A REVIEW ON WING MORPHING

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ABSTRACT

Since the inception of the first flight by Wright brothers, the aerodynamicist had been focusing on improvement of aircraft performance through suitable alteration of design parameters. Most promising geometrical parameter of the aircraft was to be the wing itself. Designers and researchers conducted large number of experiments with different varieties of aspect ratio and concluded that changing the shape of the wing during actual flight can tremendously improve aircraft performance. This technique is analogous to shape change of wings of natural flyers. This had been the genesis of shape forming or conveniently "shape morphing". Hence, shape morphing, in general, involves the change of shape of wings during flight to adapt a particular type of mission. Thus, an aircraft with a morphed wing is capable to undertake multiple missions and multiple maneuvers with combat agility, improved fuel efficiency and reduced drag. Since the wing defines the primary shape of the aircraft, an aircraft with morphed wings is conveniently renamed as a smart structure. While, the dynamic loads are fully accounted, careful considerations of the power requirement for wing planform variation will enable the smart technology as a future aviation for high performance aerial vehicles. The present paper focuses on various aspects of shape morphing and scope of future developments.

KEY WORDS: Aspect Ratio, Composite Materials, Smart Materials, Intelligent Structure.

Nomenclature
NACA: National Advisory Committee for Aeronautics.
DARPA: Defense Advance Research Projects Agency.
NASA: National Aeronautics and Space Administration.
Aspect Ratio: Wing span/ Wing chord.
C_L: Coefficient of lift.
C_D: Coefficient of drag.

Smart materials/ memory materials: They are engineered or naturally occurring materials which have the ability to change shape by means of electrical signal or temperature variation.

Composite Materials: They are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct within the finished structure.

Intelligent Structure: They are the most reliable structures available using computational systems and explicitly defined knowledge to improve serviceability and maintenance.

1.0 INTRODUCTION

Since the inception of the first flight, aircraft design and aerodynamics underwent significant changes in each decade. All the improvements were primarily focused towards obtaining air supremacy during aerial combat and hence the design changes were interlinked with military needs. Soon, the developed countries felt the importance of air mobility towards faster transformation which gave rise to the concept of civil aviation. The performance of civil aircraft has been improved by incorporating new aerodynamic designs, technologies, and material and advanced power plants. Today, the family of civil aircraft does not undergo drastic change in design except for minor modification of earlier design towards performance improvements. However, this is not true in military parlance. Significant conflicts over last half century indicate that air power must dominate to achieve a combat edge which essentially needs smart and intelligent aerial vehicles, at times unpiloted UAVs. The concept of "first kill" needs highly agile combat aircraft with highest possible performance and maneuverability to evade from the enemy. Whether it is UAV or combat aircraft, the performance of the aerial vehicle be undoubtedly high performance, high efficiency, fuel economic aircraft which will need a mission adaptive wing by changing the wing volume, chord, aspect ratios, thickness profile or planform (Figure 1). Hence, changeable wings i.e. a morphed wing shows a definite future towards next generation aircraft. The technology involved in morphing and their employability are discussed in subsequent paragraphs.

Figure 1: Wing morphing for loiter, dash and asymmetric maneuvering. [1]

Morphing is the shape changing technology that can optimize performance in each segment such as by changing the areas of the wing that leads to changes of aspect ratio and lifts. Therefore, Morphed aircraft are flight vehicles that change their shape to effect both a change in the mission of the aircraft and to perform flight control without the use of conventional control surfaces or seams. By sweeping, twisting and changing its span, area, and airfoil shape, the wing can change to fit different mission segments such as cruise, loitering and high speed maneuvering more efficiently than a fixed wing UAV. Therefore, morphing of wings is considered an important change in upcoming generation of UAV designed for military and civil applications.

Relative merits of morphing are as follows:

- To improve aircraft performance expanding its flight range;
- To replace conventional control surfaces for flight control;
- To improve performance and stealth capability;
- To reduce drag to improve range; and
- To reduce vibration or control flutter.

These applications although seem easy to achieve but, require different events of wing shape change. Using the natural system as an inspiration, researchers have long tried to develop morphing wings on aircraft to optimize their performance for multiple missions [2]. 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 as shown in the figure below.

