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INTRODUCTION MORPHING TECHNOLOGY IN UNMANNED AIRCRAFT VEHICLES (UAV)

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Abstract: *The intent of this paper is to review the origin, history and the morphing UAV types and principles of automatic command and control system based on the concept. While the mentioned UAVs have high enabling capabilities, they are limited to a single-role mission or application specific tasks.*
Keywords: *morphing, flying wing, UAV*

1. INTRODUCTION. BIO-MECHANICAL ASPECTS OF FLYING WING

Researchers have long recognized that birds were able to change their body position in flight in order to perform specific maneuvers or adjust their aerodynamic profile to suit flight condition. This orientation adaptive body shape has been termed 'morphing' in specific literature. The words 'transform' and 'morphing' are actually forms of the word 'metamorphosis', which derives from the Greek 'meta' (change), and 'morpheme' (form). That is the description of the capability to change shape or geometry of their bodies and wings for both a heightened maneuverability and a stable flight within multiple environmental conditions. Darwinist selection played a crucial role in refining the wings. The type of habitat the animal lives and how flying exploits this habitat are closely related to body size, wing shape, flight style and power of flight (Fig. 1).

Fig. 1 Different morphology of the wing is required for various flight activities (birds: 8,000 species, 2…12000 g; bats: 800 species, 3…1400 g)

This ability has always been respected and often duplicated by aviation engineers, to the extent that it was technologically possible. Nevertheless observations of birds have inspired in numerous cases the technological progress in aircraft design and development.

For instance Figure 2 shows the types of wings of four different birds. Wings with low elongation (6.8) such as pheasant wing, usually allows rapid and slow take-off, but not useful for gliding. The wings with 9.3 elongation (eagle wings) are usually longer and have feathers, which are adjusted as a type of control surface for more precise handling. Wings for waders, with an elongation ratio of 12.5 are useful for higher speeds and sliding, but not for a quick take-off, because a large amount of energy is needed to train such long wings. 13.8 lengthening wings of seagulls, are usually useful for close sliding surfaces, such as sea and land to take advantage of air currents in order to preserve energy.

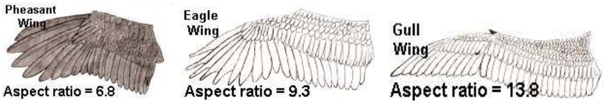


Fig. 2 Types of wings depending on the elongation

Birds and bats are capable of changing their wingspan and lower bearing surface, herein increasing the speed of advance. The rope can be modified wing and the wing twist can be transformed in order to change the aerodynamic performance.

Senses. Flying creatures and machines have to be able to detect and to sense the atmosphere around their state and their structural position and configuration in order to conduct the flight in a given environment. Examples of types of data to be collected are: air speed, altitude, air pressure, position against other objects, beside their wing' position and shape at any given time. This capability may require highly specialized sensors aboard the aircraft, such as gyroscopes and angular orientation devices to capture air pressure along the wing.

Birds are capable to make use of these senses, such as seeing, hearing, smell, but must rely also on some special sensor systems: cross-location for bats, linear and angular acceleration for birds, very sensitive mechanoreceptors that allow insects to feel the approach of potential predators. As suggested in recent research, the birds are able to feel the Earth's magnetic field, provided valuable information for navigation.

Processing. Input signals from the eyes, ears, and specialty sensor systems are to be integrated and processed in the brain or the flight computer. Processes to be performed include specialized algorithms for flight stability, guidance, navigation, and control. Flight stability is probably the most important of the above mentioned functions, because without stability is impossible to remain in flight, and lack of stability in flight could lead to tragic results. The aircraft' flight stability algorithms are executed at processing speeds and top priority. Orientation is the function that determines the current position in space with the highest possible accuracy.

On the other hand, navigation is comparing information obtained at the crossing points with known geographical positioning in order to compute the "best" way ahead for the flight to reach the desired destination. The control functions perform the navigation guidance and generate commands to steer the drive along the calculated rate. In biological flight, these commands are electrical impulses from the brain that stimulates the muscles and organs. At the aircraft, orders are also electrical signals activating the electrical or hydraulic motors.

Operation. Flying morphing requires specialized structures and actuators to alter the position of the intended structures. Natural biological flight requires dedicated and specialized skeletal muscles to perform the corresponding figures of aerial acrobatics.

