JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

A Systematic Review of Morphing Wing in Aviation Industry

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Abstract: Aircraft wings employ to generate aerodynamic lift and provide better aerodynamic efficiency. Nowadays, research extends to morphing wings capable of transforming the geometry of the wing chordwise bending, twist morphing, variable camber, spanwise, planform wise, and many more variants. However, the evolution of the morphing wing concept and extension of research in transport aircraft were reviewed. An adoption of morphing the wing creates both benefits and challenges for designing the system. This paper forecasts the different types of morphing are in practice in any commercial aircraft. This paper also discusses the benefits of various configurations of morphing technology and states the possible ways to improve aircraft performance, fuel economy, and airline competitiveness. The study expands the merits to enhance the performance from a designer's point of view. Several aerodynamic design parameters are studied and understanding the influences in performance and fuel economy. This paper focuses on the future aspects of morphing wings in the upcoming new generation aircraft.

Keywords: Morphing wing, Transport Aircraft, wing design.

1 Introduction

Humans desired to fly in the sky from the very beginning inspired by the bird's capability to dominate the sky [1]. The first persons who tried to adopt this capability were Chinese philosophers Mozi and La Bun who invented the kite approximately 2,800 years ago in the 5th century BC. after so many years first lighter than air aircraft has been made in 1783 by Joseph and Etienne Montgolfier in France and then in 1895 Shivkar Bapuji Talpade was the first person who tried to make the first heavier than air aircraft but didn't get successful in it, but after him, the Wright Brother's Wilbur and Orville Wright made Kitty Hawk the first successful heavier than air aircraft [2]. The very challenging targets of the new environment wanted the requirements of advanced aircraft configuration which will be based on more efficient aerodynamics and structures together with more sophisticated flight control [3].

Wings are the most important part of the aircraft without wings aircraft cannot fly. The wing is a type of fin that produces a lift while moving through the air. Wings have streamlined cross-sections that are subjected to aerodynamic forces and act as airfoils. The wing produces a lift at a certain speed and angle of attack. A wing's aerodynamic efficiency is expressed as a lift-to-drag ratio. A high lift-to-drag ratio requires a significantly smaller thrust to propel the wing through the air. To control the aircraft direction flaps and ailerons are used these are effective but due to gaps in between the aircraft wings and control surfaces, it creates unnecessary drag. Thus, it affects the aircraft performance and increases fuel consumption. So to cope with this loss wing morphing concept is introduced.

The origin of the word "**morphing**" is from the Greek word ***metamorphosis*** which means "change or transformation", from here the word wing morphing is developed which means a change in wings. The main purpose of wing morphing is to increase aircraft performance such as maximum speed, less fuel consumption, range, carrying capability, durability, stability, etc. The changes in the wing planform mean change in wingspan, chord length, and some geometric parameters such as chamber change, airfoil change, and thickness change [4]. Wright Brothers used the concept of wing warping (also known as wing morphing) which was an early system for lateral control of a fixed-wing aircraft, they used a system of pulleys and cables to twist the trailing edges of the wings in different directions. Ivan Makhonine was one the first to successfully use in-flight wing planform area morphing to reduce landing speed while providing a smaller wing for high-speed flight. He developed a telescoping wing planform in the MAK-10. Abdul Rahim and Cocquyt have made studies on flexible wings on micro aircraft that allow complex wing shapes to be made and after the complex wing study, they started researching seagull wings to increase the flight ability.

Our priority is now to make aviation leaders, who understand the advantages and reliability of the shape-changing wings. In November 2016 NASA entered into a joint venture with Seattle's Aviation Partners, they sell efficiency-boosting winglets for airliners. They made a new company together named Aviation Partners FlexSys to commercialize Flex Foil, which they planned to test on a commercial aircraft in 2020.