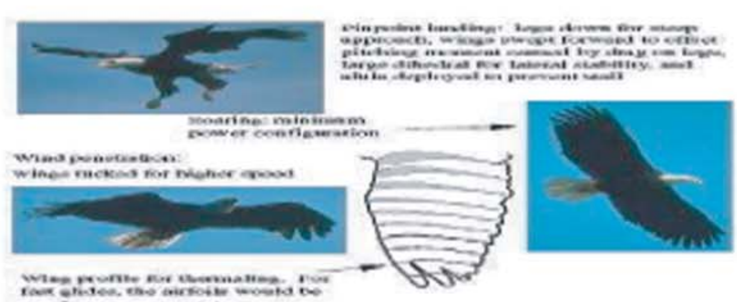

Figure 2: Different morphology of the wing required for various flight activities. [10]

Improved capability has always inspired the technological advancement in aviation industries for aircraft design and development. Figure 3 depicts three wings with different aspect ratio. Pheasant wing with aspect ratio 6.8 allows rapid take off with restriction in gliding. The eagle wings with aspect ratio 9.3 are larger with heavy feathers and thus structurally strong control surface and precise flying is achieved. Similarly, seagull wings with aspect ratio 13.8 are useful for low maneuvering as in above sea and land surfaces helping to preserve energy by taking advantage of the air currents. Thus a lesson learnt from the natural flyers that shaping the wing towards high aspect ratio leads to low energy consumption with low maneuverability while low aspect ratio adaptive wings enhance combat capability. Thus, these are the concepts of new generation aircraft designs.

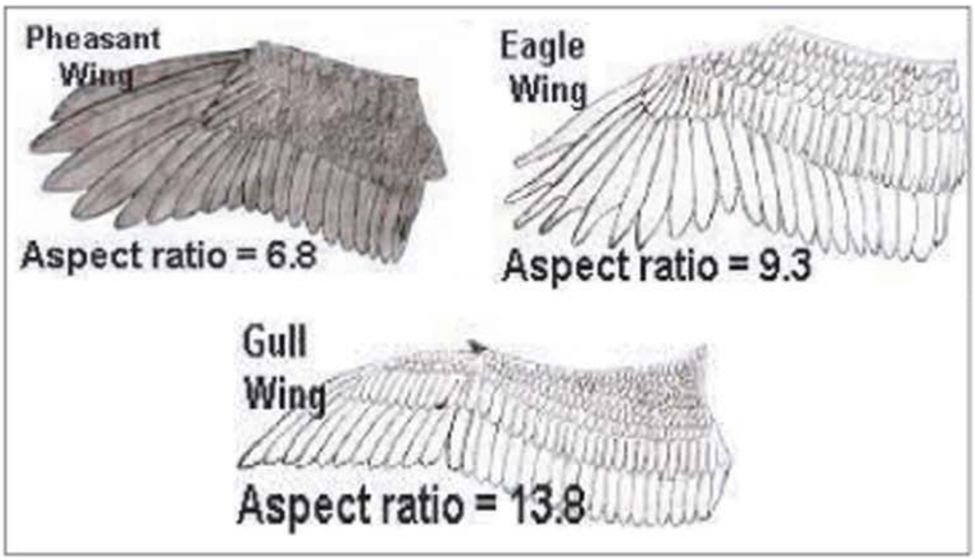

Figure 3: Various wings with different aspect ratios. [2]

2.0 MORPHING TECHNIQUES

Current developments in morphing technology allow mainly two changes: Planform changes and compliance[3]. Planform changes use rigid mechanisms for sweeping, folding, etc. and wing twisting or suitable mechanisms are used for compliance. Most common morphing techniques include wing extension, wing folding, and wing sweep. These motions are broadly studied as one dimensional (1d) and two dimensional (2d). Significant aerodynamic performance gains are only really achievable through large overall changes in the aircraft geometry via wing sweep, area and/or span. Small changes in geometry of wings such as use of deployable slats and flaps which are also currently used in wing morphing techniques has been proved really useful to improve the flight control of the aircraft. Basic morphing motions for seamless flight control include:

- Wing twist
- Wing camber change
- Asymmetric wing extension [4]

