Status and development of flexible wing aircraft

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Abstract. The flexible wing aircraft is derived from the flexible wing and can be divided into inflatable and parafoil type according to its wing type. The flexible wing aircraft has a broad application in both aerospace, missiles and unmanned aerial vehicles. This paper summarizes the current status and application prospect of flexible wing aircraft by summarizing the research of domestic and foreign scholars. Finally, this paper is summarized and the outlook for development is presented.

1. Introduction
The wing is the main component of the aircraft used to generate lift, and is usually divided into left and right airfoil profiles, arranged symmetrically on both sides of the aircraft. Some parts of the wing (mainly the leading and trailing edges) can be moved. Manipulating these parts can change the airfoils and control the distribution of wing lift or drag to increase lift or change the attitude of the aircraft. However, the function of the wing is often useless when stationary. For example, aircrafts require a lot of storage space because of the wing, and have a large turning radius when taxiing on a runway. Due to the development of defense technology and the need of global strategy, the flexible wing aircraft came into being. The flexible inflatable wing can improve missile operational performance, reduce transportation and maintenance difficulties, and improve reliability. The flexible variable camber mission adaptive wing allows the aircraft to undergo torsional deformation or bending according to different flight conditions and structural loads, to excite the drive elements to change the wing shape and angle of attack, thus obtaining the best aerodynamic characteristics.

2. Development status at home and abroad
Inflatable wing structures have been studied earlier abroad. In 1967, Ernest W. Anderson and Donald D. seath studied the vibration characteristics of an inflatable wing made of a fabric material. S. L. seldman et al. Calculated the stiffness of the inflatable beam made of aluminum foil, compared the experimental data and the simulation results. Finally, in the modeling process, it was found that the inflatable beam should be treated as a thin shell element if the filling pressure is very small [1]. Thomas C. S. Rendall et al. Carried out theoretical analysis and studied the influence of pressure, beam wrinkle and failure load on the natural frequency and bending stiffness of inflatable beam [2]. Yaniv C. gal ROM et al. Explored the failure criteria of inflatable wing, and obtained the allowable values of load and inflation pressure of inflatable wing in flight [3]. Cadogan et al. [4] and Simpson et al. [5,6] presented some analyses and test results for the mission inflatable air vehicle (MIAV) and the forward air support munition (FASM) small unmanned aerial vehicles (UAVs) incorporating multicell baffled inflated wings. The FASM has a relatively high-aspect-ratio tapered wing. The MIAV wing is straight, without initial dihedral or twist. It is of a relatively low aspect ratio, has a cambered airfoil, and is made of
orthotropic polymeric material. Wing geometry and properties similar to these configurations, available from the literature, are used to set up wing configurations to be analyzed in the current study. The novelty of the current study is in presenting an aeroelastic analysis scheme for inflated wings of the multicell baffle design, accounting for large elastic deformations. The scheme is based on classical well-established aerodynamic and structural theories and, it is hoped, can serve as an efficient design tool for inflated wings.

Compared with foreign countries, domestic research on inflatable wing is relatively late, but some achievements have been made. Northwest Polytechnic University first carried out relevant research on it. Ye Zhengyin et al. Obtained the control method of inflatable airfoil and the general design method of symmetric inflatable airfoil, and carried out performance test experiments [7]. At the same time, they have also studied the design method, fabrication technology and aeroelasticity of inflatable membrane structure. Subsequently, Zhu Liangliang et al. Summarized the general design method of general inflatable airfoil [8]. After that, Wang Wei and others from Beihang University established a deformation analysis model of inflatable wing, aiming to explore the carrying capacity of inflatable wing, and compared the experimental results with the calculation results of deformation analysis model under different charging pressures, which verified the practicability of the model, and analyzed the aerodynamic characteristics of the inflatable wing [9]. In 2011, the dynamic characteristics of inflatable wings were studied [10,11]. In the same year, ye Zhengyin et al. Applied the inflatable structure to the lift-rising structure [12,13]. At present, domestic scholars focus on airfoil design, aerodynamic shape, skin material, stiffness, vibration performance and flight test. In order to further understand the aerodynamic performance of flexible wings, Fuxing Zhang of Tsinghua University, et al. Establish MAV mathematical model, and prepare for flight simulation and flight control design, wind tunnel tests of flexible wing MAV were carried out in a low-Reynolds number wind tunnel. At the same time, wind tunnel comparative tests were carried out with rigid wings with the same airfoil, wing plane shape and size.