Skeletal mechanism provides a geometric relation between the inner and outer bone expansion. Such a mechanism allows the birds to go through a variety of positions using a single movement, each position being stable and allowing a unique capability within the flight envelope. Specialization of this skeletal mechanism for in-flight morphing which determines the required movement is produced by means of subsystems. Each of these subsystems requires specialized components to allow changes in flight. The way in which the subsystems interact is paramount for a contribution to airworthiness. Sensory signals should provide useful information for stability, guidance and navigation, not forgetting the sufficient computing capacity for speed and feed-back. Computing function should have information about the actuator configuration and the output signals in order to give the appropriate command to achieve flight stability and to successfully execute any desired motion in flight. Finally, action must have the dynamic range, the magnitudes of force and torque to make the necessary changes in body shape and position in time.

2. MORPHING CONCEPT

A morphing aircraft is generally defined as an aircraft whose shape is changed during flight to optimize performances. Types of changes include scale, chord, volume, bearing surface, the thickness profile, elongation and planform. Morphing could also be applied to command and control area in order to remove the hinges. Morphing can be used as a control element by changing the shape of the aircraft in order to change the dynamics of flight.

Wrights developed the idea to change the airplane's aerodynamic features by modifying the shape of the wings, using the techniques of structural deformation. Another method is a variable dihedral angle for aircraft's stability with the change of wingspan.

The morphing technology is not limited to crew-operated aircraft, developing a new generation of UAVs that in conjunction with the advanced technology materials has led to renewed interest for radical configurations of morphing. Current research focuses on changing wing configuration, namely: scale, thickness, planform, which showed that a morphing wing without classical surfaces lead to improved performance, herein extending the aircraft's flight envelope.

2.1 1D Change. The one-dimensional change of wingspan is represented in Fig. 3. By making a major variation in the size scale of a small section of wing, wing aspect ratio can be optimized for various flight missions. In addition, differential span change between wingtips can generate a roll moment, potentially replacing the aircraft ailerons.

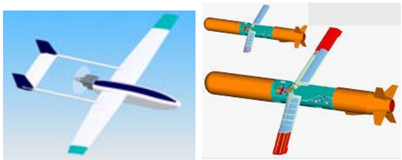


Fig. 3. Change span of UAV, 1D change.

2.2 Concept of Morphing Buckle-Wing – 3D Morphing

Fig. 4. DARPA Morphing

- The UAV (3D Morphing, Fig. 4) has the capacity to change the configuration of its wings from a single one in two wings glued to the extremities

2.3 Morphing Wing Concept Generation (NASA). There are aircraft with wings that have the capacity to change the shape of the planform during the flight with a 200% elongation, a 50 % wing area, and with 20° the wing sweep. The concept of morphing by DARPA was further developed in the Phase II program called MAS (Morphing Aircraft Structures). The 'wing folding' concept developed by Lockheed Martin allows variations on the span, aspect ratio cord's angle and effective sweep angle (Fig. 5).

Fig. 5 Morphing by Lockheed Martin MAS & NextGen Aeronautics

2.4. Total Morphing concepts for UAV. The aircraft with the total morphing are flying vehicles that change their shape in order to accomplish the stated mission without the use of conventional control surfaces or seams for flight control (Fig. 6). The aircraft built with morphing technology promise the distinct advantages of being able to fly many types of missions, to perform radically new manoeuvres not possible with conventional control surfaces, to be more fuel efficient, and to provide a reduced radar signature. The key concept is full integration of the control shape of wing structure with a truly intelligent structure. The design of these vehicles must take full account of the aerodynamic loads and must carefully consider the power requirements for shaping control to ensure an overall performance benefit.

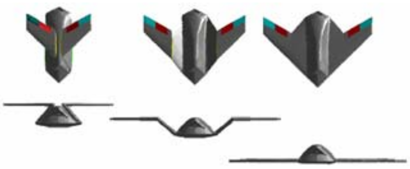


Fig. 6. Planform changes - Lockheed Martin 'Folding Wing' concept.

Morphing aircraft is an ideal aircraft with the ability to modify the external form for extreme performance requirements of the tasks (Fig. 7).