2.1 1-D Morphing and 2-D Morphing

Folding wing arrangements as suggested by Lockheed Martin as shown in figure below is one of the two ways to achieve large planform changes for wing morphing. The other is wing extension. Cruise missiles manufactured by Raytheon Corporation using wing extension phenomenon demonstrated a huge increase in the range[1]. The extension, if used

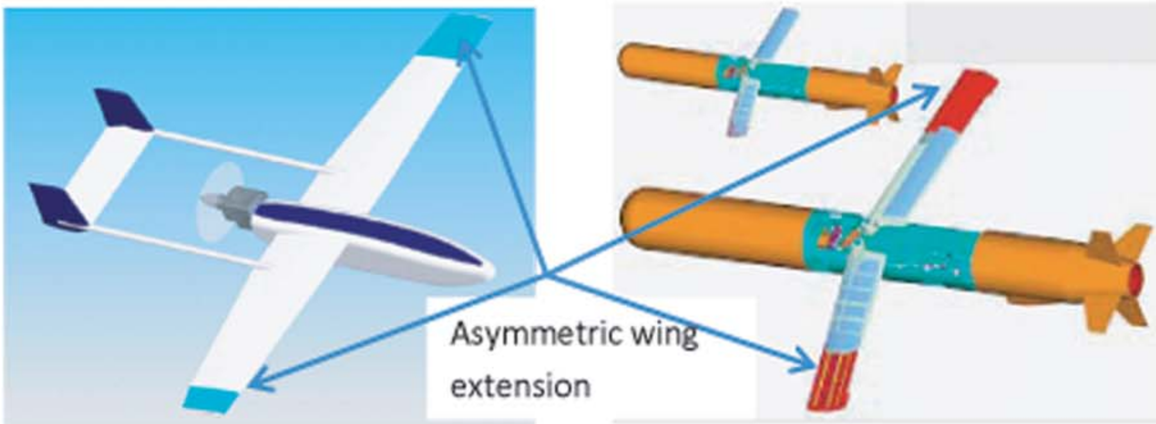

Figure 4: 1D morphing [10]

asymmetrically, can be beneficial for roll control also. Therefore, the cruise missile system was again used to discover possibilities for the roll control. As a result, it was found that differential span change between wingtips can generate a roll moment, which potentially replaces the aircraft ailerons and hence optimization of aspect ratio became feasible. The two-dimensional change of wingspan is represented in figure below.

from single wing to two wings glued at the wings tips. This kind of change is considered as 3-D morphing (Figure 5) and commonly known as buckle wing morphing. The buckle wing in flying conditions looks like a normal wing with slightly thicker wing of higher aspect ratio. Two thinner wings are fused together to form a single wing which morph into a biplane configuration as shown in figure 6 with its extremities joined together