Longbin Liu et al. from National University of Defense Technology (NUDT) designed the inflatable airfoil using NACA2412 as the reference airfoil profile[14], and used the flexible skin stress analysis theory and established an improved stress expression model considering the influence of distributed masses based on the strength limit theory of the airfoil skin material to obtain the permissible inflatable pressure range of the flexible film airfoil .

In order to analyze the aerodynamic characteristics of flexible wings, Wang Haoyu[15] and others from Beihang University used CFD software to analyze the lift drag ratio characteristics of different wing airfoils. The effects of wing bulging and bending deflection on the aerodynamic characteristics of loitering munition were obtained. The flight test of flexible wings was carried out using model flight technology. The results show that the drag coefficient increases about 5% due to the bulge of the flexible wing surface. A certain deflection makes the lift coefficient increase greatly compared with that without bending deflection. By innovatively adding smooth skin to wings, it is helpful to improve the load capacity and flight performance.
3. Future application prospect of flexible wing aircraft

(1). With the development of theory and technology of inflatable wing, the advantage of low cost of inflatable wing will be gradually highlighted. It can be used in deformable aircraft in the future, and it can also be widely used as the research carrier of various experiments.

(2). With the continuous development of UAV technology, the requirements for various indicators of UAV are higher and higher. The design method of inflatable wing can effectively reduce the weight of UAV, improve its carrying efficiency and stealth performance, and improve the folding and unfolding efficiency of UAV, which is convenient for transportation and strategic deployment.

(3). Membrane structures have been increasingly used in inflatable structures such as aircrafts. In order to meet the strength requirements, lightweight requirements and configuration requirements of membranes on the surface of inflatable structures, this paper proposes a new structure named as mesh reinforced membrane (MRM). It is made of pure membrane which has a layer of mesh made of films on it.

(4). An intelligent flexible inflatable wing UAV structure is provided, which is composed of intelligent flexible inflatable wing, propeller, airframe, landing gear, protective cover, tail wing, high-
pressure gas storage bottle, missile and other general components; it is foldable, small in size, light in weight, simple in structure, low in energy consumption, long in cruise time, and higher in fast maneuverability and anti-jamming characteristics. Flexible inflatable wing can be rapidly deployed under high-pressure inflation conditions. Under the condition of meeting the performance requirements of UAV, it can greatly make up for the shortcomings of fixed wing UAV and give better play to the performance of intelligent UAV; helps UAVs to be miniaturized, easy to store, carry and transport, and can realize the functional advantages of reconnaissance, observation, emergency communications, disaster monitoring, rescue, intelligence gathering and quick response attack on enemy targets.

(5) Inflatable airfoils have potential in deformable aircraft and airships. The structural characteristics of an inflatable wing are significantly different from a traditional hard wing, and there are many bumps on the profile of inflatable wing. The aerodynamic characteristics and aeroelastic behavior brought about by the effects of these bumps are increasingly appreciated.

4. Summary and Prospect

4.1. Summary
Although many researches have been done on the flexible wing aircraft at home and abroad, the research results are not very perfect. Especially in the conformal design, there is no more accurate approximation method, and there is still a lot of research work to be done.

4.2. Prospect
(1). Flexible deformation is related to aeroelastic problems, so if we want to understand the flight characteristics of inflatable wing more accurately, we need to do some research on aeroelastic in the future.

