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History and Future Development of Morphing-Wing Aircrafts

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Abstract: Morphing-wing aircraft can alter the shape of their wings to achieve different flight performances. Such changes are made to achieve the optimum aerodynamic profile for the current flight environment. The morphing wings greatly improve the flight efficiency and reduces the energy loss in different environments. Morphing designs can be categorized into three distinct types based on their fundamental mechanisms: rotation of specific segments or the entire wing, telescoping, and inflation of particular components or the entire wing. With the continuous technological innovation and practical applications, many famous type of morphing-wing aircrafts have left marks in human's aviation history. Although morphing-wing aircrafts have been shown to be mostly withdrawn from service, the research on morphing-wing aircraft has promoted the development of aviation technology and provided valuable reference for the design of modern fighter aircraft. In order to speculate on the future development of morphing-wing aircraft design, this article overviews the history of morphing-wing aircraft, analyses the reasons for the abandonment of morphing-wing design, and finally discusses the potential trend of morphing-wing aircraft. This article may offer a reference for the design of aircraft.

Keywords: morphing wing, aircraft design, aircraft structure.

1. Introduction

Morphing-wing aircraft are designed to alter their wing configurations to optimize performance across a range of flight conditions. This innovative approach enables the aircraft to perform various missions effectively [1]. For optimal low-speed operations, wings with a high aspect ratio and low sweep angle are preferred, whereas high-speed flights benefit from wings with a low aspect ratio and high sweep angle. By modifying key external parameters such as span, area and sweep, the aircraft can be adapted in real time to changing mission requirements, thereby increasing flight efficiency and reducing energy consumption.

Wings have a variety of mechanisms for morphing, including folding, telescoping (expansion and contraction), and manoeuvring multiple wing segments. Morphing designs generally fall into three broad categories: (a) rotation of specific airfoil segments or the entire wing, (b) expansion and contraction adjustments, and (c) expansion of selected segments or the entire wing. The selection of morphing techniques involves careful consideration of the materials used, the internal structure, the drive system and the control mechanisms. The designer must therefore weigh the required morphing

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capability against the associated costs. Furthermore, structural integrity, kinematics, weight, and the seamless integration of various subsystems were great challenges.

In the 1960s, the USA and the USSR began to develop morphing-wing fighters like F-14 and MiG-23. And then, supersonic morphing-wing bombers like B-1B and Tu-160 were produced. Through the continuous technological innovation and practical applications, the research on morphing-wing aircraft has promoted the development of aviation technology and provided valuable reference for the design of modern fighter aircraft. Although the morphing-wing design bring a lot of benefits to aircrafts, it is not surprising that morphing-wing aircrafts have been shown to be mostly withdrawn from service. The morphing-wing concept is no longer the dominant design of aircraft in the world, while the related research is still going on.

This article overviews the history of morphing-wing aircraft, analyses the reasons for the abandonment of morphing-wing design, discusses the potential trend, and finally speculate on the future development of morphing-wing aircraft design. This article may offer a reference for the design of aircraft.

2. Current Development of Morphing-Wing Aircraft

2.1. Classification of Morphing-Wing Aircraft

Wing morphing involves a range of mechanisms, such as folding, telescoping through the extension and retraction of wings, and the coupling or decoupling of different wing segments. Based on the fundamental methods that facilitate significant alterations in shape and size, morphing-wing aircraft can be divided into three primary categories: (a) rotation of specific segments or the entire wing, (b) telescopic wings, and (c) inflatable components.

2.1.1. Rotation

Morphing wing can be implemented by rotating either the entire wing or specific sections, resulting in designs like variable dihedral or sweep wings [2]. One approach to three-dimensional wing morphing involves out-of-plane folding of wing segments to adjust wing area. This method was utilized in the North American XB-70 supersonic bomber, which made its debut flight in 1964. By rotating the outer panels of the delta wing downwards, the wing’s length-to-depth ratio could be optimized for both low subsonic and supersonic speeds. The wedge-shaped lower fuselage and downward-slanting wingtips helped slow the airflow and created compression lift at high Mach speeds.

In-plane morphing, as another type of morphing, involves changing the sweep or span of a wing by moving it along a surface in two dimensions. This morphing style is variable-sweep wing, allowing the wing to be swept back for high speed flight or returned to its original position for low speed efficiency. Variable geometry design is particularly suited to military aircraft, where it is critical to balancing performance under varying speed conditions. A jackscrew mechanism moves the wing hinge along a short horizontal track to fully extend the wing to full swept back in 30 seconds.

