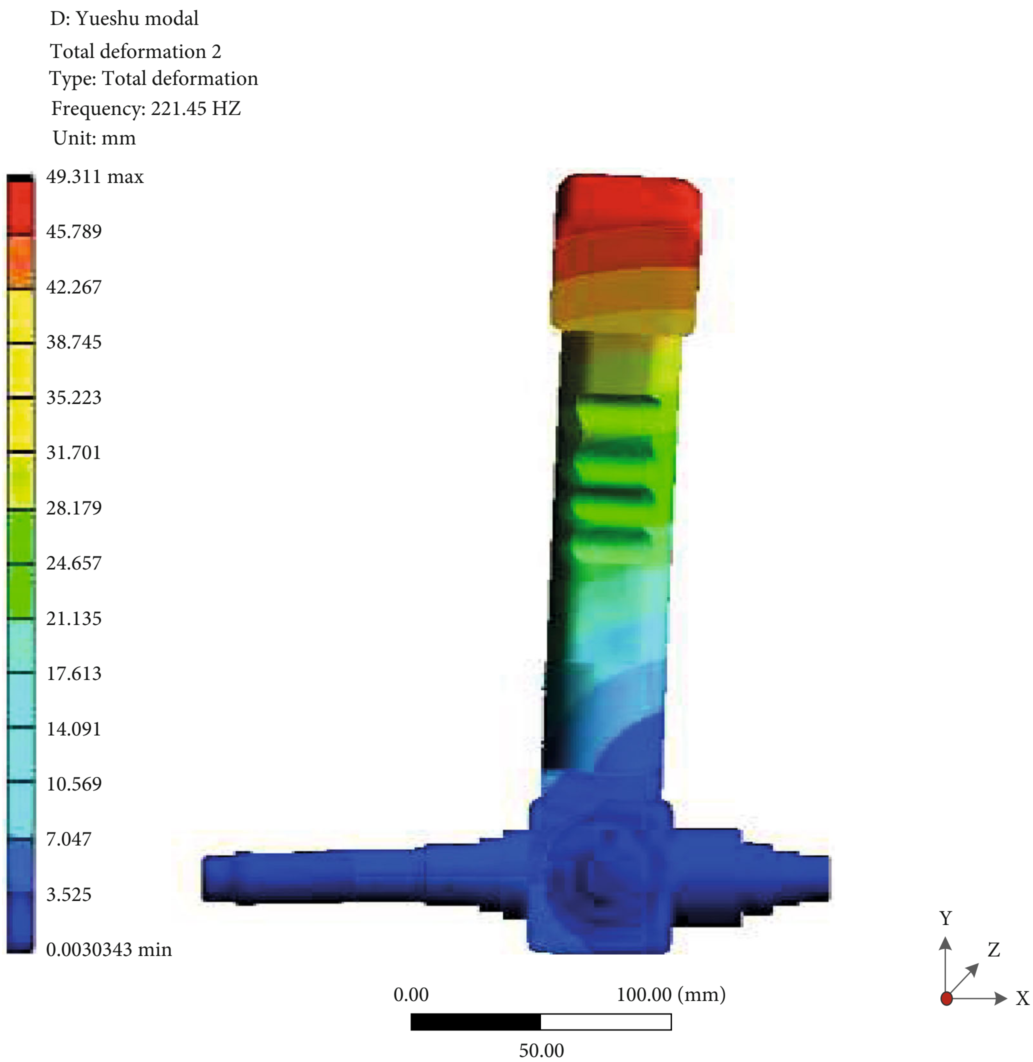
Design point	P_1 (mm)	P_2 (mm)	P_3 (mm)	P_4 (Hz)
DP1	0.1	0.1	0.100	57.85
DP2	0.5	2.6	6.767	60.19
DP3	0.7	7.6	1.211	60.63
DP4	0.9	1.35	4.544	60.74
DP5	1.1	6.35	7.878	60.53
DP6	1.3	3.85	2.322	60.74
DP7	1.7	0.725	8.989	60.48
DP8	2.1	3.225	3.804	60.75
DP9	2.5	1.975	1.581	60.77
DP10	2.7	6.975	4.915	60.71
DP11	3.1	9.475	2.693	60.65
DP12	3.5	5.4125	9.359	60.42
DP13	3.7	2.9125	0.841	60.72
DP14	4.1	1.6625	7.507	60.61
DP15	4.5	4.1625	5.285	60.69
DP16	4.9	1.0375	3.063	60.72
DP17	5.1	6.0375	6.397	60.62
DP18	5.7	2.2875	3.558	60.73
DP19	5.9	7.2875	6.891	60.55
DP20	6.1	4.7875	1.335	60.72
DP21	6.7	5.25625	2.446	60.73
DP22	6.9	2.75625	5.779	60.65
DP23	7.5	6.50625	3.927	60.69
DP24	7.7	4.00625	7.261	60.58
DP25	8.1	0.88125	5.039	60.65
DP26	8.5	3.38125	2.816	60.63
DP27	8.7	8.38125	6.149	60.51
DP28	9.1	7.13125	0.964	60.62
DP29	9.5	9.63125	7.631	60.36
DP30	9.9	5.56875	5.409	60.53