2 Morphing Wing

2.1 History

Morphing wing technology has been part of the aviation industry since the time of the Wright brothers, they have been used morphing wings for the wright flyer (the first successful plane). They use the twisting wing morphing which is one among many, which has been done with the help of bicycle tubes and with cardboard. The shape of the wing is curved due to which the wing pushes air downward and lift has produced due to pressure difference. Nowadays flaps and ailerons control surfaces are used in place of wing morphing. The wing morphing was discarded because of their complex mechanism and ability of proper flexible material needed for wing morphing. However, continued research in this field is going on since 1903 and its potential use has been realized. As aviation technology advanced and material sciences also advanced the newer material, structures and mechanisms were introduced in the industry. Thus, wing morphing has been reintroduced in the aviation industry as recent research shows it provides better performance and economy [5] as compared to conventional wing configurations. In the year 2007, the study of Pneumatic Telescopic Wing Design and Manufacturing has done. The Telescopic wing developed at the University of Maryland they have explored the idea of using the variable span wing morphing to increase the performance of aircraft in such a way its maneuverability, maximize aerodynamic performance for a given mission profile and possibly act as an effecter of roll control for UAVs should also run smoothly. [6] it is been observed that in the next decades the wing morphing technology has been enhanced in Span extending blade tip, Spa extending morphing wing, GNAT Spar wing, Morphing wingtip, Morphing conceptual wing A320 vertical tail, Model aircraft for validation and experimentation of Robust innovative controls. In the year 2020, Airbus has introduced the A350 XWB aircraft which has morphed winglets to improve the performance of aircraft and helped in decreasing fuel consumption.

