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The Prospect of the Morphing plane's Application in Civil Aviation

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Abstract. In 2020, Airbus tested an plane called "albatross", which is a small version of Airbus A321. It is made of carbon composite and glass fiber reinforced resin and has been continuously developed in Felton, South Gloucestershire, England for more than 20 months. This paper describes various plane designs using variable technology, and introduces the albatross as an example. And the nonlinear dynamic characteristics and aerodynamic interference caused by the deformed parts will be discussed. Finally, the general and special challenges of these problems to civil plane operation are summarized. The research results of this paper can provide theoretical reference for the design of deformable civil plane in the future.

Keywords: plane design, Dynamic modeling, Fault tolerance, Intelligent material, Morphing plane.

1. Introduction

The technical principle of morphing plane is to adaptively change the wing shape of the plane to achieve the best flight performance under different flight mission states. Since the beginning of the last century, countries around the world have carried out a series of research projects. After decades of efforts, the United States and other advanced countries in aviation technology have successively made major technological breakthroughs in the 1990s, which greatly promoted the breakthrough progress of relevant basic theories and key technologies. With the further development of the market in the 21st century, the aviation industry has begun to develop in a more environmentally friendly and scientific direction. Many companies and enterprises have developed programs for deformed structure plane. Since 1980, National Aeronautics and Space Administration and the MIT, in cooperation with other institutions around the world, have proposed a variety of morphing plane project plans, such as the active flexible wing (AFW) project [1] and the intelligent wing (SW) project [2]. At the same time, in Europe, the German Aerospace Center (also known as DLR) also studied deformed structures in 1995. Since 1995, the European Research Institute has begun to study deformed wings [3]. As of 2011, 64 organizations in the world, including Airbus and another well-known company Bombardier, have joined in a project called Saritsu.

Albatross One, a project of Airbus, which developed a semi air elastic wing inspired by albatross. Albatross is a kind of sea bird that mainly lives in the hemisphere sea. These birds are masters of

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flying. They can fly long distances and hundreds of miles. Their project aims to replicate this flight technology and design a lighter and more efficient plane. This paper describes various plane designs using variable technology and takes albatross as an example. By enumerating the problems that the deformed structure may face in the design and flight, this paper puts forward the prediction and suggestions for the future development of the deformed structure, and provides theoretical and technical references for the design of the deformed plane in the future.

2. The development of today's morphing plane

2.1. The AlbatrossONE was inspired from albatross

Their flying skills are incredible. This majestic seabird can "lock" its wings on its shoulders and fly long distances easily. In the face of gusts, albatrosses can "open" their shoulders to better control the wind speed. The behavior of the semi aeroelastic hinged wing tip is similar to Figure 1. They applied this structure to plane wings by using the idea of bionics.

Figure 1. The latest AlbatrossOne flight tests [4].

Semi automatic hinges can do the same thing, but Airbus said that although this technology is not new, it has been able to lock and unlock the plane in flight with changes in air conditions. Its semi aeroelastic hinged wing tip can compared to fixed wingtips, it can combat the effects of turbulence, reduce wing load, increase roll rate, avoid wingtip stall during landing, reduce drag, and thus significantly reduce fuel burn and carbon dioxide emissions. The deformable structure being developed by clean sky will have two or even three hinges, in order to make the wing more like a bird's wing and allowing the arc of the wing to rotate or move continuously. Therefore, people have more freedom to change the shape of the wing.

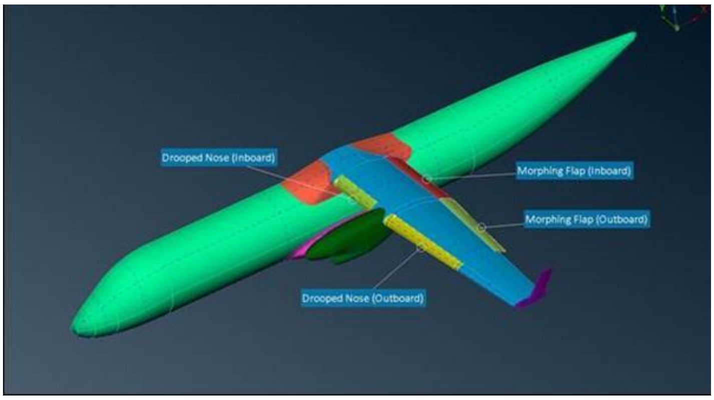

Figure 2. Clean Sky's morphing wing method [5].