According to the above optimization results, the modeling is reestablished in SOLIDWORKS; that is, the hole diameters at both ends of the pitch axis and the roll axis are modified to D1 = 0, D2 = 3 mm, and D3 = 7 mm, respectively. Import the modified control isolation mechanism model into workbench for constrained modal analysis again. Through the solution analysis, the first 6-order vibration mode diagram of the optimized operation isolation mechanism is obtained, as shown in Figure 5, and the first 6-order modal analysis results are shown in Table 4.



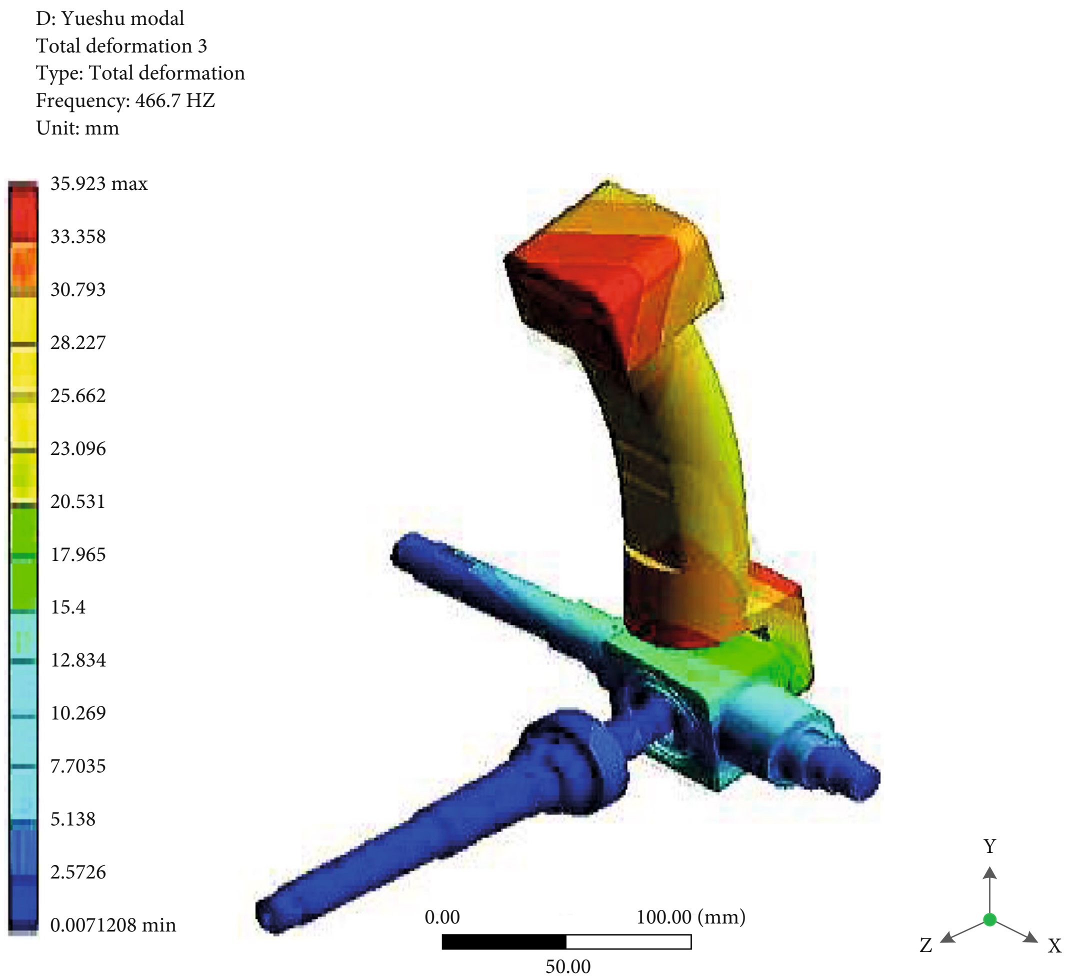
(a) 1 conforming modal shape

Figure 5: Continued.