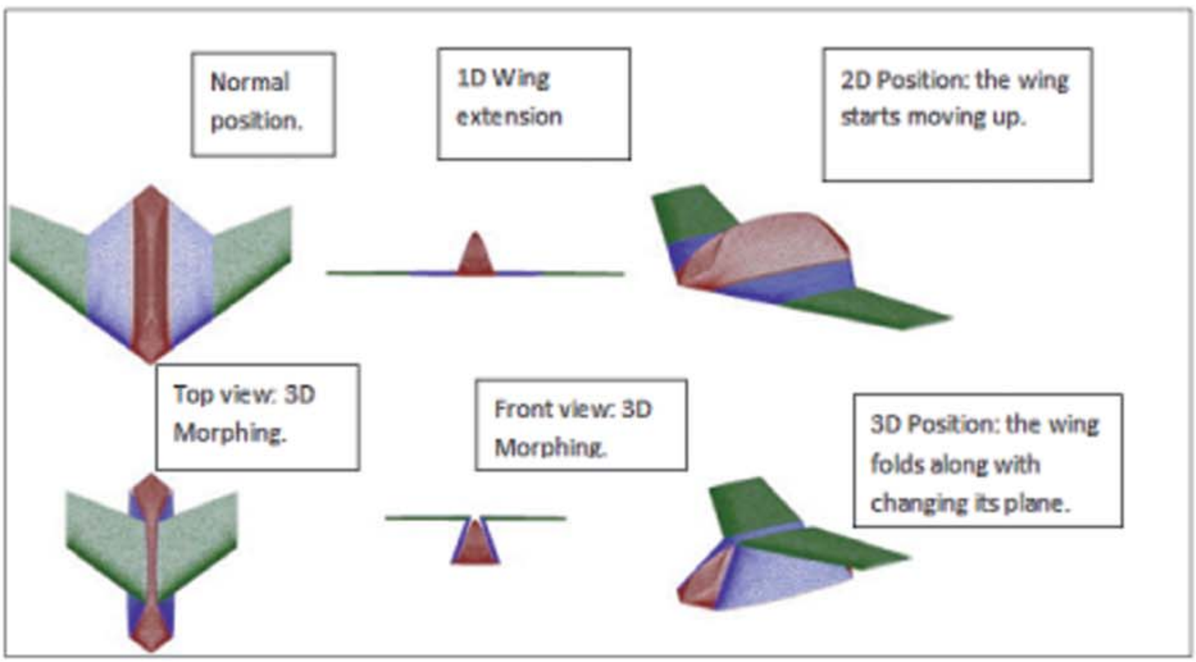

Figure 5: 1D, 2D and 3D Morphing in an aircraft [10]

whenever need arises. When both wings are on, the UAV generates maximum lift and becomes more agile.

2.2 3-D Morphing (Introduction of Buckle wing)

The UAV shown in figure 6 demonstrates the variable wing concept as it changes it configuration

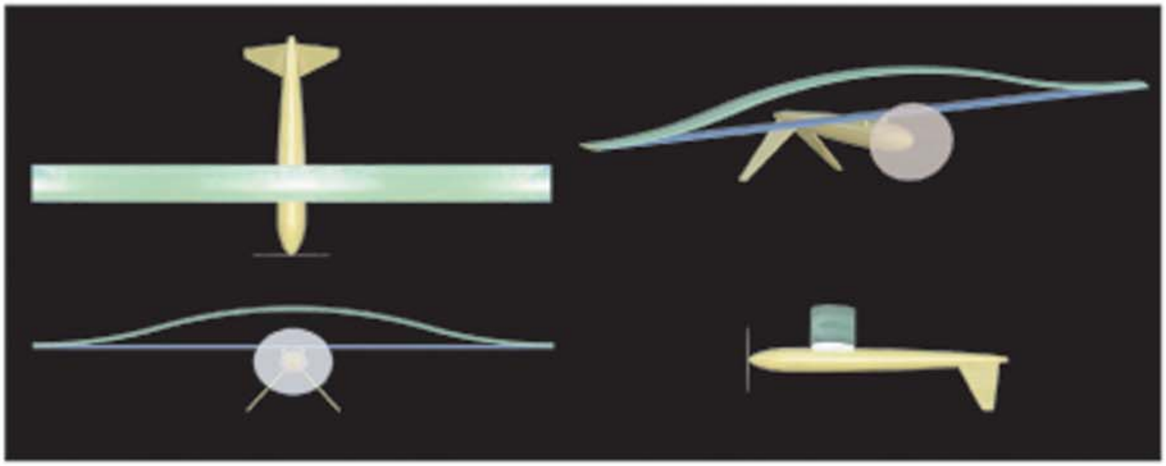

Figure 6: Different view of Buckled wing UAV [10]

As reference to conclusions of various research papers published on buckle wing such as the unique Buckle-Wing illustrated in figure 6 will be capable of independently changing wing loading, aspect ratio, and wing section shape while in flight improving its maneuvering abilities and increasing its range/endurance as compared to the traditional wing. Thus, this design will prove to be an exclusive discovery to handle the competing objectives of modern UAVs.

The Buckle-Wing consists of the lower and upper lifting surfaces having no body attachments with the lower wing having some stiffness. Varieties of buckling deformations are performed by the pinned, clamped or different restricted sliding configuration and thus by controlled buckling of the elastic lift surfaces.[5]

3.0 TOTAL MORPHING CONCEPTS FOR UAV

Morphing technology of UAV differs from conventional wing aircraft as the power requirement and the mechanism needed is less complex. The aircraft based upon total morphing concepts are capable of changing their shape in order to perform their desired mission without using the traditional control surfaces. These morphed wing aircraft can perform a wide range of maneuvering that lies beyond the reach of the traditional wing aircraft. The concept of morphing is the full summation of control shape of wing structure with a truly intelligent structure[6]. To have an overall benefit from those intelligent structures one must calculate the aerodynamic loads of each component of aircraft along with the power that is required for shaping control. Below are some of the concepts researched till date that can be implemented within the total morphing concepts.

