Improved Immune Genetic Algorithm to Optimize the Design of Wing Structure of Competition Aircraft

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Abstract: An improved immune genetic algorithm is used to design and optimize the wing structure parameters of a competition aircraft. According to the requirements of aircraft design, multi-objective optimization index is established. On this basis, the basic steps of using immune algorithm to optimize the main design parameters of aircraft wing structure are proposed, and the optimization of the wing parameters of a competition aircraft is used as an example for simulation calculation. The design variables in the optimization are the size of the wing components, and the optimization goal is to minimize the weight of the wing and the maximum deformation of the wing structure. Research shows that compared with traditional optimization methods; the improved immune genetic algorithm is a very effective optimization method. At the same time, a prototype is made to check the validity and feasibility of the design. Flight test results show that the optimization method is very effective. Although the method is proposed for competition aircraft, it is also applicable to other types of aircraft.

1. Introduction

The competition aircraft refers to the aircraft that participates in the limited-range load air drop project of the National Aviation and Aerospace Model Championship. In the development and manufacturing of competition aircraft, the wing is a necessary force transmission and force bearing component. The structural quality of the wing has an important influence on the flight performance of the whole aircraft. Therefore, it is indispensable to carry out weight reduction research on the wing [1-3]. With the help of suitable optimization methods, more reasonable wing structure parameters can be designed, so that the aircraft can load as much load as possible within the range of available engine power.

The immune system has the ability of self-regulation, and the ability to generate and maintain diverse antibodies based on antibody concentration, which can be applied to parameter detection optimization. Zhang Cuo [4] took alloy composition, pouring temperature, cavity vacuum pressure, casting pressure and mold temperature as input layer parameters, and mechanical properties (tensile strength) and corrosion resistance (corrosion potential) as output layer parameters. A genetic algorithm BP neural network optimization model with a 3×15×1 three-layer topology was constructed. The results showed that the average relative training error of the tensile strength of the model output was 3.46%, and the average prediction error value was 3.40%; the average relative training error of corrosion potential is 3.78%, and the average prediction error is 3.59%; Li Tao [5] et al. proposed technologies such as immune-based large-scale network intrusion dynamic forensics, as well as network security risk detection and control, although there have been relevant researches on immune principle algorithms at home and
abroad. However, due to the complexity of the algorithm, the long time, the selection of the crossover operator and the mutation operator are easy to fall into the local optimum (premature) and other problems, we still need to break through[6-8]. In order to avoid the problems of the above-mentioned immune hybrid algorithm, this article combines the immune algorithm with the genetic algorithm (GA) [9-11], and proposes a new secondary selection immune genetic algorithm (IGA); the algorithm adopts a new initialization method to improve the quality of the initial solution of the population, designs a reasonable coding mechanism, selection strategy, adaptive cross-mutation operation, and combines operations such as immunization and immune memory to improve global convergence and shorten the convergence speed of the algorithm.

This article takes a competition aircraft as the research object, and uses the method of combining IGA and Ansys finite element structure simulation to optimize the structure parameters of the aircraft wing. In the multi-objective optimization design of the competition aircraft wing structure, the wing weight and the wing structure deformation are taken as the optimization objectives for improvement.

2. IGA is used for optimization of wing structure parameters

Through the optimization of the wing structure parameters of the competition aircraft, the goal of optimizing the weight of the aircraft is achieved. The population size is 500, the maximum evolutionary generation is 1000 generations, the hybridization probability is 0.95, and the mutation probability is 0.02. The specific process of using genetic algorithm to optimize the main design parameters of the wing structure is shown in Figure 1.