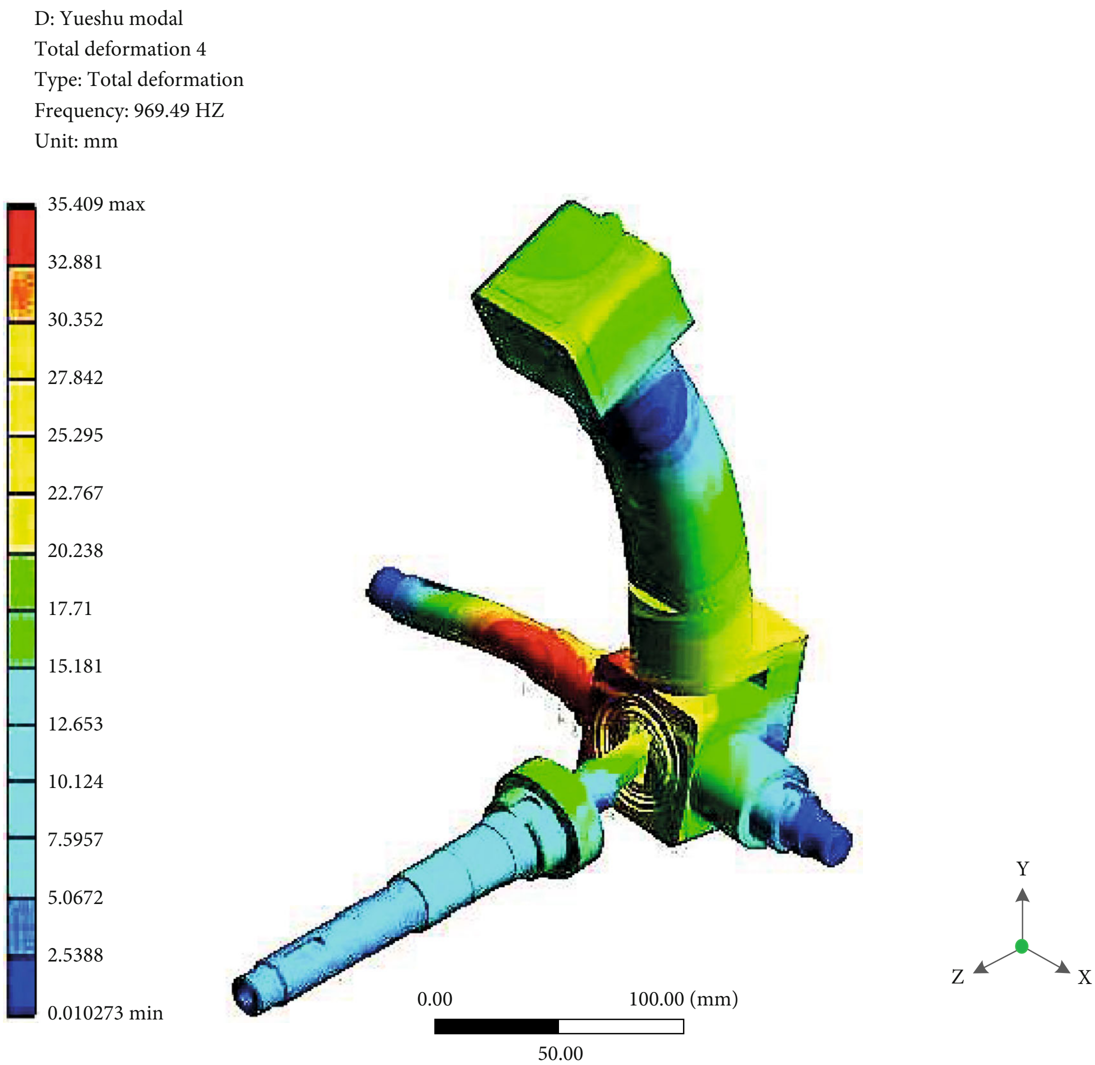
(b) 2 conforming modal shape

Figure 5: Continued.