The oblique wing developed by NASA Dryden Flight Research Centre is an innovative variable geometry wing. This design allows the wings to rotate their vertical axis from 0° to 60°, thus changing the shape of the aircraft to adapt to different speeds. At low speeds, the wings remain perpendicular to the fuselage to maximize lift. However, at high speeds, the wing is canted to reduce drag. The wing is turned in a single direction and the right wingtip is moved forward to achieve the desired dihedral positioning.

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2.1.2. Telescopic Wing

A retractable wing consists of a number of segments whose cross-sectional dimensions are reduced towards the outer end. By extending or retracting these sections, the span and surface area of the wing can be changed, thus affecting its aerodynamic performance. This design approach is categorized as a two-dimensional, in-plane morphing system. The telescopic wing concept originated in the 1930s, with the MAK-10 being the first of its kind, debuting in flight in 1931. In the MAK-10 design, the outer section of the wing could slide into the inner section, allowing the wing span and area to contract for high-speed flight and expand for lower-speed maneuvers, including takeoff and landing. The extension and retraction mechanism was powered pneumatically, enabling the MAK-10 to adjust its wingspan from 13 to 21 meters, with a wing area variation between 21 and 33 square meters.

Later, in 1937, the telescopic-wing aircraft RK was developed, featuring a telescoping mechanism composed of six overlapping wing sections aligned along the chord. These sections were extended and retracted by a tensioned steel wire, operated manually from the cockpit. When retracted, all segments were concealed within the fuselage, resulting in a 44% reduction in wing area.

2.1.3. Inflatable Wing

Inflatable wings provide a compact solution, reducing stowed volume to less than one-tenth of their deployed size. The stiffness and durability of these wings are controlled by internal air pressure and the elasticity of the restraining material. Such wings allow UAVs to pack their wings and control surfaces into extremely small spaces, making them suitable for launching from guns, fitting into aerial drop units, or deploying quickly either on the ground or mid-flight. The most basic inflatable wing design includes a single inflatable tube as the main spar, while a series of cylindrical spars or internal baffles covered by a skin can also create a chord-wise wing box structure.

These inflatable wings can also be rigidified through two main techniques. One approach involves applying a UV-sensitive coating to the wing fabric, which hardens in seconds when exposed to ultraviolet light, whether from the sun or an internal source. Another approach is inflation gas reaction rigidification, where the inflation gas contains a curing agent that chemically reacts with a resin in the structure, solidifying the wing after deployment.

2.2. Famous Morphing-Wing Aircrafts

The F-111, introduced in 1967 after development in the 1960s, was the first production aircraft to incorporate variable geometry wings. Designed to meet both the Navy's and Air Force's distinct requirements, the F-111 achieved versatile performance: with fully extended wings, it could lift off or land within a 2,000-foot runway, while fully swept wings enabled it to reach speeds over Mach 2. Its wings could shift from a 16° forward position to 72.58° fully swept back. However, placing the wing pivot inboard led to considerable drag at high speeds.

Other variable-sweep wing aircraft soon followed. In 1967, the Soviet MiG-23 made its first flight as a fighter-bomber, while two years later, in 1969, the Tupolev Tu-22M Backfire—a supersonic strategic bomber—also debuted. Another notable aircraft, the F-14, entered service in 1974 and featured a range of wing sweep angles from 20° to 60° to optimize lift and drag balance, with the capability to fold back to 75° to save storage space [3]. Remarkably, it could fly and land even if the wings were asymmetrically swept, a feature valuable for emergency landings.

Also in 1974, the Panavia Tornado, a supersonic ground-attack aircraft developed through a collaboration between the UK, Germany, and Italy, took its first flight. The 1960s and 1970s saw more than six major military aircraft with variable-sweep wings, but the technology's complexity and weight, due to the intricate gearboxes needed for wing movement, led to higher maintenance demands and reduced fuel efficiency. By the 1980s, these challenges meant variable-sweep technology was

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largely abandoned in new military aircraft designs, as developers turned to alternative methods to achieve speed and maneuverability.

3. Advantages and Disadvantages of Morphing-Wing Aircraft

3.1. Advantages of Morphing-Wing Aircraft

The morphing wing technology has many benefits for a fighter jet. The main benefit is the ability to successfully land and take-off on short runways, as well as the pilot's ability to provide optimal control with precise and correct responses, regardless of speed. In particular, the ability to land and take-off from short runways and several other advantages have allowed morphing-wing aircrafts to be used as naval aircrafts on carriers, as the runways on carriers are quite short.

As a straight, unwept wing approaches the speed of sound, sonic shockwaves progressively pile up and cause significant drag. The total drag can be decreased by sweeping the wing at an angle, whether backwards or forwards. However, this approach also shortens the total span of a particular wing, which results in poor cruising performance and rapid take-off and landing speeds. The morphing wing technology makes a great contribution to the aerodynamics of the aircraft.