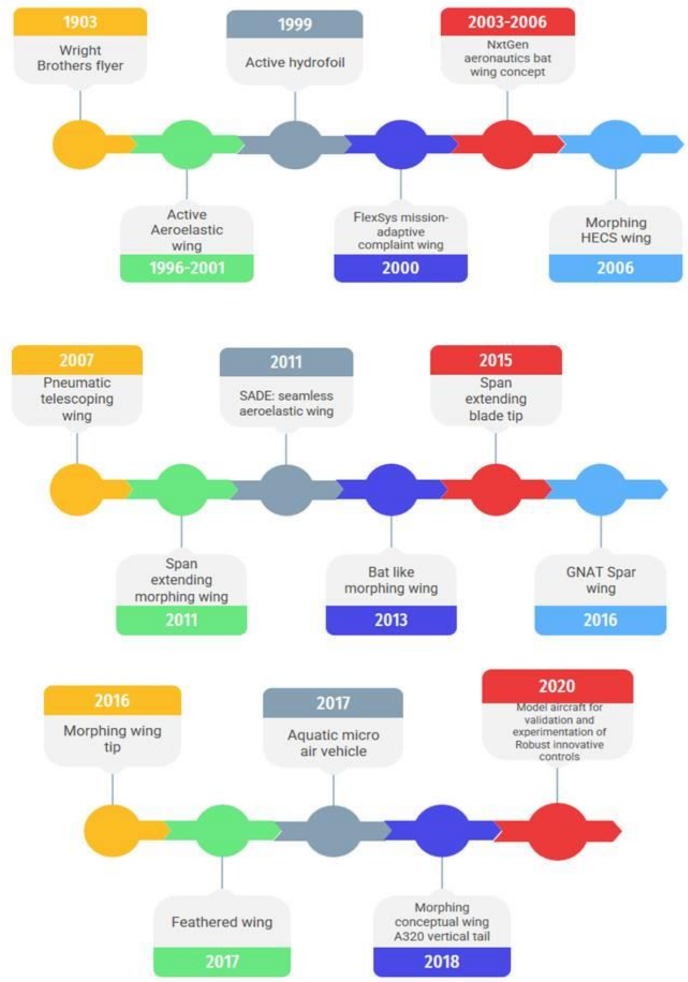

Fig.1. Timeline of morphing wing

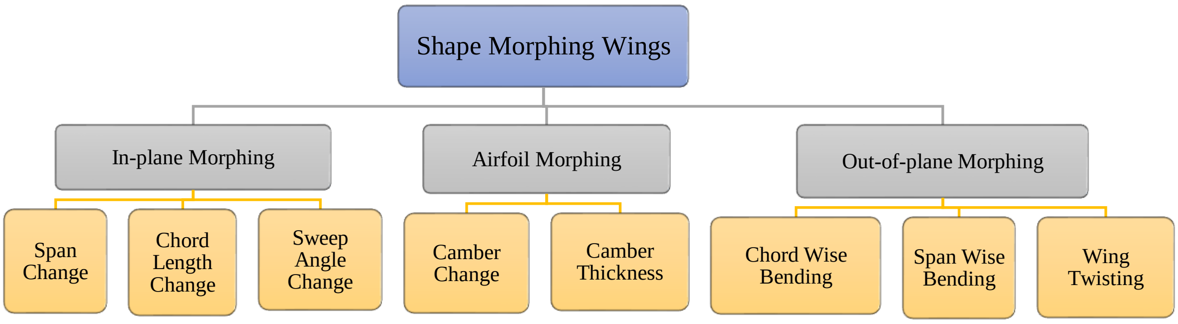

Fig. 2. Classification of Morphing

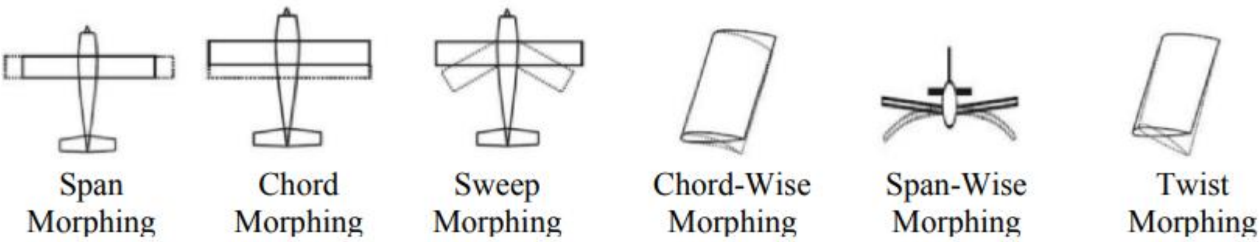

Fig. 3. Illustration of morphing wing [7]

2.2 Variants of Morphing Wing

Morphing wing can be classified into three categories:
(a) In-plane Morphing,
(b) Airfoil Morphing, and
(c) Out-of-plane Morphing.

2.2.1 *In – plane Morphing*

Span change:
The ends of wings are called wing tips and distance from one wing tip to another wing tip is called span [8]. Span morphing can change the shape of aircraft according to different flight conditions and to improve flight performances [8, 9].it provides better range and economy to transport aircraft by changing the span of wing according to the flight conditions [10]. Span morphing is a concept which deals with change in wingspan to accommodate different flight regimes. Focusing the span moving factor which depends on wing area and aspect ratio. Both these factor drastically affect span change morphing [11]. Such change in wingspan leads to improve range and better fuel efficiency. Incorporating span wise wing morphing has low manoeuvrability at certain cruise speed. On controversy to conventional wing, span length is smaller as wingspan morphing mechanism. Due to that, conventional wing can achieve high speed, better manoeuvrability and lacking for long range flight. The basic concept of span wise morphing is by increasing the aspect ratio end wing area .By increasing aspect ratio and wing area leads to increase wingspan and decreases spanwise lift distribution for same lift .Lift of span morphing increases as a result of increase in wing span, Mach number and angle of attack .Span morphing may improve the aerodynamic performance up to 25% for speed and range between 13.9 to 30.6 metre per second. In 1931, Ivan Makhonine has designed a variable span wing. He designed the first telescoping wing on MAK 10-aircraft .This mechanism allowed span to extend up to 62 percentage and wings space to 57 percentage. A wide advantages of wingspan morphing is to increase the aircraft range and endurance and helps to, reduce take-off and landing distance. However, span morphing may offer high advantage by reducing combat aircraft wingspan which lowers the wing aspects ratio. Insufficient use of resource, increased cost are limitations of span morphing.