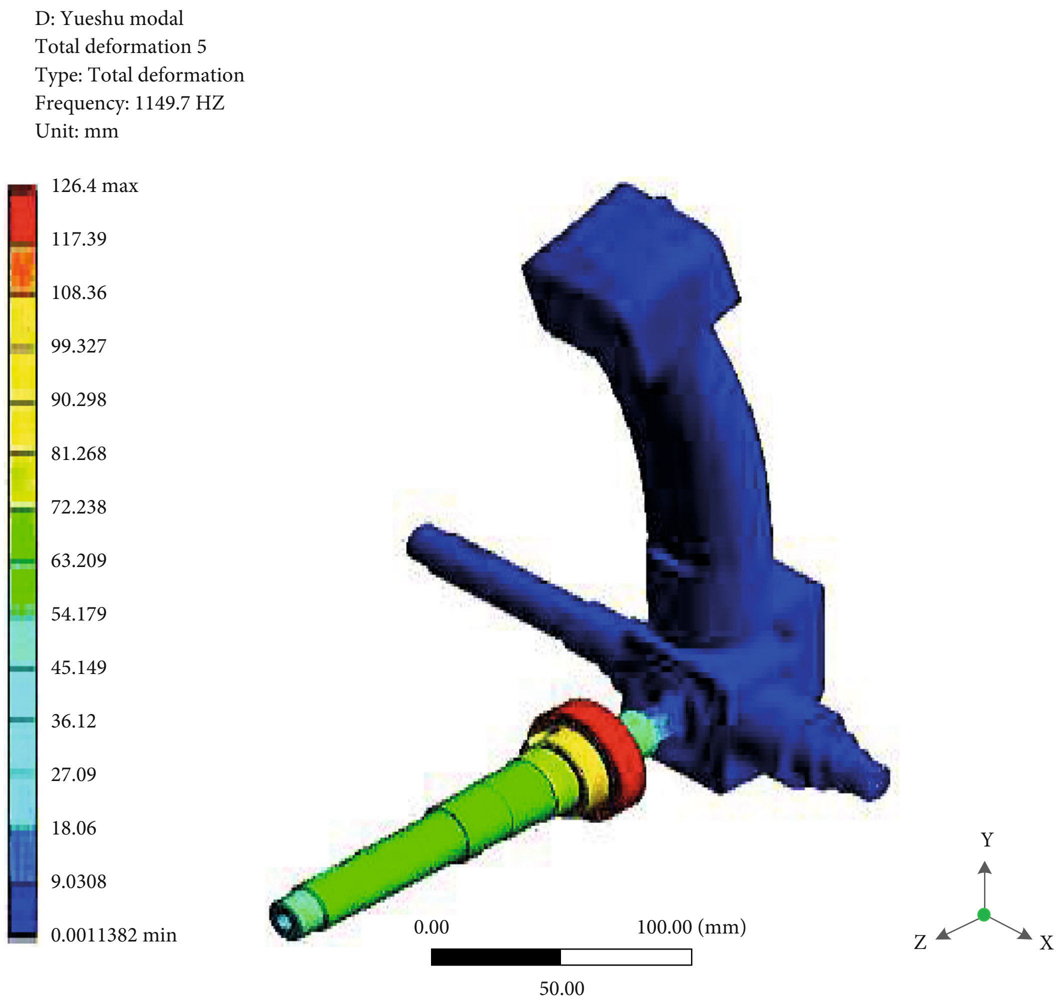
(c) 3 conforming modal shape

Figure 5: Continued.