3.1 The Variform Concept in Morphing

As the name suggests the Variform wing is simply a wing that changes planform as fuel is consumed in order to maximize the lift to drag ratio. This drastically increases the range of the aircraft but with less fuel. As the fuel is used up, the wing could morph into the shape of a FX 60-126 airfoil. This is shown in figure 7, where the outside line is the larger NACA airfoil and the inner solid section is the sleeker shape.

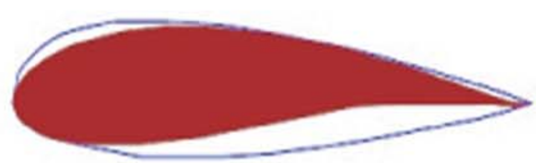

Figure 7: Airfoils for Variform concept[7]

Storing the fuel in balloons like bladders as shown in figure 8 below can be one of the ways to facilitate this type of morphing in the wing. When the bladders are filled the shape would look like the outer profile in figure 7 above and when empty the shape would look like the inner solid-filled shape. The simplest bladder configuration, as shown in figure 8A, would just be an oval or any simple geometric shape. However, to achieve greater control of how the wing changes over time, a non-symmetric shape could be used as the bladder

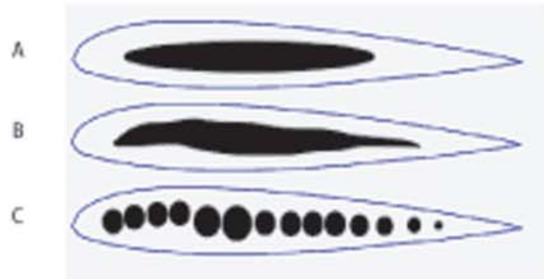

Figure 8: Various bladder configurations [7]

(Figure 8B), or even possibly multiple bladders of different size and shape seen in part C of the same figure as given by researches [7].

3.2 Inflatable wings morphing

To meet the demand of controlling the aircraft during flying time, one special type of wing is used instead of conventional wing which can inflate and deflate and are capable of changing the shape of its tips along with the airfoil such as NACA profile (NACA 8318 and 0018) is known as the inflatable wing. Basically this idea of "inflatoplane" came at a very early stage of aviation. [8]

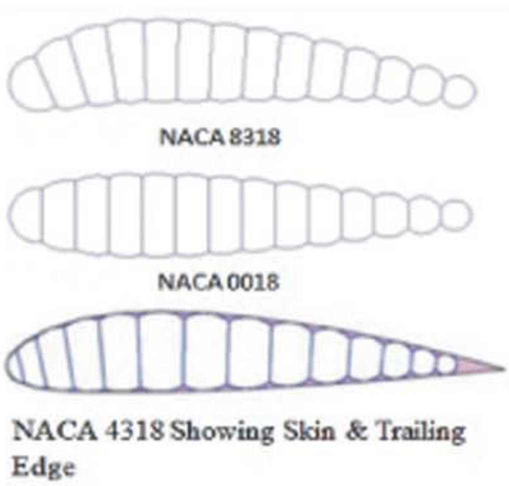

Figure 9: Inflatable wings [8]

Basically this idea came for using inflating and deflating wing for storage and transport. These inflatable wings have been under the development for some years especially for the UAV application. In the past few years inflatable wings have been manufactured by the "ILC Dover " which are jointly tested by the University of Kentucky with University of Maryland in 2003-2004.[8]

4.0 VALIDATION

According to the experiment conducted by Virgina Tech, wind tunnel test of a model was sized to fit in the 6ft Stability Tunnel and to satisfy the Defense Advance Research Projects Agency (DARPA) requirements of a 35% independent span change in each wing, a 40° independent sweep, a 12% chord change, a +20° twist and a 32% change in planform area. This is accomplished by a series of pneumatic and electric actuators, and controlled remotely through a PC 104 board. Details can be found in [9]. The data that is available in the figure 10 shows the simulated results of wind tunnel test of morphed wing aircraft. In that plot it is directly shown the lift and drag ratio comparison for typical wing and morphed wing aircraft. And from this CL vs. CD plot it is clear how these vary or how low the drag can be maintained over a large range of lifts.[9]