![Flow chart of optimization of transmission algorithm](image)

The objective function of the mathematical model for the optimization of the wing structure of the competition aircraft is shown in (1):

\[
\begin{align*}
\min & \quad f_1 = F(x_1, x_2, \ldots, x_{20}) \\
\min & \quad f_2 = D_{\text{max}} \\
\text{s.t.} & \quad \sigma_i \leq [\sigma], i = 1, 2, \ldots, 10
\end{align*}
\]

Among them, \(f_1\) is the mass of the wing component (kg), and \(D_{\text{max}}\) is the maximum deformation of the wing structure (m). The constraint condition is that the structural strength of the wing component material is less than the allowable strength. The physical meanings and optimization results of the design variables \(x_1, x_2, \ldots, x_{20}\) are shown in Table 1. Through the optimization results, it can be seen that most of the plate thickness and edge strip area have changed. The optimization results of the two objectives of wing weight and structural deformation are shown in Figure 2. It can be seen from the figure that the weight used in the final plan is 0.388kg, and the Y-direction displacement is 0.0737m.
Table 1 Values of design variables and optimization results {replaced}

| Variable | Physical meaning | Material | Original parameters | Upper and lower limits of design variables | Value after optimization (m) |
|----------|------------------|----------|---------------------|--------------------------------------------|----------------------------|
| $x_1$    | 1# flank plate thickness | paulownia | 0.002               | [0.001, 0.004]                             | 0.002                      |
| $x_2$    | 2# flank plate thickness | laminate | 0.003               | [0.002, 0.004]                             | 0.002                      |
| $x_3$    | 3# flank plate thickness | paulownia | 0.003               | [0.001, 0.004]                             | 0.002                      |
| $x_4$    | 4# flank plate thickness | laminate | 0.002               | [0.002, 0.004]                             | 0.003                      |
| $x_5$    | area of rib boom | pine | 5.0×10^{-6} | [4.0×10^{-6}, 6.0×10^{-6}] | 4.0×10^{-6}                |
| $x_6$    | beam 1# web thickness | paulownia | 0.002               | [0.001, 0.003]                             | 0.001                      |
| $x_7$    | beam 2# web thickness | laminate | 0.002               | [0.001, 0.003]                             | 0.003                      |
| $x_8$    | 1# upper beam flange | pine | 6.5×10^{-5} | [5.0×10^{-5}, 8.0×10^{-5}] | 7.5×10^{-5}                |
| $x_9$    | 2# upper beam flange area | pine | 6.5×10^{-5} | [5.5×10^{-5}, 7.5×10^{-5}] | 7.0×10^{-5}                |
| $x_{10}$ | 1# lower beam flange area | pine | 4.0×10^{-5} | [3.0×10^{-5}, 5.0×10^{-5}] | 3.5×10^{-5}                |
| $x_{11}$ | 1# lower beam flange area | pine | 0.9×10^{-5} | [0.5×10^{-5}, 2.0×10^{-5}] | 0.5×10^{-5}                |
| $x_{12}$ | mast 1# web thickness | pine | 0.003               | [0.001, 0.004]                             | 0.001                      |
| $x_{13}$ | mast 2# web thickness | paulownia | 0.002               | [0.001, 0.003]                             | 0.002                      |
| $x_{14}$ | mast 3# web thickness | light wood | 0.002               | [0.001, 0.004]                             | 0.002                      |
| $x_{15}$ | mast 4# web thickness | paulownia | 0.002               | [0.001, 0.003]                             | 0.003                      |
| $x_{16}$ | 1# mast flange area | paulownia | 1.5×10^{-5} | [0.5×10^{-5}, 2.5×10^{-5}] | 2.0×10^{-5}                |
| $x_{17}$ | 2# mast flange area | light wood | 1.5×10^{-5} | [0.5×10^{-5}, 2.5×10^{-5}] | 1.2×10^{-5}                |
| $x_{18}$ | 3# mast flange area | paulownia | 1.5×10^{-5} | [0.5×10^{-5}, 2.5×10^{-5}] | 1.6×10^{-5}                |
| $x_{19}$ | 4# mast flange area | light wood | 1.5×10^{-5} | [0.5×10^{-5}, 2.5×10^{-5}] | 1.4×10^{-5}                |
| $x_{20}$ | wing skin thickness | light wood | 0.002               | [0.001, 0.003]                             | 0.001                      |
3. Analysis of optimization results