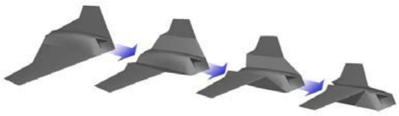


Fig. 7. DARPA Morphing aircraft

Case of Flexible Wing (Inflatable Wing). This wing inflates during flight (University of Kentucky) and it is reinforced under the action of UVs during the ascension made with the help of a balloon. Researchers from Dover had a similar approach (Fig. 8), with wings powered by piezoelectric means. The wing is inflated and deflated, according to the needs of control during the flight and is able to change shape tips, such as NACA profiles (NACA 8318 and 0018).

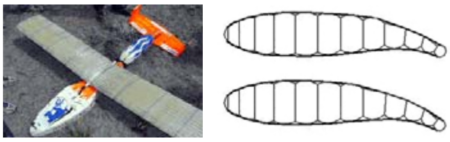


Fig. 8. Inflatable wing

Another interesting morphing UAV concept comes from 1950, involving the idea of inflating and deflating wing for storage and transport. The idea came from the auto casings produced by GoodYear which created "Inflatoplane", a plane for rescuing the pilots dropped-in behind the enemy lines.

Morphing for rotary wing (RW). Using the latest piezoelectric technology, European Aeronautic Defense and Space Company (EADS) has been able to successfully reduce the noise of helicopter blades by 20%, while reducing vibration in the cockpit by 90%. This allows a smooth and comfortable flight for the crew and passengers. They have accomplished this by incorporating multiple piezoelectric amplifiers, which measure actively and reduce vibrations caused by blade at high speeds. Board of flight of the blade has 2-3 actuators able to modify the geometry with 10 degrees. The actuators are controlled through fiber optics by the control block mounted above the rotor hub. Actuator reacts so quickly that each flap on each blade can be opened and closed 30-40 times in a rotation when the rotor has 400 rpm (rotations at cruising speed). Piezoceramic actuators are suitable for this application because they are able to move very quickly against high forces on short lengths. Any other approach would be unlikely and impractical.

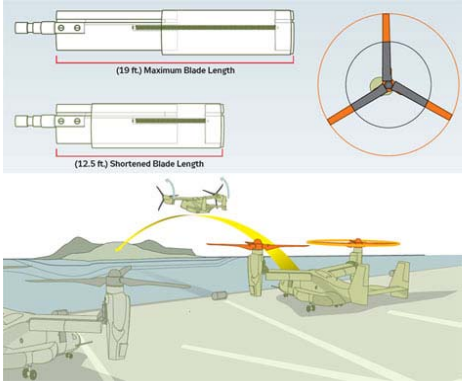


Fig. 9. V-22 Osprey rotor morphing

The blades of the RW aircraft have also been modified by increasing the length through centrifugal forces, based on the methods developed by State University of Penn. This would be ideal for a vehicle which needs the available power to lift higher.

3. FUTURE DEVELOPMENTS IN THE FIELD OF MORPHING UAV

NASA Dryden Flight Research Center is promoting the idea of morphing structures that will improve various aspects of flight. It is believed that a morphing structure could bring a reduction in noise, an increase in fuel efficiency, improved safety and handling, lower approach and landing speeds, better adaptability to short tracks, and extensive versatility.

