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# MORPHING WINGS OF AIRCRAFT

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**Abstract**

*Goal of the paper is to describe use of morphing wings on aircraft and their possible use to increase aerodynamic efficiency of aircraft. Paper is divided into two parts. First part focuses on design and material requirements of morphing wings as well as describes some of studied concepts. Second part compares studied concepts using gathered data and proposes possible combinations of concepts with goal of further increase of aerodynamic efficiency.*

**Keywords**

Morphing wings, Drag reduction, Aerodynamic efficiency, Aerodynamics, Comparison

## 1. INTRODUCTION

Flight performance differs in different parts of flight. Due to this aircraft are designed so that they reach optimal flight performance in part of flight where they remain for longest amount of time. This however means that in any other part of flight optimal flight performance is not reached. Reduction in flight performance results in increase of fuel consumption and emissions. To improve flight performance in certain parts of flight secondary control surfaces are used. These surfaces allow to increase lift generated by wing and thus improve flight performance during landing and take-off, however use of secondary control surfaces increases drag of aircraft. Ideal solution of flight performance optimalization is such that allows flight performance optimalization during full duration of flight without imposing sever disadvantages. Potential solution of flight performance optimalization is use of morphing wings. These wings are capable of changing their shape in plane and space. Changes in shape of wing allow aerodynamic optimalization of wing and thus allow improvement of flight performance in all parts of flight. Paper is focused on description of few concepts of morphing wings and then compares described concepts with goal of assessing practical use of these concepts.

## 2. HISTORY

Historically morphing wings are not new technology. These wings were first used in airplane of Wright brothers in year 1903. Airplane Wright flyer used bending of canvas wing to control roll of aircraft [1]. After this during 1930 till 1940 many more aircraft using morphing wings appeared. For example, Mak.10 which was capable of changing its wingspan [2], LIG-7 which was capable of changing its wing chord [3] and many more. Important airplane for morphing wings however was X-5 created in 1951. X-5 was a test bed for a variable-sweep wing. Data gained during testing performed on this aircraft were later used in construction of first aircraft equipped with variable-sweep wings such as F-14 Tomcat [4]. Variable-sweep is first concept of morphing wings successfully introduced into active service in history. More concepts of morphing wings were tested from 1964 till 2000. For example, folding wings of XB-70 [5], oblique wing of AD-1 [6] and mission adaptive wing of F-111. Result of morphing wings research conducted at that time was however that although these new wings bring aerodynamic improvements, their complexity and use of rare and special materials makes them unusable in practice with exception of variable-sweep wing, which was successfully used. Currently research in area of morphing wings focuses on creation of wing capable of changing its camber. Of course, there are many other concepts which focus on changing wing shape in different ways. For example, changes of wing chord, wingspan, wing thickness etc.

## 3. CONSTRUCTION AND METERIAL REQUIREMENTS

Morphing wings usually differ from regular wings with their elasticity. Elasticity is mostly necessary to allow easier change of wing shape. This however means that such wings will have special construction and material requirements. These requirements tend to differ between each concept however certain basic requirements can be set. Material used in construction or construction itself of morphing wings must be elastic, yet strong enough to resist to aerodynamic loads acting on the wing. After shape morphing construction must be capable of keeping its new shape and be capable of changing its shape back to original shape [7]. Shape change is mostly allowed by use of actuators located inside wing. Another way of inducing wing shape change is use of aeroelastic deformations. If actuators are used, they must meet certain requirements. They must be as small as possible, energy efficient and be capable of resisting loads acting on construction or be capable of transmitting these loads on other part of construction which can resist these loads. Question of material candidates that meet set material requirements was discussed in thesis from Virginia Polytechnic Institute and State University in 2003 [8]. This thesis set 4 material categories as potential candidates. These categories were polyurethanes, copolyesters, shape memory alloys and woven materials. Conducted testing on material deformation and load resistance resulted in incomplete results. Polyurethanes and copolyesters were successfully tested in single plane deformation, however during two plane deformation testing both categories ripped. Shape memory alloys were too brittle and thus could not be tested. Woven materials were ruled out based on load testing as this material was unable to resist aerodynamic loads. From these results it is apparent that finding material that could be used in construction of morphing wing is difficult. Despite of this such materials do exist. Materials from material category of smart materials are best candidates. Smart materials are materials capable to react to outside stimulation and change their characteristics based on this stimulation. For example, heating a shape memory alloy causes it to become more elastic. These materials can be used to create composites that are elastic, yet strong enough. They can be also used to create smart actuators which are lighter than regular actuators and generate enough force to change wing shape [9].