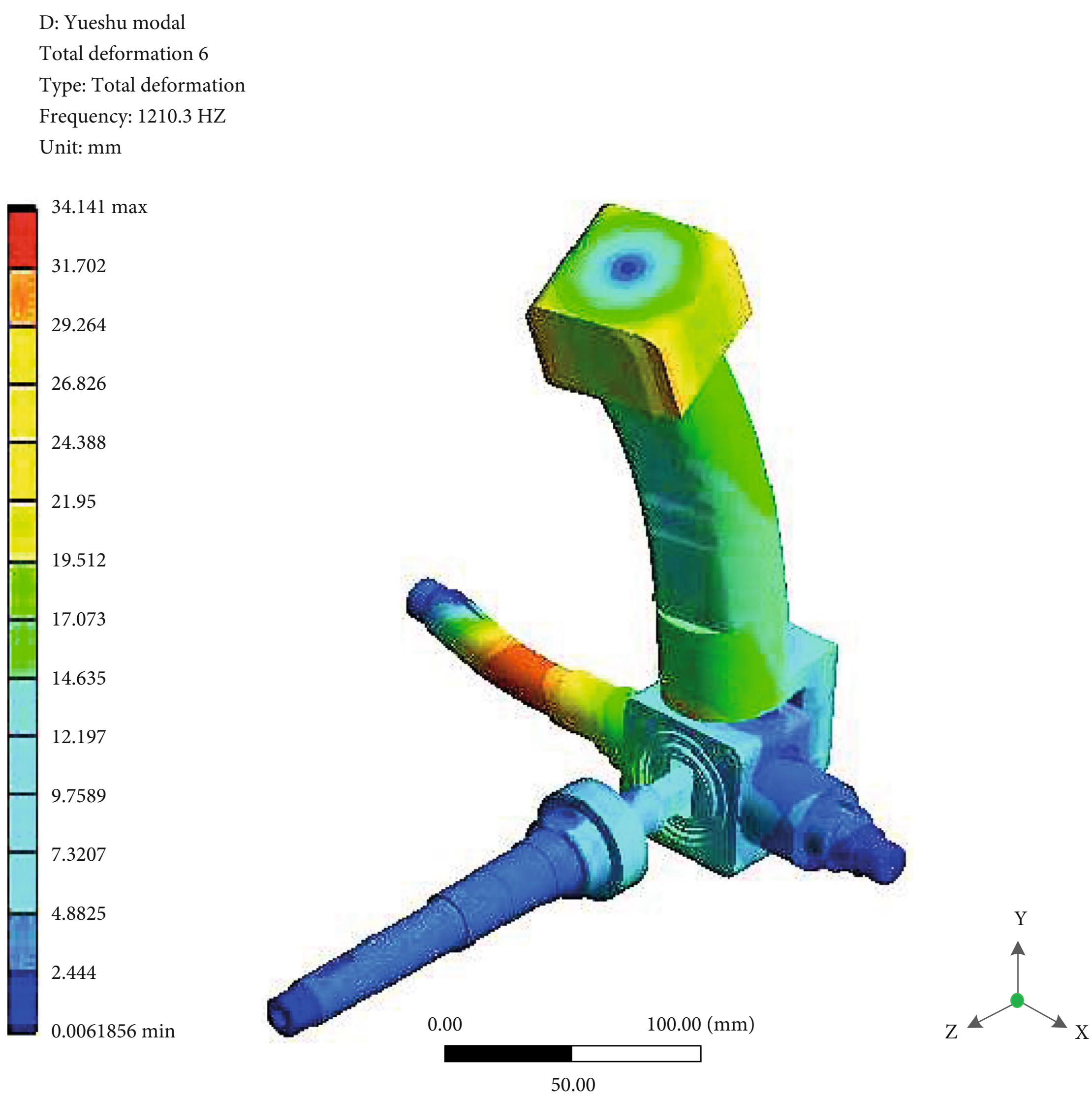
(d) 4 conforming modal shape

FIGURE 5: Continued.