(2). Long, thin, high aspect ratio wings are considered the key to future long-range aircraft design. And unlike the short, rigid wings found on most of today's aircraft and missiles, the long, thin, flexible wings are susceptible to uncontrolled vibration (known as flutter) and may be subjected to bending forces due to gusts and atmospheric turbulence. In order to improve the operational performance, efficiency, safety and serving life of flexible aircraft structures, the key technologies of flutter suppression and gust mitigation should be studied.

(3). The surface bulge of flexible inflatable wing will increase the drag coefficient and reduce the lift drag ratio, which will have a certain impact on the load capacity. It can be improved by adding skin.

(4). The deflection of flexible inflatable wing will increase lift coefficient and lift drag ratio. Reasonable deflection is helpful to improve load capacity and flight stability, which should be considered in the structural design of flexible inflatable wing.

References
[1] S.L. Veldman, O.K. Bergsma, A. Beukers, et al. Load Deflection Behaviour of Inflated Beams Made of Various Foil Materials[C]. AIAA 2004-1504, 2004.
[2] Thomas C. S. Rendall, Chris P. Cormier, Pier Marzocca, et al. Static Buckling and Dynamic Behaviour of Inflatable Beams[C]. AIAA2006-1701, 2006.
[3] Yaniv C. Gal-Rom, Daniella E. Raveh. Analytical Failure Criteria of an Inflated Wing[C]. AIAA2010-2637, 2010.
[4] Cadogan, D. P., Scarborough, S. E., Gleeson, D., and Dixit, A., “Recent Development and Testing of Inflatable Wings,” 47th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Newport, RI, AIAA Paper 2006-2139, 2006.
[5] Simpson, A. D., Smith, S. W., and Jacob, J., “Aeroelastic Behavior of Inflatable Wings: Wind Tunnel and Flight Testing,” 45th Aerospace Sciences Meeting and Exhibit, Reno, NV, AIAA Paper 2007-1069, 2007.
[6] Simpson, A. D., Jacob, J., and Smith, S. W., “Flight Control of a UAV with Inflatable Wings with Wing Warping,” 24th AIAA Applied Aerodynamics Conference, San Francisco, AIAA Paper
2006-2831,2006.

[7] Lv Qiang, Ye Zhengyin, Li Dong. Design and Capability Analysis of an Aircraft with Inflatable Wing [J]. Flight Dynamics, 2007, 27(4): 77-85.

[8] Zhu Liangliang, Ye Zhengyin. Research on A Universal Design Method for Inflatable Wings [J]. Journal of Air Force Engineering University, 2009, 10(5): 16-21.

[9] WANG Wei, WANG Hua, JIA Qingping. Analysis on bearing capacity and aerodynamic performance of an inflatable wing [J]. Journal of Aerospace Power, 2010, 25(10): 2296-2301.

[10] Tan Huifen, Cui Yujia, Wang Changguo, Xie Jun. VIBRATION CHARACTERISTICS ANALYSIS OF INFLATABLE WING [C]. The Chinese congress of theoretical and applied mechanics, 2011.

[11] Wang Weijian, Yang Chao. Flutter analysis of inflatable wings [J]. Journal of Beijing University of Aeronautics and Astronautics, 2011, 37(7).

[12] Jiang Yuewen, Ye Zhengyin, Zhang Zhengke. Model of inflatable structure/fluid interaction for variable leading edge [J]. Chinese journal of theoretical and applied mechanics, 2010, 42(1).

[13] Long Yaosong, Jiang Yuewen, Ye Zhengyin. Application of inflatable structure in airfoil lift enhancement [C]. The Chinese congress of theoretical and applied mechanics, 2011.

[14] Liu Longbin, Jia Yicong, Wei Yuan, Hu Fan, Zhang Shifeng. Structural design and mechanical deformation simulation of flexible inflatable wing for miniature missile [J]. Journal of National University of Defense Technology, 2018, 40(06): 30-37.

[15] Wang Haoyu, Wang Hua. Research on Aerodynamic Performance of Inflatable Wing for Loitering Munitions [J]. Tactical Missile Technology, 2017(03): 41-46.