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Multi-objective design and optimization of wings

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Abstract. Nowadays, with the fast development of technology, aircrafts have been successful advanced. As we all know, wings are one of the most significant parts of the aircrafts, therefore, multi-objective design and optimization of wings has become a critical issue among many researchers. This paper mainly introduces several approaches to improve the wing in different conditions, including optimization design of civil airplanes, design and optimization of aircraft wing structure at low Reynolds numbers, Wing Design and Aerodynamic Characteristics of Biomimetic Flapping Wing Micro Air Vehicles and so on, the purpose of this article is to give a brief introduction to these relatively new research methods and make the public understand more about this field. The primary approaches of this article are literature analysis and review. This paper finds that algorithm and artificial intelligence are fundamental to improving wings, and all the design needs to reduce the amount of energy as much as possible, which is also the most important requirement.

Keywords: Aerospace Engineering, Wing Design Aerodynamics, Aerodynamic Optimization Design, Wings Optimization Design.

1. Introduction

Optimization design is a new technology developed on the basis of the widespread application of modern computers. In engineering design, designers can conduct semi-automatic or automatic design on a computer based on optimization principles and methods, integrating various factors, to select the best design scheme under existing engineering conditions. The entire optimization process can be expressed in optimization. During the flight of an aircraft, there will be strong coupling between the fluid and the aircraft structure, resulting in strong coupling. Due to the complex interaction between stationary or moving fluids and elastic structures, computer software is generally used to assist in calculating the interaction forces between them in modern aircraft design to obtain an optimal aircraft design solution. Since then, many researches have been carried out in this field. For example, in February 2020, the Multidisciplinary Analysis and Design Center at Virginia Tech developed a two-layer optimization framework for the unmanned aerial vehicle mAEWing2 to study the effects of incorporating active aeroelastic tailoring into the high-performance adaptive aeroelastic wing project funded by National Aeronautics and Space Administration(NASA). Researchers suggest that this method ensures controllable flutter by relaxing the passive flutter boundary and using active flutter controllers, thereby reducing the weight of the aircraft. In June, the team also developed a distributed design optimization software for high aspect ratio aircraft using transonic flutter analysis in the Linux operating system. The software can perform multidisciplinary design optimization and vibration analysis in distributed

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computing environments for mid to long-range transonic wing aircraft with nonlinear transonic speeds. This paper mainly discusses the optimization design of variable curvature wings for civil aircraft, wing design and aerodynamic characteristics of biomimetic flapping wing micro air vehicles, strategies and methods for multi-objective aerodynamic optimization design of supercritical wings, aerodynamic optimization design of large civil aircraft wings based on Proxy Model, optimization design and verification of competition wing structure, aeroelastic tailoring optimization design based on variable stiffness composite material wings. After considering a variety of method of this research, this research analyzes different types of documents and figure out the advantages and the disadvantages of each approach and make a review. This article provides a conclusion of these methods; therefore, it is easy for later researchers to find new ideas and do deeper research.

2. Main basis of optimizing wings

2.1. Optimization design of variable curvature wings for civil aircraft

2.1.1. Purpose. Energy conservation and emission reduction are important tasks in the current design and research of civil aircraft. One of the most effective ways to achieve this goal is to reduce the resistance of the entire aircraft through aerodynamic technology. In order to further reduce the cruise resistance of civil aircraft, researchers from various countries have begun to explore the application of various new technologies in civil aircraft, including the continuous variable wing trailing edge curvature technology

2.1.2. Discuss and conclusion. The discrete adjoint technique was used to solve the gradient of aerodynamic parameters on design variables. The Free Form Deformation (FFD) method was used to parameterize the entire mechanism, and the Reynolds Averaged Navier Stokes Equations (RANS) .The equation was used as the flow field evaluation method to build an aerodynamic optimization design system. The variable curvature of the trailing edge of the wing can be seen as a simplification of the "Variable Camber Continuous Trailing Edge Flap" (VCCTEF) system, ensuring its engineering feasibility. The influence of continuous variable curvature of the trailing edge of the wing on cruise aerodynamic characteristics was studied, and by conducting two-wheel optimization designs that consider and do not consider full aircraft torque balancing, the necessity of considering torque balancing in variable curvature wing optimization design was explored. In variable curvature wing optimization design, the pressure distribution shape of the wing was improved by changing the wing trailing edge curvature, and the shock wave intensity was weakened; The lift coefficient distribution of the optimized configuration without considering full aircraft trim constraints is closer to the optimal lift coefficient distribution compared to the optimized configuration with full aircraft trim constraints being located outside. However, the load displacement reduces the pitch moment of the wing, thereby increasing the lift loss of the entire aircraft trim. After adjusting the installation angle of the deflection tail, the drag coefficients under each lift coefficient are greater than those of the optimized configuration with torque trim. Therefore, in the optimization design of variable curvature wings, it is necessary to consider torque balancing constraints [1].

2.2. Design and optimization of aircraft wing structure at low reynolds numbers

2.2.1. Purpose. Airfoils and small aircraft designed based on low Reynolds numbers have complex and significant effects on wing flowability in terms of maintenance, transportation, and other functions. Based on viscosity effects and non-deterministic effects, they can have a significant impact on wing lift and other performance. Therefore, when designing the wings of such aircraft, it is necessary to fully consider issues such as aerodynamics and wing spatial position to ensure that the aircraft wings have good aerodynamic performance and ensure that there is no conflict between the wings and other components of the aircraft.