Chord length Change:

When an airplane flies, the chord lines of the wing sections Are not normally parallel to the direction of flight terminology, for pilots direction is always expressed in relation to due north on a compass and measured clockwise. The angle between the chord line and direction of flight or of the undisturbed stream is the geometric angle of attack. The chord length morphing mechanisms goal is to increase the wing's chord length. Normally, leading or trailing edge flaps are used to increase the chord length of a conventional aircraft, resulting in a gap and an unsmooth wing surface. However, the chord morphing concept has significant advantages in terms of minimizing wing drag by eliminating the gap and maintaining the flat surface of the wing [8]. Previous experimental aerodynamics have shown that using a chord morphing win can improve aerodynamics performance in terms of lift coefficient and lift to drag ratio. The use of chord morphing wing provides greater control the use of traditional ailerons. Lift is proportional to area and square of indicated speed.

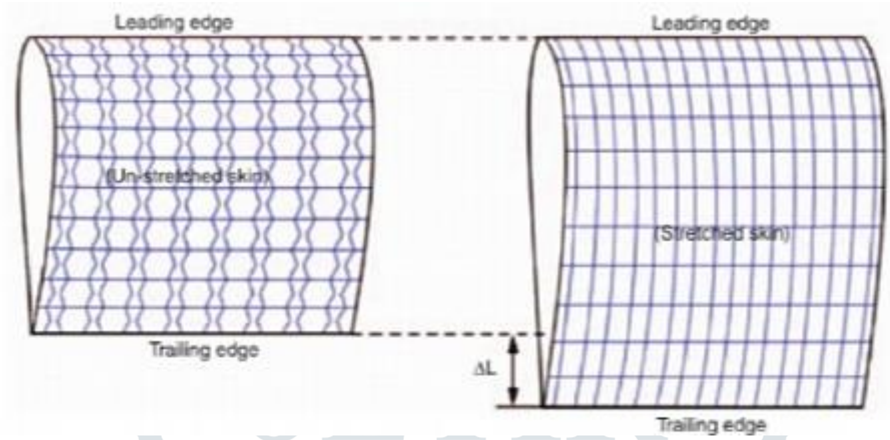

Fig.4. Chordwise length morphing [12]

Chord morphing theory offers an enormous edge by reducing the drag produced on wing by remove the gap and maintain the plane surface of the wing.

Sweep angle change:
Sweep angle of a wing is the angle between lateral axis and quarter chord line. Variable morphing wings sweep concept deals with adjusting aerodynamic performances and improves lift to drag ratio -. Wing sweep angle is normally used to decrease drag at high subsonic speed by reducing its wing aspect ratio. Sweep is important for lowering the wave drag but it also decrease the overall lift coefficient which needs to be compensated with baseline platform area, high lift systems or both .Hence variable sweep would be desirable because it makes it possible to reduce weight due to high lift system or wing size. Variable forward swept wing (VFSW) is the kind of typical morphing aircraft's. Forward swept wing have better efficiency at low speed. They have a higher lift drag ratio meaning less fuel is burned .By changing forward swept angle the aerofoil of variable forward swept wing will also change which is based on incoming flow and this change has a very important influence on flight performance . Variable wing has been adopted in military aircraft to achieve faster supersonic cruising speed size. There disadvantages is that forward swept wings are extremely durable.

2.2.2 Airfoil Morphing

Camber change:
This concept is inspired from the birds. With the use of this concept, plane can get a high lift-to-drag ratio and better control on our flight. Camber change is required for generating more lift, less drag and high speed. This method is also used to increase the performance of the plane and economy. In 18th and 19th century, many different types of flying machine are tested because mankind want to fly in sky. In 1903, finally one attempt is successful. Wright brothers were successful to fly world's first plane. This aircraft was successful because of simple aerofoil technology. The wings of aircraft are able to produce lift force in engineer's way. The wings are in curve shape due to which the wings push air downward. Camber change uses newton's third law of motion. Same concept is used in modern aircraft in which flaps are used to increase the lift. When flaps are in downward direction, there is an increase in wing area. As the curvature and the area of air increases, deflection is more and the aircraft gets more lift. When flaps are in upward direction, there is again increase in lift but that time flaps also produces drag. There are two type of camber variation with one structural system providing a smooth contour having no additional gaps. First one is chord wise camber variation and second span wise differential camber variation.
Chordwise camber variation - Chordwise camber variation improve the aerodynamic efficacy by optimizing the L/D ratio [13]. L/D is the ration, its results from wing data, altitude, Mach number and aircraft weight. Chordwise camber variation helps to reduce the fuel consumption [14].
Spanwise camber variation – spam wise camber variation give good control on flight. Its helps to distribute load [14]