(e) 5 conforming modal shape

Figure 5: Continued.



(f) 6 conforming modal shape

Figure 5: Vibration mode diagram of the first 6 steps of operating isolation mechanism.

Table 4: First six-order modal analysis results of operating isolation mechanism.

Order	Natural frequency (Hz)	Vibration mode characteristics
1	71.14	Except that the roller is not affected, the rest rotates around the x-axis
2	221.45	The pitch axis is locally bent along the y-direction, and the handle rotates around the z-axis
3	466.70	Except that the roller is not affected, the rest is twisted around the x-axis
4	969.49	The roller rotates around the z-axis, the pitch axis bends along the y-direction, and the handle rotates around the x-axis
5	1149.70	It is mainly due to the expansion deformation of the roller and its rotation around the z-axis
6	1210.30	The pitch axis bends in the z-direction, the roll axis rotates around the z-axis, and the handle rotates around the y-axis

It can be seen from the vibration modal diagram of the first six steps of the vibration isolation mechanism in Figure 5 that the vibration modal diagram of modal analysis only describes the form of structural vibration, and its deformation value is not the absolute size of the actual amplitude. The deformation of the mechanism in practical work depends on the coupling relationship between the external excitation direction and frequency and mode. The first mode shape is in the x-axis direction, and the cross roller and pitch axis are not affected. The second mode shape is in the z-axis direction, and the handle is obviously affected. The third-order modal shape is a three-dimensional view; the roll rotor, pin shaft, and pitch shaft interact; and the deformation shape is not obvious. In the fourth mode shape, structure 1 has obvious deformation and large force, which causes the roller rotor to break away from the frame. In the fifth mode shape, the cross roller is greatly stressed and affected. The bending in the middle of the sixth mode shape structure 1 is obvious.

By comparing the modal analysis results before and after the optimization of the control isolation mechanism, it can be seen that the natural frequency of the optimized mechanism is significantly improved, with the first-order natural frequency of 71.14 Hz and the second-order natural frequency of 221.45 Hz. The excitation frequency will not fall within the range of 53.35-287.89 Hz, so the mechanism will not resonate during operation. At the same time, the vibration modes before and after the first three steps of optimization are the same, and the vibration deformation has almost no change. The vibration modes of the fourth step are different, and the vibration deformation decreases significantly after optimization, and the position of the maximum deformation becomes the pitch axis. The vibration mode of the 5th order does not change much, but the vibration deformation increases, the vibration mode of the 6th order is different, and the vibration deformation hardly changes. The vibration mode diagram of modal analysis only describes the form of structural vibration, and its deformation value is not the absolute size of the actual amplitude. The deformation of the mechanism in actual work is determined by the coupling relationship between the direction and frequency of external excitation and the mode.

5. Conclusion

The aircraft control system is used to transmit the pilot's control command, make each control surface of the aircraft deflect according to the law of the command, produce aerodynamic control force and torque, and realize the stable control of various flight attitudes. Therefore, it affects the flight performance and flight safety of an aircraft to a great extent. Traditionally, the aircraft mechanical control system is divided into soft type, hard type, and hybrid type. The mechanical control system with push-pull cable as the main transmission component has been widely used in light/ultralight aircraft. Therefore, this paper designs the mechanical structure of the aircraft ASD control isolation control. This paper analyzes the mechanical control principle of the active rod system, classifies the control lines, calculates the transmission ratio of the aircraft control isolation system, and finally realizes the mechanism design of the aircraft ASD control isolation system. In the future study, advanced science and information technology will be introduced to further realize the stable control of various flight attitudes.