Fig. 10. Morphing technology envisaged by NASA

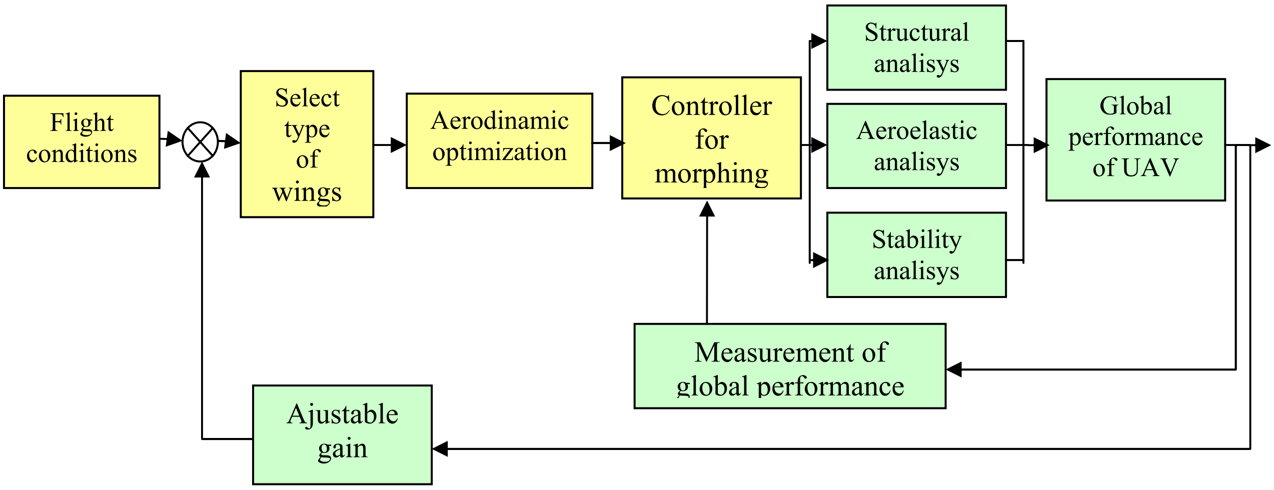
Another research trend is credited to Hypercomp NextGen, Fig. 11, which performed substantial changes in plan, form and surface.

Fig. 11. NextGen Morphing design

The latest research has been performed on UAVs, preferred for experiments due to their reduced scale. Advanced composite materials improve design approach, and as a result they allow development of new structures and actuators, lighter and reliable.

Composite materials are very important in the aviation industry because of differences they make related to weight, strength and flexibility. Memory materials are being researched, but they appeared to be very promising, with their ability to change shape by means of electrical signal or temperature variation. Bending the material is preferable because it provides better aerodynamic avoiding turbulent flows. However, smart materials still have a long way to become trusted ones.

4. PROPOSAL FOR A MODERN UAV STRUCTURE



Limitations to the concept of morphing

The limitations imposed by the concept of morphing described below for optimized wing complies with the conform limits of the execution mechanism. The main differences between optimized wing shape and deformed wing shape are the following:

- Reorient the wing sections in the deformable space occupied by the mechanisms and therefore loss of this area of wings;
- Failure of the mechanism to provide an optimal structure to a good aerodynamic shape with curved lines between control points;
- Limitation of the mechanism in changing the profile for low-speed flight.

Structural Transformation

Structural morphing or control surface for aerodynamic components could provide significant performance improvements. For instance, changing the shape reduces the drag during various stages of flight. Variable geometry for trailing edge has an extremely strong influence on the wing pressure distribution.

It not only controls the local rear load on the wing but also the flow around the profile that obviously leads to controllability with significant effect on flight characteristics, even applied to only a few degrees. This is known as "Variable Camber", a technique that can be used to adjust the wing characteristics with differentiated cross-section for the whole scale in different circumstances and, therefore, be used to reduce drag and the loads on the wing (weight) in order to reduce fuel consumption and emissions.

A variety of approaches have been investigated to achieve change in structural shape. These range from use in accordance with the mechanism to the bi-stable concepts, which are a form of behavior that occur eg in structural or non-symmetric composite laminates.

Post-buckling has also been used successfully to increase the performance of piezoelectric actuators used to control a wing and to allow optimization of design variables profiles. Structural buckling leads to a reduction of structural stiffness, therefore, a reduction of the driving force to produce a given shift.

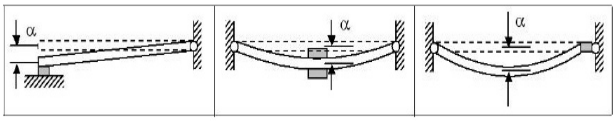


Fig. 12. Comparisons of amplitude for piezo-actuators, linear actuators respectively (left), the composite beam (middle), and buckling of composite (right)

5. CONCLUSIONS

Dedicated special missions require exceptional maneuverability of the UAV. Morphing solutions are analyzed and compared according to a global indicator focused on controllability, aggressive handling, but reduced manufacturing costs are important in selecting the most suitable morphing strategy.

The concept of modularity is well adapted to the proposed concept of semi-flexibility for flying wing with high elongation ratio. Inertial sensors used to measure the response characteristics of flight maneuvers together with qualitative analysis lead to improved overall performance of the flying wing aerodynamics.

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