The morphing wing technology allows for pilot to adjust the lift force and optimum sweep angle for wing by controlling the position of wing, whether forward or backward. The aircraft often moves through several sweep schedules as it is maneuvering, such as during aerial combat, when the wing sweep control is set to the automated mode. The aircraft automatically adjusts the sweep angle, but the pilot can take control if necessary. The pilot may choose more sweep at a particular Mach number to produce a slightly faster acceleration

The wings can be adjusted to sweep forward or backward as needed, allowing the sweep angle to vary based on speed requirements. This character has the advantages of high integrated flight performance and low fuel consumption, and may play a higher operational efficiency in different combat missions [4]. The increase of the sweep angle at high speeds will reduce the air friction generated on the surface of aircraft, enlarging the combat radius by significantly saving fuel, especially in interception missions. Reducing the sweep angle at low speed will increase the lifting force surface by enlarging the wing surface to save fuel, especially in landing, take-off, and low-speed missions.

3.2. Disadvantages of Morphing-Wing Aircraft

There are also disadvantages of the morphing wing technology. This technology adds complexity to the structure of the aircraft and flight mechanics, and as a result, the body life of the aircraft is shortened, and the maintenance cost increases significantly compared to fixed-wing aircrafts. In addition, as the morphing wing adds weight to the aircraft, it may cause a decrease in the amount of payload capacity and cause an extra increase in fuel consumption.

Since the aircraft often makes changes in the sweeping angle according to the required situation in the air, the system that makes changes in the sweeping angle becomes more sensitive than the system on fixed-wing aircraft, and the service life is seriously shortened. For instance, F-14 fighters remain heavy due to traditional design and manufacturing methods, resulting in elevated production and maintenance costs [4]. As a result, the frequency of maintenance increases in order to keep the service life at the same level as other aircraft, and accordingly, the maintenance cost is usually higher than fixed-wing aircraft.

Changing the wing sweep angle by the pilot or autonomously during flight causes the aircraft's center of gravity to shift forward or backward. As the wings are swept back, the aircraft's center of gravity shifts, leading to an increased moment arm between the aerodynamic wing and the center of gravity [5]. If the sweeping angle decreases, the wings come forward and the center of gravity shifts to the front of the plane as the front side of the plane will get heavier, on the contrary, if the sweeping angle increases, the wings of the plane will slide back, and the center of gravity will also shift to the back as the rear side of the plane will get heavier.

4. Future Forecast of Morphing-Wing Aircraft

Conventional fixed-wing designs often fail to provide optimal aerodynamic efficiency throughout the flight envelope, hence there is a growing demand for multi-role aircraft in both the military and civil sectors [6]. The ability of morphing-wing aircraft to modify their configuration to suit a variety of operational requirements makes them more favorable to unmanned aerial vehicles (UAVs) [7]. This flexibility is an important approach to contemporary aviation challenges.

The core of morphing-wing technology is the ability to dynamically change the shape of the wing during flight, thereby improving key performance factors such as structural efficiency, survivability, and stealth. The effectiveness, intelligence and reliability of morphing-wing UAVs depend on the following technologies: morphing configuration methods, non-linear and non-stationary morphing modelling techniques, and complex flight control systems.

Morphing-wing design have tended to prioritize specific objectives, which may inadvertently compromise other fundamental performance metrics. For example, increasing the lift-to-drag ratio can improve aerodynamic efficiency, but may lead to increased structural weight and increased failure potential. As a result, techniques that increase wing flexibility to mitigate gusts may compromise its load-carrying capacity. In addition, asymmetric variable span designs, while improving maneuverability, may increase instability during flight.

Each performance contributes significantly to the overall function, so a holistic design approach must be adopted to ensure safety and operational effectiveness. Integrating and optimizing various objectives and multidisciplinary constraints to enhance the overall performance of the aircraft, particularly in reducing drag, lowering noise, weight management, and structural health monitoring, is crucial. Furthermore, establishing clear standards for evaluating deformed flying configurations is crucial for consistently evaluating their performance.

5. Conclusion

This article provides an overview of the different characteristics and classifications of morphing-wing wing aircraft, summarizes the latest developments in various morphing-wing designs, and discusses the advantages and disadvantages of various aircraft. In order to facilitate the creation of more advanced morphing-wing models in the future, it is crucial to incorporate, design, and optimize multiple objectives and interdisciplinary constraints to improve the overall performance of the aircraft. The insights presented in this article provide reference for the future development of transformable wing aircraft.

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