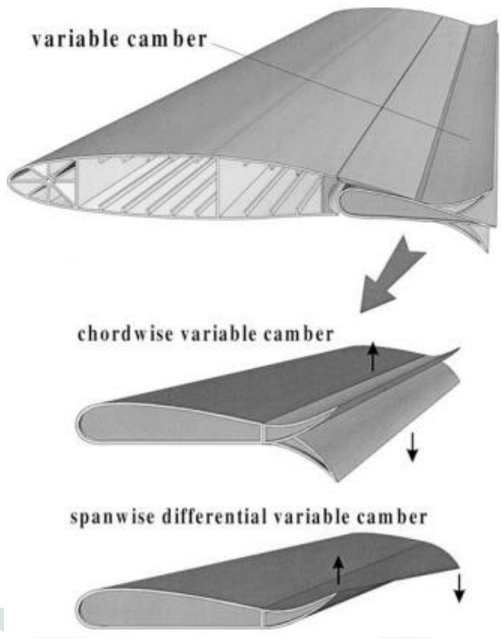

Fig. 5.Chordwise and spanwise differential camber variation of Fowler flaps [14]

Camber thickness:

Camber thickness states that when the thickness of the camber might increase or decrease leads to increase better performance and controllability. [15].
There are two types of Camber: a) Symmetrical Camber, and b) Asymmetrical Camber

Symmetrical Camber has high thickness. This type of Camber is used in heavy plane. Symmetrical Camber gives high lift to plane because of more thickness but speed of this airfoil is less than Asymmetrical Camber. Whereas, asymmetrical Camber has low thickness. This type of Camber is used in small or medium plane. Asymmetrical Camber give high speed to plane but because of less thickness of plane it generates low lift
.
Camber thickness change mechanism: - In Camber there we have actuators or stringers and compliment mechanism system (CM) [16] which we use to increase or decrease the thickness of airfoil. In old airplanes or aircraft's we were use flaps or elevator on the place of airfoil. The flaps or elevators are very heavy. The gap between plane to the flaps or elevator are create too much drag which effect on the aerodynamic performance. In airfoil, airfoil or its mechanism is lightweight or there are no any kind of gap in between, so it's not effect on aerodynamic performance. Various benefits of camber thickness change provides good control of airplane, increases the airplane aerodynamic performance, improve the lift to drag ratio, and also improve economy or time for travel.

2.2.3 Out-of-Plane Morphing

Chordwise bending:
Chord wise bending is the change in the trailing edges of the wing. It is achieved by flexible bending of the wing with respect to chord and camber of the aerofoil as shown in the fig (a) [2]. The flexible bending of the trailing edge is achieved by the usage of hinged stingers having a structure similar to finger fig(b), interconnected at specific points to have flexibility, actuators are used to deform the wings in order to achieve morphing effect. In addition, the usage of carbon fiber enhance the flexibility of the skin. The conventional flaps are expected to be replaced by the chord wise bending with usage of Adaptive Trailing Edge Device (ATED) [17]. This bending is related to the variable camber. The usage of conventional flaps in the trailing edges gives control to an aircraft but due to the gaps in between the joint of the flaps and wing it creates an uneven surface thus hindering the flow of the air and creating turbulences. However, there is aerodynamic power loses, so to reduce these loses the chord wise bending comes handy as it maintains the smooth continuous contour flow over the wing and provides better stability in flight and turbulence reduction. This reduction in turbulence specifically increases the aerodynamic profile and performance of the aircraft fig (c). Further helps to reduce the fuel consumption of the aircraft. The camber variation is concentrated at trailing edges as at this region aerodynamic and structural viewpoints are highly effective. Some cautions are to be taken in consideration while morphing the trailing edges. First of all, primary function of flap with modified cambering should not affect rate of increase in lift. Due to causes of lift, aircraft structure may lead to bending which influence structural stiffness must be controlled [14]. Looking into the internal structure, system need to be compatible with different types of wing requirements including actuators and mechanical linkages. Using the morphing system, Chord wise and spanwise differential change can be executed in single wing structure.