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2.2.2. Parameterized description and structural design methods for airfoils at low reynolds numbers. When designing wings at low Reynolds numbers, coordinate points in the surface curve are usually used to represent the invisibility of low Reynolds numbers on wing lift, drag, and other aspects. Other variables are designed to study and optimize the wings. Among them, variables include wing profile parameters, which are obtained by setting different parameters to obtain separation and other curve models. Based on the model, structural optimization and adjustment are carried out, and specific parameterization descriptions of the airfoil can be carried out to make the design more scientific and comprehensively consider various influencing factors. When describing specific parameters, research needs to be conducted from two aspects:

Firstly, by setting the wing to a non-moving folded state and analyzing and describing the specific spatial geometric relationships of other components using airfoil curves, specific design improvements can be made;

According to application requirements, within a controllable range, describe the variables of the wing as little as possible to reduce the possibility of blind optimization and reduce optimization efficiency, and avoid unnecessary loss of benefits due to blind optimization generating functions without practical application value.

The design method of airfoil structure at low Reynolds numbers should be combined with the actual needs of wing improvement design. Before design, it is necessary to determine the specific optimization direction and develop a specific framework for optimization. The design process varies greatly based on different algorithms. For example, the design process based on genetic algorithms can be roughly summarized into five parts: a. determining specific design criteria and requirements; b. Design specific geometric parameters for optimization and express them as specific optimization problems; c. Using genetic algorithms to calculate the impact of different lower variables on wing performance; d. Conduct numerical simulation according to the improvement strategy and construct specific parameter curves; e. Further analysis and optimization of the wing through validation [2].

2.3. Aerodynamic optimization design of large civil aircraft wings based on proxy model

2.3.1. Purpose. The research on large-scale civil aircraft is a major issue related to the development of China's national economy and scientific and technological progress. In the future, the design of large civil aircraft will develop towards greater efficiency, safety, economy, comfort, and environmental protection, which puts higher demands on its aerodynamic performance. Furthermore, developing large civil aircrafts can also contribute to other high-tech fields, so it is one of the most important elements of the aerodynamic optimization design.

2.3.2. Main points of this design. These design criteria for large civil aircraft wings place high demands on aerodynamic optimization design methods. The aerodynamic optimization design method used must be able to efficiently handle optimization problems with multiple design objectives, multiple constraints, a large number of design variables, and high nonlinearity. Due to the efficiency and global optimization characteristics of proxy optimization algorithms, this paper adopts this method to conduct research on aerodynamic optimization design of large civil aircraft wings [3].

2.4. Optimization design and verification of competition wing structure

Composite materials have unique advantages such as lightweight, high-strength, designability, fatigue resistance, and integration of structural functions. Currently, advanced composite materials have become the basic materials for aircraft structures. Weight reduction is an eternal theme in aircraft structural design. Applying advanced composite materials to aircraft structures can correspondingly reduce weight by 20% to 30%, which is an effect that other advanced technologies find difficult to achieve The design and forming technology of composite material wings has always been a focus of research both domestically and internationally. The integrated forming technology and multidisciplinary optimization design considering manufacturing and cost will inevitably become the development direction of future composite material wings. Integral forming can achieve excellent mechanical properties, but there are still many problems in process and design. Structural design has been transformed from isotropic material structural design to layer cutting optimization design with single-layer basic mechanical properties being orthotropic. Structural design should fully utilize the excellent performance of composite materials related to fiber orientation, by selecting appropriate fiber orientation, ply ratio, and ply order, that is, by cutting materials to meet design requirements, in order to achieve structural optimization design [4].

By utilizing the Opti Struct module in Hy-per-mesh optimization software, an optimized wing structure scheme of composite material structure was obtained through optimization of body elements, free size optimization of composite shell elements, and layer group size optimization, combined with its processability. Further optimization and improvement were carried out, resulting in the lightest wing that meets performance requirements in the history of the competition. This design practice and experience can be used for reference in the design of other composite structures [5].

2.5. Optimization design of wing structure for light and small composite wing unmanned aerial vehicle

Unmanned aerial vehicle, also known as unmanned aerial vehicle, is a type of unmanned aerial vehicle that is powered, unmanned, capable of carrying multiple mission equipment, and performing multiple tasks. Unlike manned aircraft, unmanned aerial vehicles (UAVs) have significant characteristics such as small size, lightweight, low cost, long endurance, high safety, and flexibility, and are highly favored by countries around the world [1-4]. According to different technical characteristics, drones can be divided into fixed-wing drones, multi-rotor drones, unmanned helicopters, composite-wing drones, umbrella-wing drones, flapping-wing drones, etc. Fixed-wing, multi-rotor, and helicopter are the main models in the current drone market, and the number of composite wings is gradually increasing. According to the design requirements of the wing, the preliminary structural layout of the wing is determined through structural mechanics analysis of the aircraft. Complete the layer design of various components of the wing, and perform layer settings, mesh generation, and contact settings to complete an appropriately simplified finite element model of the wing. Finite element analysis was conducted on the wing structure under both takeoff and landing and flight conditions, and the initial deformation and stress of the wing structure met the design requirements. In order to minimize the weight of the wing structure as much as possible, some strengthening structures were removed. Therefore, four schemes were analyzed in order under level flight conditions, and the optimal scheme was determined. The structural weight of the wing was reduced by 3.2%, and the wing tip deformation was reduced by 12.6% [6].

3. Conclusion

This article mainly introduces some methods of Multi-objective design and optimization of wings, After discovering some new ideas for improving the wings in different conditions, reducing the cost of energy is one of the most basic requirements. In addition, this article also has many deficiencies, since the limited time, the further discovery of the research has not been done, therefore, this article does not cover many approaches. In the future, with the fast development of algorithms and artificial intelligence, the research can also focus on more accurate design programs and change the way of traditional design.

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