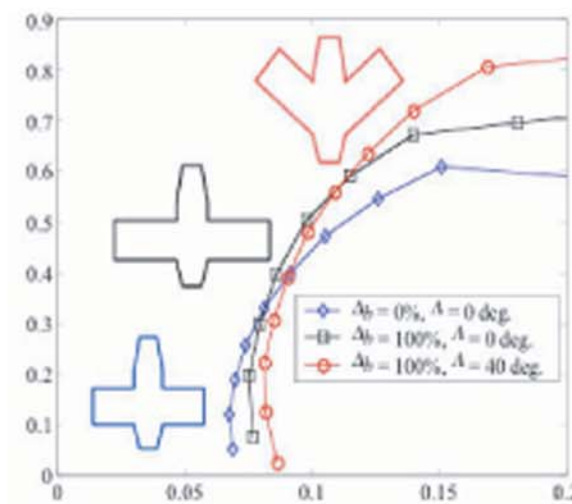

Figure 10: CL vs. CD for conventional and morphed wings[9]

5.0 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 by changing the areas of the wing that leads to changes of aspect ratio and lifts. By sweeping, twisting and changing its span, area, and airfoil shape, the wing can be changed to fit different mission segments such as cruise, loitering and high speed maneuvering and thus provide combat edge to advanced UAVs.

Figure 11: Morphing technology foreseen by NASA [10]

Another research trend is credited to Hypercomp NextGen (figure 12), which performed substantial changes in plan, form and surface with same geometry change as described above.

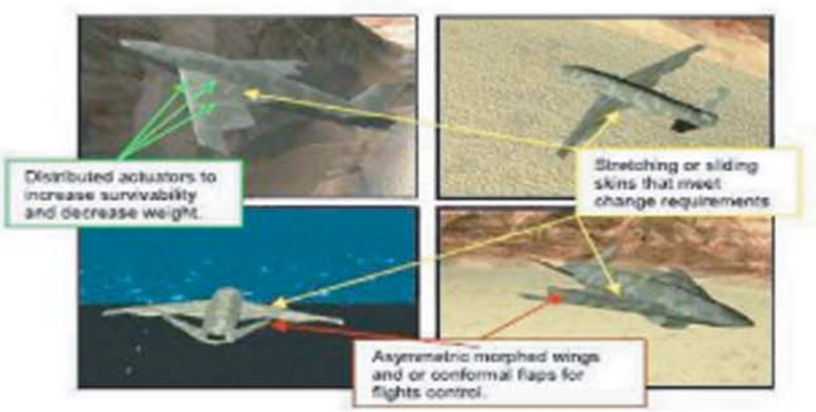

Figure 12: NextGen Morphing design[10]

Due to their reduced scale, UAVs nowadays are the first choice for the researchers to carry out their experiments. Composite materials are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct within the finished structure. Use of advanced composite materials has improved our design approach, and thus development of new lighter and reliable structures and actuators has been viable. Therefore, Composite materials are very important in the aviation industry because of differences they make related to weight, strength and flexibility. Memory materials which have the ability to change shape by means of electrical signal or temperature variation are being researched as they appeared to be very promising. However, smart materials still have a long way to become trusted ones.[6]

6.0 CONCLUSION

It is well understood that morphing is a promising technology, which enhances aerodynamic performance of aircraft. Adaptive shapes and variable planform modify the wing chord, span, sweep and aspect ratio of the wing to suit typical operational requirements. A variable planform with high aspect ratio reduces the induced drag and the power requirements while adding weight due to additional dimension. And the converse is true for the low aspect ratio aircraft. However with the advent of modern technology and advanced material it is possible to reduce the weight of the aircraft keeping the power to weight ratio at an acceptable range. It is also important in the military parlance to hide the presence of an aircraft by stealth dimension. Adaptive wings with morphing technology are capable of providing the stealth dimension which remains a lucrative arena in the military doctrine.