A wide benefits of using Chordwise morphed wing as compared to conventional wing are as follows:

- Better aerodynamic profile and have a higher aerodynamic efficiency (L/D)
- Enhances the serviceable flexibility due to change in lift/drag ratio
- Reduction in fuel consumption and increases the cruise range of aircraft
- Reduces structural weight due to limiting wing root movement
- Reduces vibrations across the wing surface area

Chordwise camber variation –

Further the research has been drastically extended at a new variation of Chordwise camber [14]. This new morphing method is to achieve optimum fuel economy by variable camber deflection with respect to camber line. Actuators and linkages are placed on camber line, it changes the camber size to increase the aerodynamic efficiency with respect to chord. The lift to drag ratio is optimized to achieve this condition. During a flight weight reduction happens as fuel is constantly being consumed this have a negative effect on L/D ratio. Camber variation helps to reduce this negative effect. To achieve this aerodynamic profile, the camber of the wing must be large at the beginning of the flight, and then subsequently reducing the size of camber as in the flight fuel consumption and weight reduction constantly going on.

Advantages of Chordwise camber variation –

- Chordwise camber variation provides better lift to drag ratio according to research it provides more than 10 percent improvement in (L/D) as compared to present conventional wings [14].
- In comparison to conventional wings Chordwise cambered morphed wings provide more than 12 percentage improvement in CL value
- In comparison to conventional aerodynamic profile this profile provide better range and low speed performance
- It also provides reduction in the adverse pressure gradient of wing [8]

Span wise Bending:

The span-wise morphing is the concept to improve the aerodynamic performance of the aircraft. Fixed high aspect-ratio wings have an advantage in fuel efficiency, and operate at relatively low cruise speeds. On the contrary, aircraft with low-aspect ratio wings are faster and have better maneuverability, but show poor aerodynamic efficiency. A variable-span wing has potential to open the door for the advantages of each configuration. Aircraft with span morphing wings have been built and flown in the past. Some of the examples of aircrafts which have used the concept of span wise morphing are Makhonine MAK-10 in 1931, as the designers of early 1930s were interested in changing the configuration of wings for better take off and fast flight. Two
Aspects were explored, the first primarily involving camber and hence lift coefficient reduction and the other a decrease of wing area by span reduction at high speed. The main feature was a telescopic wing which increased the span for take-off by 26 ft. 3 in or 60% of its high speed configuration [1].

The variable-span concept is also applied in rotary-wing aircraft, and shows similar advantages as fixed wings. For stowed rotors, the concept alleviated dynamic and strength problems associated when stopping the rotor during flight, while for compound helicopters this concept reduced drag at high forward speeds. This concept offers some solutions to the technical problems of large civil tilt rotors. The rotors could change diameter in flight, so that a large diameter rotor (helicopter size) is used in hover and a smaller diameter rotor (propeller size) is used in cruise.

Conclusion

Wing morphing is a proven technology to enrich aircraft performance and fuel economy in a drastic phase. This paper aims for a systematic study of wing morphing evolution in transport aircraft. A study says that the wing morphs from Wright Brothers to the active aero-elastic wing. Later in 20's the concept and development of the Hyper-elliptic Cambered Span (HECS) wing drastically improved the aerodynamic efficiency. Morphing technology extended on the wingtip by increasing the aspect ratio leads to drag-reduction. This innovative idea was extended and applied both in Airbus A320 in vertical tail for better stability. Even Airbus A350 XWB has drastically implemented morphed wing and improved the performance of the overall aircraft. In the current year 2021, the HECS wing is used in swept as well as an unswept wing to enrich the lift-to-drag ratio. In a nutshell, the rate of change of camber thicknesses provides good control of the airplane, increases the airplane's aerodynamic performance, improved the lift to drag ratio of the airplane, and improves the economy. Further research can be extended into transport aircraft to improve the fuel economy and improve the airlines profitability.