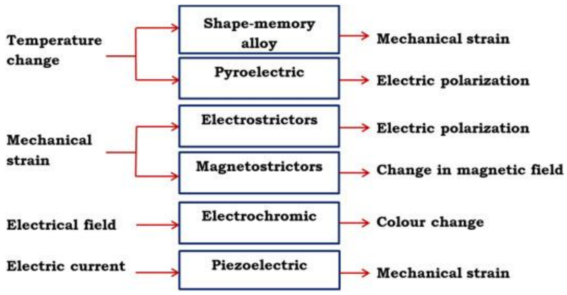


*Figure 1: Groups of smart materials and their interaction on outside stimuli [Nabila Shehata, Mohammed a. Addelkarseem, Enes t. Sayed, Davidson e. Egirani, Alfred w. Opukumo, Smart materials: the next generation].*

## 4. NEW CONCEPTS OF MORPHING WINGS

In this part paper focuses on description of new concepts of morphing wings that were chosen. These concepts are mission adaptive compliant wing (MACW), variable camber compliant trailing edge flap (VCCTEF), active aeroelastic wing (AAW) and adaptive aspect ratio (AdAR).

### 4.1. MACW a VCCTEF

Concepts MACW a VCCTEF are concepts of morphing wing that focuses on changes in camber. To achieve this both concepts change shape of continuous trailing edge. Shape change however is achieved differently. Trailing edge of MACW concept uses compliant structure which does not neede lot of force to change its shape [10].

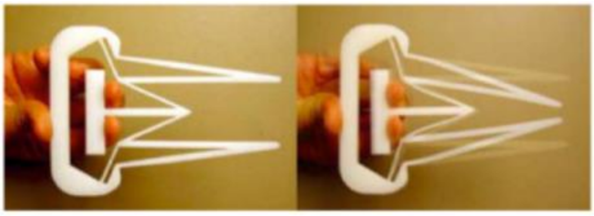

*Figure 2: Functioning principle of compliant structure used in MACW. [10]*

Concept VCCTEF uses continuous trailing edge that is divided into 12 sections. Each section is composed of 3 segments. Shape change is achieved by changing position of each of these segments [11].

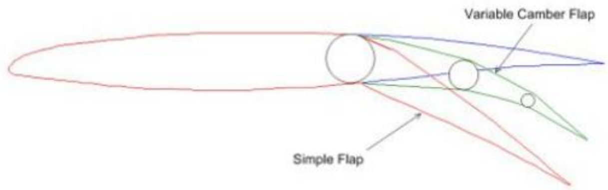


*Figure 3: Comparison of VCCTEF wing with regular wing. [11]*

Both solutions have their advantages. Compliant structure of MACW avoids creation of localised high stresses as entire structure changes shape. This means that structure is very unlikely to fail due to material fatigue. Compliant structure also allows use of common materials such as steel or aluminium. Since compliant structure does not have any joints there is no need for lubrication [10]. Construction of VCCTEF may be considered more complex, however it allows more precise aerodynamic optimalization as each segment may be positioned differently which allows for large variations of shapes of trailing edge [11]. Both concepts potentially allow optimalization of lift distribution on wing as both concepts are capable of variable trailing edge deflection [10], [11]. This optimalization would allow reduction in root bending moment which in turn allows reduction of construction strength. This means that wing construction would be lighter. Deflection of trailing edge of both concepts results in lesser drag increase than deflection of regular flap. Trailing edge of both concepts is continuous and thus generates less drag then regular trailing edge. Reduction of drag means increase in aerodynamic efficiency. Aircraft equipped with wings of either MACW or VCCTEF would thus have increased range and reduced fuel consumption.

### 4.2. AAW

Concept AAW uses aeroelastic deformation to induce changes in wing shape. Thin and elastic wing is deformed under aerodynamic load.