Data Availability

The data used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

Acknowledgments

The research is supported by the Training Objects of "Blue Project" in Jiangsu University.

References

[1] F. Zhang and F. Cheng, "Time domain analysis of nonlinear flutter of control surface clearance of an aircraft," *Progress of Aviation Engineering*, vol. 12, no. 4, pp. 99–104, 2021.

[2] L. Zhang, Y. Zhang, Z. L. Yang, and L. N. Gou, "Design technology and application of combined integrated loading device for large aircraft control system," *Science, Technology and Engineering*, vol. 19, no. 36, pp. 357–362, 2019.

[3] H. L. Li, G. M. Zhang, J. F. Lin, and N. Zhang, "Application of mode conversion in aircraft control system test," *Engineering and Test*, vol. 59, no. 1, 2019.

[4] R. Kang and J. Chen, "Study on aircraft takeoff and landing interval under isolated operation mode of double runway," *Aeronautical Computing Technology*, vol. 51, no. 3, 2021.

[5] L. Q. Ma, "Research status and development of fault tolerant control technology for structural damage aircraft," *Flight Mechanics*, vol. 39, no. 5, pp. 1–7, 2021.

[6] Y. Z. He, H. Wang, and J. C. Mu, "Research and application of aileron control system function inspection test technology," *Engineering and Testing*, vol. 59, no. 3, pp. 68-69, 2019.

[7] R. C. Munjulury, H. Devadurgam, S. Rajagopal, and P. Krus, "Analytical design of conventional and electrical aircraft environmental control systems," *IOP Conference Series: Materials Science and Engineering*, vol. 1226, no. 1, article 012111, 2022.

[8] F. Qiao, J. Shi, X. Qu, and Y. Lyu, "Adaptive back-stepping neural control for an embedded and tiltable V-tail morphing aircraft," *International Journal of Control, Automation and Systems*, vol. 20, no. 2, pp. 678–690, 2022.

[9] I. Zaitceva and L. Chechurin, "The estimation of aircraft control system stability boundaries by the describing function method," *Cybernetics and Physics*, vol. 9, no. 2, pp. 117–122, 2020.

[10] A. Buelta, A. Olivares, E. Staffetti, W. Aftab, and L. Mihaylova, "A Gaussian process iterative learning control for aircraft trajectory tracking," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 57, no. 6, pp. 3962–3973, 2021.

[11] K. Kurul, "Structural design of part of aircraft control system Bachelor thesis, [Ph.D. thesis]," vol. 19, Tech. Rep. 8, Çukurova University Engineering Faculty Department of Mechanical Engineering, 2020.

[12] X. C. Liu and Y. Zhang, "Research progress and prospect of vulnerability assessment methods for key structures of combat aircraft aviation," *Science and Technology*, vol. 32, no. 12, 2021.

[13] Z. G. Wang, F. Li, L. Y. Yao, H. Yu, Z. R. Zhao, and J. L. Zheng, "Research on motor servo control method of active control device," *Aircraft Design*, vol. 40, no. 5, pp. 4–7, 2020.

[14] L. W. Xing, "Seasonal inspection of CESSNA172R aircraft control system," *China Science and Technology Information*, vol. 26, no. 13, pp. 39-40, 2019.

[15] Z. T. Wu, X. R. Li, J. Du, and C. Ding, "Fault evaluation method of aircraft control system based on flight parameter data," *Computer Measurement and Control*, vol. 27, no. 7, pp. 275–279, 2019.

[16] F. Yi, H. W. Jiang, and L. D. Li, "Research on joint on-line calibration technology of aircraft control parameters," *Journal of Electronic Measurement and Instrument*, vol. 35, no. 5, pp. 146–153, 2021.

[17] Y. X. Xia, X. D. Shu, S. Zhang, Z. X. Li, Z. Pater, and J. Bartnicki, "Feasibility study on thinning and thickening of thin-walled pipe fittings in three-roll skew rolling," *Procedia Manufacturing*, vol. 50, pp. 179–182, 2020.