After the final plan is calculated in IGA, since the spar is the main force component and bears all the normal tension and compression stresses, it is necessary to refine the mesh of the wing through the ANSYS Workbench platform. However, in order to avoid sudden changes in the size of adjacent grids, reduce the difficulty of grid division and solve the workload, a uniform grid with a size of 2mm is adopted. The model has a total of 980,024 nodes and 877,874 units. In this paper, the general evaluation criterion Element Quality is used for grid inspection. The average grid size obtained by the test is 0.07, indicating that the grid quality is excellent. When establishing the wing finite element model, the front and rear wing spars are restrained by fixed support at the wing roots. The load borne by the wing structure is mainly aerodynamic load. In this paper, the aerodynamic load is applied to the upper and lower surfaces of the wing skin in a distributed force. The results show that the initial wing meets the design requirements, but there is a lot of room for optimization. Compared with the original plan, the quality of the optimized plan is reduced by 23.5g, which is a relative reduction of 17.8%; the Y-direction structural deformation is reduced by 15mm, which is a relative reduction of 21.5%; the minimum residual strength of the original plan is 2.37Mpa, which is the optimal plan. The minimum residual strength is 1.15Mpa. Through comparative analysis, the optimized scheme is superior to the original scheme in terms of wing weight, structural deformation and residual strength. The comparison between the original plan and the optimized plan is shown in Table 2. The optimized positions of the front and rear wing spars are more concentrated on the main force-bearing area of the wing, which can reduce the thickness and width of the wing spar and realize the lightweight of the wing structure; the rib thickness has little effect on the stiffness and strength of the wing structure. Selecting 2mm can minimize the wing mass, which is more reasonable; the position of the rib plate has little influence on the quality of the wing, but has a relatively large influence on the strength and stiffness. Therefore, the optimization of the position of the rib plate to a certain extent is conducive to improving the strength and stiffness, and the optimized data also well proves the accuracy of the sensitivity analysis.

| Scheme            | Weight /Kg | Maximum deformation in Y direction /m | Minimum residual strength of pine | Minimum residual strength of laminates | Minimum residual strength of paulownia | Minimum residual strength of light wood |
|-------------------|------------|--------------------------------------|----------------------------------|---------------------------------------|----------------------------------------|----------------------------------------|
| Original scheme   | 0.445      | 0.0895                               | 2.26                             | 2.45                                  | 1.21                                   | 1.19                                   |
| Optimization scheme | 0.336    | 0.0615                               | 3.07                             | 3.38                                  | 1.63                                   | 1.24                                   |
4. Mechanism and test flight of sample aircraft

According to the optimization results, the wing component parameters of the original competition aircraft are modified to make the competition aircraft. The fabrication of the sample aircraft is shown in Figure 3 (a), and the flight test is shown in Figure 3 (b). By gradually increasing the load weight during several test flights, the maximum load of the competition aircraft can be determined to be 34kg. The main reason for the increase of the load is that IGA reduces the wing mass and improves the flight stability, and it also proves the feasibility and accuracy of the structural optimization design of the competition aircraft using IGA.

![Figure 3](image)

Figure 3 Production of sample aircraft (a) and flight test (b)

5. Conclusion

Through the combination of immune algorithm and genetic algorithm (GA), a new quadratic selection immune genetic algorithm IGA was proposed to overcome the problems of complex algorithm, too long time, easy local selection, and at the same time, it was applied to the design of the wing of the competition payload aircraft for practical verification. IGA and Ansys finite element structure simulation were used to optimize the wing structure. The results show that the weight can be increased to 34kg while reducing the wing mass and ensuring its flight stability. And the immune algorithm also has a certain application prospect in other types of competition aircraft.

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