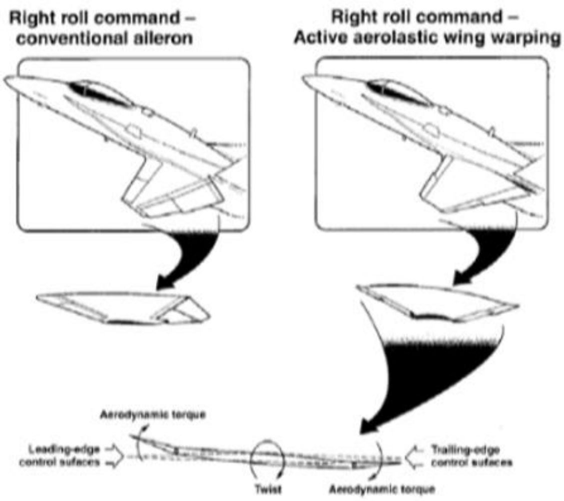


*Figure 4: Function principle of AAW. [Syed Ali Hussain, The morphing wing]*

This fact is usually undesirable as this leads to aeroelastic phenomena such as aileron reversal and flutter. Concept AAW uses primary and secondary control surfaces controlled by special flight control systems to induce controlled aeroelastic deformation. These deformation cause wings shape to change in desired which allows to use wing itself as a control surface. This leads to improvement of roll rate at high speeds and drag reduction as control surfaces do not need large deflections. Construction consists of regular primary and secondary control surfaces which is quite advantageous. For AAW to work however wing must be elastic. Concept was tested on F/A-18 Hornet which had wing retrofitted from prototype aircraft YF-17. Wing of YF-17 much thinner and more elastic than wing of F/A-18. Elastic wings have less robust construction than regular wings which leads to weight reduction of aircraft. Concept AAW thus allows for weight reduction, improvement of high-speed control authority and drag reduction [12], [13].

### *4.3. AdAR*

Concept AdAR allows change of wingspan without large changes of wing chord while keeping wing skin continuous. Changes in wingspan allow to control lift generated by a wing, aircraft roll-rate and generated induced and parasitic drag. Concept AdAR can also be used to cause asymmetry in wingspan and can thus be used to control roll of an aircraft. Concept construction is relatively simple. It consists of moving and fixed spar and strap drive system. Strap drive is used to allow movement of movable spar on which sliding ribs are located. These ribs are connected to elastic wing skin consisting of elastomeric matrix composite. Sliding ribs are responsible for keeping fixed minimal and maximal distance from other ribs. This is necessary to keep the wing skin stretched when wing is not extended and to protect the wing skin from damage when wing is extended.

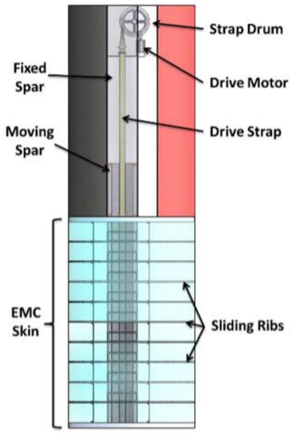


*Figure 5: Construction of concept Adar. [14]*

Wing skin must be stretched at all times to increase resistance to aerodynamic loads. Concept is currently still in development phase. Development focuses on finding an optimal number of sliding ribs. Number of sliding ribs dictates wings resistance to chord deformation. More sliding ribs increase this resistance however also increase actuation forces necessary to change wing shape [14].

## 5. COMPARISON OF MORPHING WINGS

Concept comparisons is conducted based on aerodynamic efficiency and construction complexity. Values of aerodynamic efficiency are taken from sources used in their description. If these values are unavailable, they are approximately set based on simulations crated and conducted in Autodesk CFD or if coefficient of lift and drag are known they are calculated. Values are set for angle of attack of 3° with full flap deflection with exception of concept AAW and AdAR. Values for AAW are set for 5° wing twist with +10° leading edge deflection and +3° trailing edge deflection. Values for AdAR are set for 3° angle of attack with no flap deflection at maximal wingspan.

### *5.1. Aerodynamic comparison*

Set values of aerodynamic efficiency of concepts is given in table 1.

*Table 1: Values of aerodynamic efficiency of concepts.*

| | |
|---|---|
| **MACW** | 127 (12.7) |
| **VCCTEF** | 17.2 |
| **AAW** | 4.32 |
| **AdAR (2 m)** | 3.38 |

Values for concept MACW are set based on graphs found in source for concept MACW [10]. Resulting value of aerodynamic efficiency is calculated to be 127. This value is absurdly high and is possibly so high due to use of lift and drag coefficients gained from 2D flow simulation. Approximate value of aerodynamic efficiency for this concept is 12.7 since all other values are in similar range. Aerodynamic efficiency for concept VCCTEF was set during testing of the concept. Maximal reached aerodynamic efficiency was 17.2 with lift coefficient of 0.51 that was used during concept testing. Values for concept AAW were unavailable and approximate simulation of concept was conducted in Autodesk CFD. Based on conducted simulation value of aerodynamic efficiency is 4.32.

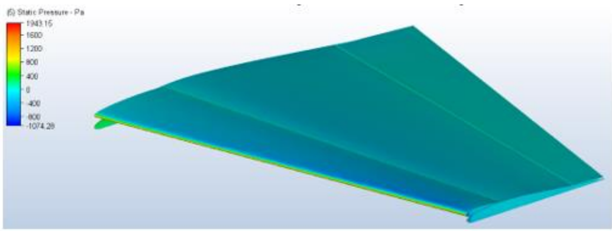

*Figure 6: Pressure distribution of simulated AAW model. [authors]*

Values for concept AdAR were also unavailable and approximate simulation was again conducted in Autodesk CFD. Based on results of simulation the aerodynamic efficiency of concept is 3.38 for wingspan of 2m.