China has also made great progress in developing deformable plane. Some Chinese scientific research institutions have incorporated intelligent flexible skin into their deformable plane design and introduced a new deformation mechanism. For several examples, hit uses composite wing skin structure facing in-plane shear deformation [6], and BUAA has made a new adaptive variable curvature wing which having double rib structure [7]. These designs have laid a solid foundation for the development of China's morphing plane technique. In the year of 2018, the Chinese government launched the the national numerical wind tunnel (NNW) which is a independent software project. The point of this project is using computational fluid dynamics (CFD) and the research and development of numerical simulation software for fluid dynamics. The relevant CFD and mesh deformation technique will have a positive impact on the design of civil deformation plane.

After over one hundred years of development in 1903, the structure of deformable plane has been upgraded from heavy rigid deformation structure of heavy machinery to active deformation of flexible structure using intelligent materials. The main deformation methods have also been optimized, from the old sweep back/forward and stretch methods to variable wing tips, such as AlbatrossOne, and combined deformation methods, such as clean sky. It can be clearly seen that the development of smart materials has significantly solved the problem between deformation realization and structural weight. In addition, the deformation is optimized and becomes more continuous and more controllable. Meanwhile, due to the flexibility and continuity of intelligent materials and structures, the system will produce vibration during flight. This phenomenon brings new problems such as nonlinear aeroelastic and makes the model of the system much more changeable and complex. The nonlinear aeroelasticity becomes more obvious. In addition, higher requirements are put forward for flight control methods.

3. Suggestions

3.1. A uniform standard is needed

Although the researchers have made great improvements on the deformed plane, they still have not reached an agreement on the design standards such as the deformation scale and flight quality. Therefore, it is difficult to evaluate the deformability and aerodynamic performance.

Early this century, as the challenges have grown, many scientists have devised criteria for wing deformation. The design criterion of flexible wing skin with variable radian is discussed [8]. The aeroelastic deformation region of the deformed plane is optimized by multidisciplinary design, including wing, structural parameters and pre-deformed shape [9].

3.2. Basic reference and criteria

In the traditional plane design process, multidisciplinary optimization (MDO) methods, ideas and standards are usually used to improve the performance of traditional plane in single mission requirements [10]. Design of morphing plane needs to fit for multi-mission, which totally changes the traditional single-mission plane design method [11]. The design requirements of deformable plane multi-mission targets make the design methods and standards more complex and diversified. When designing a deformable plane. Through years of theoretical analysis, simulation and flight test, the effectiveness of several typical deformation methods is verified.

3.3. Dynamic modeling applied to the design of deformed plane

The airflow surrounding the morphing plane is nonlinear and unstable, which affects control performance and degrades flight quality. In addition, it is also a very important research, flight control methods and dynamic modeling that can adapt to plane deformation process. Today, scientists have made great progress in related areas. Dynamic modeling of the deformable plane and flight control of the deformable plane. Compared with traditional plane, the deformable plane exhibits strong time-varying nonlinear dynamics during deformation. Thus, building appropriate dynamic models can not only describe the system characteristics but also not overcomplicate the controller. This is an important factor in flight quality improvement.

Table 1. Different effects of different designs [12].

Variable Span	
Raise:	Endurance time, Lift drag ratio;
Reduce:	Maximum speed, Parasitic drag.
Variable Wing Area	
Raise:	Lift
Reduce:	Reduce parasite drag, Reduce stall speed;
Variable Sweep	
Raise:	Critical Mach number, Maximum lift coefficient.
Reduce:	Wave drag
Variable Camber:	Change the angle of attack, Change airfoil efficiency.
Wing Twist:	Change spanwise lift distribution, Reduce induced drag, Gust Load Alleviation.

For deformable plane, its dynamics and kinematics characteristics have strong nonlinearity and fast time-varying and high coupling characteristics, which makes the system modeling very changeable Secondly, the elastic characteristics of the deformed and this results in an obvious aeroelastic movement in the system, and leading the system to higher-order characteristics. But the reduction of model order and unmodeled modes limits the accuracy of modeling. Therefore, it's need to select correct modeling methods according to different deformation characteristics. Today, morphing plane's method can be divided into 3 kinds: (I) Multi-body modeling method; (II) Flexible body modeling; (III) Modeling method for flexible body (Table 2 shows the dynamic modeling method of deformable plane) Of course, all methods above are very important and extensive used in traditional plane's design.

Table 2. Classification of methods for morphing plane [12].