REFERENCES

[1] Robert D. Vocke III, Curt S. Kothera, Benjamin K.S. Woods, Edward A. Bubert, and Norman M. Wereley, a paper on One Dimensional Morphing Structures for Advanced Aircraft, University of Maryland, College Park, MD,Techno-Sciences, Inc., Beltsville, MD, USA.

[2] Alexander, David E. Nature's Flyers: Birds, Insects, and the Biomechanics of Flight. 2002(hardcover) and 2004(paperback). Baltimore: The Johns Hopkins University Press. ISBN 0-8018-6756-8(hardcover) and 0801880599(paperback).

[3] M.I. Friswell, a paper on The Prospects of Morphing Aircraft, School of Engineering, Swansea University, UK.

[4] Michael I. Friswell, Daniel J. Inman, A paper on Morphing Concepts for UAVs, Department of Aerospace Engineering, University of Bristol, Bristol BS8 1TR, UK, Center for Intelligent Material Systems and Structures, Virginia Tech, Blacksburg, VA 24061, USA.

[5] ShawnE.Gano, JohnE.Renaud, StephenM.Batill, Andr´ esTovar, Shape Optimization For Conforming Airfoils, 44th AAIA(2003-1579), Department of Aerospace and Mechanical Engineering University of Notre Dame, Notre Dame, Indiana.

[6] Lauren Butt, Steve Day, Joseph Weaver, Craig Sossi and Artur Wolek, Onur Bilgen, Dr. William Mason, Dr. Daniel Inman, , a paper on Wing Morphing Design Utilizing Macro Fiber Composite Smart Materials, Virginia Tech, Blacksburg.

[7] ShawnE.Gano, JohnE.Renaud, a paper on Optimized Unmanned Aerial Vehicle With Wing Morphing For Extended Range And Endurance, Department of Aerospace and Mechanical Engineering University of Notre Dame, Notre Dame, Indiana.

[8] David Cadogan and Tim Smith DE 19946, Frank Uhelsky , DE 19946, and Matt MacKusick , De 19946, a paper on Morphing Inflatable Wing Development for Compact Package Unmanned Aerial Vehicles, ILC Dover, Frederica and AIAA.

[9] Neal, D.A., Good, M.G., Johnston, C.O., Robertshaw, H.H., Mason, W.H. & Inman, D.J. Design and Wind Tunnel Analysis of a Fully Adaptive Aircraft Configuration. 45th AIAA/ ASME/ ASCE/ AHS/ ASC Structures, Structural Dynamics & Materials Conference, Palm Springs, California, 19-22 April, 2004, paper AIAA-2004-1727.

[10] www.google.com, www.wikipedia.com and www.nasa.gov

[11] Seigler, T.M. Dynamics and Control of Morphing Aircraft, PhD Thesis, Virginia Tech, USA, August 2005. http://scholar.lib.vt.edu/theses/available/etd-08162005-134143/

[12] Gurdal. Z, Design Tailoring of Laminated Composite Structures., 46th AIAA/ ASME/ ASCE/ AHS/ ASC, Structures, Structural Dynamics and Materials Conference, Austin, Texas, 18-21 April 2005, paper AIAA-2005-2164.

[13] Naval Research Laboratory (James P. Thomas), Structural Performance with Energy Storage for Air Vehicles through Multifunctional Design and Fabrication, December 14, 2001.

[14] Pedro Manuel Magalhães da Costa Aleixo , Morphing Aircraft Structures - Design and Testing an Experimental UAV , paper thesis, Technic University Lisbon, 2007.

[15] Daniel T. Grant, Modeling And Dynamic Analysis Of A Multi-Joint Morphing Aircraft, abstract thesis, University of Florida, 2009, USA.

[16] Anna-Maria R. McGowan, Lucas G. Horta, Joycelyn S. Harrison and David L.Raney, Research Activities Within NASA's MorphingPro-gram, NATO-RTO Workshop on Structural Aspects of Flexible Aircraft Control, Ottawa, Canada, October 18-21, 1999.

[17] Gallington et al, "Chapter 6: Unmanned Aerial Vehicles", Future Advances in aeronautical Systems, 1996.

[18] Steven J Zaloga, illustrated by Ian Palmer, UNMANNED AERIAL VEHICLES (Robotic Air Warfare 1917-2007).