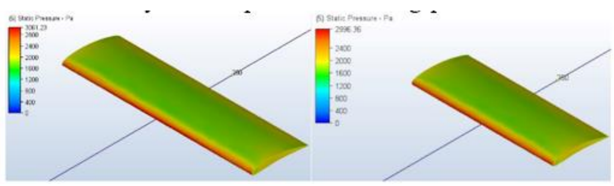

*Figure 7: Pressure distribution of simulated ADAR models. [authors]*

Based on gained values of aerodynamic efficiency can concept VCCTEF be determined as most aerodynamically efficient. In addition, by using optimalization of lift distribution can this efficiency be further increased. Despite not reaching highest values of aerodynamic efficiency concepts AAW and AdAR can be possibly combined with either concept VCCTEF or MACW on one wing to further increase aerodynamic efficiency.

### *5.2. Construction comparison*

Concept VCCTEF is most complex of all the described concepts. It's segmented construction may prove difficult to maintain in service. Used actuators in this concept also are not uniform. For end segments of each section of trailing edge, electric actuators are used. For first two segments of each section, smart actuators are used. Sections of trailing edge are interconnected by elastic material. This material may not be readily available further complicating maintenance. Construction of concept MACW may be complex in terms of production however it may prove less difficult to maintain than concept VCCTEF. As the actuation force does not need to be large less powerful and lesser number of actuators may be used. This reduces number of components that may fail. Concept can also use common materials such as steel which is more readily available. Compliant structure does not use any joints and thus removes necessity of lubrication and reduces number of components that can fail yet again. Failure of compliant structure is also quite unlikely as structure avoids generating local high stresses and thus avoids material fatigue failure. One large problem however may be in case of damage of compliant structure as repair of this structure may prove complicated. Concepts AdAR and AAW have relatively simple construction. Concept AAW uses regular control surfaces and elastic wing. This means that it's maintenance will be similar to maintenance of regular wing. AAW however needs special flight control system to work properly. Software of this flight control must function properly at all times to maintain control of aircraft unless some backup control is installed. Construction of concept AdAR is also fairly simple. There are however two problems with this concept. First problem is that wing skin is made from elastomeric matrix composite which may be expensive or not readily available. Other one is that failure of sliding rib may lead to structural failure of wing skin. Other then those two problems concept AdAR should not prove to be difficult to maintain in service however large emphasis must be given on ribs maintenance.

Structural complexity of concepts VCCTEF and MACW is their main disadvantage however they bring larger aerodynamic advantages than concepts AAW and AdAR. On the other hand, simple structures of concepts AAW and AdAR allow for potential combination with concepts VCCTEF and MACW further improving aerodynamic efficiency.

### *5.3. Combination of concepts*

Concepts AdAR and AAW may seem pointless in comparison to MACW and VCCTEF. However, despite they low values of aerodynamic efficiency in comparison to MACW and VCCTEF they still allow for aerodynamic improvement although small. Their simple construction is their biggest advantage in this case as it allows for possible combination with concepts VCCTEF or MACW. Such combination will lead to further increase of aerodynamic efficiency. Potential combinations are AAW and VCCTEF or MACW and AdAR and VCCTEF or MACW. Combination of AAW with either VCCTEF or MACW would allow replacement of regular control surfaces with morphing trailing and leading edge which generates less drag. Such combination would allow for AAW to work while generating less drag. Combination of AdAR with either MACW or VCCTEF would allow for roll control based on asymmetry of wingspan while regular flaps would be replaced by morphing trailing edge. This combination would also lead to further drag reduction and thus increased aerodynamic efficiency.

## 6. CONCLUSION

All described concepts have proven ability to improve aerodynamic efficiency of wings. In aerodynamic terms concepts VCCTEF and MACW have proven to be most capable. Concepts AdAR and AAW have proven to be less aerodynamically effective than VCCTEF and MACW however their relatively simple construction allows for possible combination with concepts VCCTEF and MACW. Such combination would possibly allow further improvement of aerodynamic efficiency. Research in terms of morphing wings should continue in the future. It is necessary to conduct testing of aerodynamic loading of such wings and to assess their aerodynamic efficiency. Based on results of such tests there should be focus of creating legislation and norms that would allow for such wings to enter service. Research of morphing wings should not be solely focused on creation of new concepts but should also focus on improving already existing concepts and their possible combination with other concepts with goal of further improvement in terms of aerodynamic efficiency.

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