References

[1] Agarwal, Ramesh K. 2016. Recent Progress in Some Aircraft Technologies, Morphing Technologies: Adaptive Ailerons.

[2] Weisshaar, Terrence A. 2013. Morphing Aircraft Systems: Historical Perspectives and Future Challenges. Journal of Aircraft, 50(2).

[3] De Gaspari, Alessandro; Ricci, Sergio 2015. Knowledge-Based Shape Optimization of Morphing Wing for More Efficient Aircraft. International Journal of Aerospace Engineering, 2015(), 1–19.

[4] Li, Daochun; Zhao, Shiwei; Da Ronch, Andrea; Xiang, Jinwu; Drofelnik, Jernej; Li, Yongchao; Zhang, Lu; Wu, Yining; Kintscher, Markus; Monner, Hans Peter; Rudenko, Anton; Guo, Shijun; Yin, Weilong; Kirn, Johannes; Storm, Stefan; Breuker, Roeland De 2018. A review of modelling and analysis of morphing wings. Progress in Aerospace Sciences.

[5] Martins, Joaquim R. R. A., 2016. "Fuel Burn Reduction Through Wing Morphing," Encyclopedia of Aerospace Engineering, Green Aviation, Wiley, pp. 75–79

[6] Samuel, Julie Blondeau; Pines, Darryll J. 2007. Design and Testing of a Pneumatic Telescopic Wing for Unmanned Aerial Vehicles. Journal of Aircraft, 44(4)

[7] Laxman Hattalli, V., & Srivatsa, S. R. 2018. Wing Morphing to Improve Control Performance of an Aircraft - An Overview and a Case Study. Materials Today: Proceedings, 5(10), 21442–21451.

[8] Zaini Helmi, Ismail Iswadi Noor., Mechanical Engineering Colloquium, MEC 2016: A Review of Morphing Wing (2016).

[9] Henderson, Benjamin K.; Yu, Yuemin; Liu, Yanju; McMickell, M. Brett; Leng, Jinsong (2009). SPIE Proceedings [SPIE SPIE Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring - San Diego, California, USA (Sunday 8 March 2009)] Industrial and Commercial Applications of Smart Structures Technologies 2009 - Design and aerodynamic characteristics of a span morphing wing.

[10] Gao, B., Kang, R., & Chen, Y. 2016. Deployable Mechanism Design for Span Morphing Wing Aircraft. Mechanism and Machine Science.

[11] Nirmit Prabhakar. Embry-riddle aeronauticle university scholary commons 2014: Design and Dynamic Analysis of a Variable-Sweep, Variable-Span Morphing UAV.

[12] Olympio, K. R.; Gandhi, F. 2010. Flexible Skins for Morphing Aircraft Using Cellular Honeycomb Cores. Journal of Intelligent Material Systems and Structures, 21(17), 1719–1735.

[13] https://www.grc.nasa.gov/www/k-12/airplane/geom.html

[14] Hans Peter Monner. 2001. Realization of an optimized wing camber by using formvariable flap structures. , 5(7), 445–455.

[15] M. Leahy, 2013. Multidisciplinary Design Optimization of a Morphing Wingtip Concept with Multiple Morphing Stages at Cruise.

[16] Marks R Cristopher, Culler Adam, 2015. Variable Camber Compliant wing – design, AIAA.

[17] Arena, Maurizio; Nagel, Christof; Pecora, Rosario; Schorsch, Oliver; Concilio, Antonio; Dimino, Ignazio, 2019. Static and Dynamic Performance of a Morphing Trailing Edge Concept with High-Damping Elastomeric Skin. Aerospace, 6(2).