Modeling method		**Morphing method adopted**
Multi-body modeling method	1 Newton-Euler method	Variable sweep; Variable span Asymmetric telescopic wing Combined morphing
	2 Lagrange's equations of second kind	Variable sweep; Flapping wings In-plane morphing wing
	3 Kane method	Asymmetric variable sweep Folding wing
Linear variable parameter modeling method	1 Mechanism modeling method	Variable wing camber; Folding wing Variable sweep; Variable span
	2 System identification method	Flapping wings
Modeling method for flexible body	Discretization and modal reduction	Folding wing; Telescopic wing Flexible wing; Z-wing Variable trailing edge camber

3.4. Multibody modeling method

No matter how large the wing deformation scale is, the adaptive deformation of the wing is achieved by the following two technical approaches without exception. One is the induced strain of smart

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materials to drive the structure to produce the required deformation. Piezoelectric materials, shape memory alloys and magnetostrictive materials have the most potential as adaptive wing deformation actuators. Another approach is to take the current conventional material structure and combine the mature control and drive technology into the concept of adaptive wing using a special integrated mechanism form to achieve the adaptive deformation of the wing structure. Different solutions of deformed wings require different modeling idea and methods. For example, when designing large variable plane, multi-rigid body modeling and parametric modeling are more reasonable, but there are still some challenges for example equilibrium dependence and large modeling error. For deformable plane with airfoil adjustment or active flow control, parametric modeling is used to model the flexible body. This idea also has its own problems, for example incomplete system description, low modeling accuracy, limited dynamic adaptability, and it’s dynamic model is very complex. The design of reliable and highly accurate dynamic models that adapt to fast deformations is the focus of the field of morphing plane.

4. Challenges and direction

In order to reduce design compromises and allow plane to spontaneously adjust wing shapes according to flight conditions, designers have long focused on techniques for changing wing geometry during flight. Early variant wing solutions often came at a cost, complexity or weight. As technology advances, recent developments in advanced structural design techniques and smart materials help overcome the limitations of traditional variants and improve the overall benefits of existing solutions. Although there's a lot of design going on in this area, methods for implementing, modeling, and controlling shape-shifting plane are still in the basic stage, with the following bottlenecks.

4.1. New fault-tolerant systems for changeable characteristic of morphing plane

The percentage of sensor failures in morphing structure is very high. The failure mechanism of morphing plane is very changeable. Thus, old fault-tolerant control system for single fault or faults with the same mechanism will not be applicable to deformable plane. Therefore, researchers should combine the methods based on knowledge, analysis model or the data they collected during the test to detect possible faults. The fault diagnosis and isolation structure of multi-layer system is established to further improve the fault monitoring under the constraints of flight control resources.

Considering its theoretical feasibility under the constraints of practical computing power is the first problem that scientists should noticed, and then develop an optimized fault-tolerant algorithm for deformable plane, which has low computational resource occupation.

4.2. Modeling method that considering aeroelasticity

In conclusion, our existing modeling methods have the ability to precisly describe the dynamic characteristics of general morphing plane. However, when facing a high-speed deformable plane, it’s precision is limited and its dynamic adaptability is poor. In addition, as more smart materials get involved, most deformed plane are flexible and resilient. Therefore, the deformed structure will have aeroelastic properties regardless of the degree of deformation. If the often used deformation wing modeling method is adopted, the accuracy of its dynamic model will dropped, and high-order and high-dimensional phenomena will appear. Especially when the flight environment is changeable and complex, the aeroelastic problem of flexible body and complex air flow is more prominent. Thus, considering the influence of aeroelasticity, not only combining with the fluid solid coupling characteristics, establishing a reasonable dynamic model and accurately describing the nonlinear characteristics of the system but also not over complicate controller are still the research challenges in this area.

4.3. Limited smart material

To make a reasonably deformed wing structure, the driver, structural design, drive system design, aero-structure integrated modeling and simulation, control system design, wind tunnel test and flight demonstration verification should meet the deformation requirements of the wing. As an anisotropic material, composite material has its macroscopic properties, damage The mechanism and failure law are different from general metal materials or non-metal materials. The research on composite materials must adopt the research idea of "design/evaluation" integration. Depend on On the multi-layered and interconnected nature of composite damage and failure processes, its complex damage evolution process and fracture behavior cannot be effectively described. Therefore, it should be combined with modern advanced test and testing technology to explore from a more detailed and microscopic level. Discovery of new laws of damage evolution and destruction, and, at the same time, the characteristics of the material's structural material identity, with the help of computer-aided design, from the material Starting from the meso-design of the composite material, realizing the integrated optimization of the material and structure of the composite material designed to maximize the potential of composite materials. This is what scientists should be concerned about.

5. Conclusion

In this paper, the development that had be done and configuration design methods of deformable plane is summarized, for example, multi-body modeling method can be adopted, and introduces the future direction and related challenges, such as flexible materials, mobile mechanisms and corrugated structure skin. This paper can provide some suggestions for the development of civil morphing plane. Finally, the limitations of the deformable plane, for example how to design a control system when facing the highly nonlinear aeroelasticity and dynamic deformable plane systems, and the urgent problems to be solved are emphasized.

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