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A review on Aerodynamic performance of NACA Airfoil for various Reynolds number

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Abstract. Morphing and shape shifting technologies offer a wide range of applications in airplane design and are complicated to operate effectively with current existing methods. Variable camber wings is a innovative control surface technology designed as aero elastic wing shaping control device which minimizes drag throughout its flight envelope and increases performance in different flight conditions which leads to corresponding increase in airplane flight efficiency. In order to achieve these results one has to rely on different flight actuator configurations and techniques to achieve variable camber mechanism. Variable camber can be achieved span vice or chord wise on an aerofoil where a slight variation in thickness changes lift coefficient. Variable camber wing is a flexible structure that changes its shape profile at different aerodynamic load these types of wings are tested under different load conditions and Reynolds number in wind tunnel facility to have a detailed study on the performance. In this paper an attempt has been made to cover all the shape shifting and morphing wing technologies and compare the results and discuss the possibility of adaption of such technology in aerospace industry.

1. Introduction

Lift generated by a wing of an aircraft can be varied by different lift augmentation devices. Basically the idea is to vary the camber of the wing with lift augmentation devices by changing the cross sectional area of the wing, there are plenty of lift augmenting devices invented, tested and implemented in airplanes mainly to change the area of the wing. Flaps, slots and slats or combination of all these has been widely used in almost majority of all the airplanes. Over the years attempts were made by relevant scientist to make available aerofoil with some type of variable camber mechanism so that the pilot may be capable to adjust his airfoil from aa sudden augmentation of lift to sudden change in cruise speed at will. The benefit gained by such a mechanism has given way to many patents which has been taken out and various numerical, analytical and experimental methods are applied for knowing the performance of the slots, flaps, slotted flaps.US air force has shown an extreme interest in variable camber aerofoil's and wing geometry(Hodson *et al* 20 15**)**, lot of research is done on varying the camber externally on the wing surface introducing different techniques, and recent literature survey has revealed NASA working on shape shifting wings which is about varying the geometry of the wing during flight which will be advantage at different flight profile of a spacecraft. Morphing wings posses the ability to reduce or even eliminate the size of discrete control surfaces and allow the wing of an airplane to obtain an aerodynamic wing profile at each instant at different mission profile(Upendar *et al* 2018). But few researchers has come with an idea of varying the camber internally by increasing the area of the aerofoil by a system which actuates and increases the area at different mission profiles when ever required, this not only reduces the weight of the aircraft, it has the potential to eliminate Flaps, and slots which is relied heavily by the aircraft for lift augmentation at different flight regimes, developing an aerofoil which is capable of varying camber internally to produce lift and will be tested at different pressure, velocity and density parameter and the result will be compared with the base NACA profile geometry.NACA24012 is a five digit NACA series airfoil extensively used in aviation sector. NACA24012 when used with simple flaps produces high Cl values in comparison to other symmetric and complex control surface airfoils. Wind tunnel testing's and flow visualization on the airfoil depicts variations of velocity, static and dynamic pressures over the surfaces with concerned boundary conditions.

2. Variable Camber Compliant Wing

Hodson et al. done research on VCCW (variable camber compliant wing) developed by US air force research lab Ohio, wind tunnel outcomes were presented for this a full scale wing with an interior acquiescent mechanism to get active camber mechanism was created with scale model replicas were and tested from angle of attack series varying from -20 to +20 degrees at a Reynolds number of 2.4×10^5 and the wing aerodynamic forces were calculated down using upright wind tunnel having a six component interior strain gauge sense of balance and outcomes were tabulated , Few more articles were generated from computer aided (CAD) designs of identical plan form and camber distribution with NACA0010, NACA2410, and NACA8410 aerofoil section. These additional test articles serve as baselines for comparison of the scan-generated wings. It has been shown that the scan-generated test articles with uniform 2% and 8% camber distributions reveal similar aerodynamic characteristics to the baseline wings with standardized NACA 2410 and 8410 airfoil sections, correspondingly. From these outcome we are able to conclude that the VCCW, when command to a specific span wise camber distribution, will exhibit similar aerodynamic performance characteristics to a finite wing that is composed of NACA XX10 series airfoils with the same span wise camber distribution.

2.1. *Variable Camber Compliant Wing – Wind Tunnel Testing*

At subsonic flight velocity camber of airfoil was varied from NACA2410 to NACA8410 achieving 6% change in chord at maximum camber position. With the help of a single actuator mechanism motion of leading and trailing edges are controlled with exact vertical distance both moved in respect of spar. optical measurement systems quantifies change shape of the wing and further analysis over 13 sections inside from airfoil is done by XFLRS software. test results show in between -4degree and 8degree AOA cL increases substantially and surface pressure coefficient is calculated. change in maximum camber is measured by VCCW.

2.2. *Electro Active Polymer Actuators For Variable Camber Mechanism In Propellers*

John et al. did research on an electro dynamic hydrodynamic surfaces which is made out of polymer, the surface is a section a set of propeller blades whose camber is varied by deflecting trailing edge surfaces, The actual idea is to place actuators into the propeller blades flexibility in determining and the capability to grip a force without expend energy (catch state) offer electro dynamic polymers with recompense larger than electromagnetic actuators, which also not have the torque to directly drive the blade deflection. The variable camber predicament does not require fast retort and thus strain rate and power density are not considered. In such cases actuators connecting the motion of ions, such as conducting polymers, with short ion travel distance and small interior resistances being key to obtain swift response. then EAPs are even more preferential as of their low density. The need to hold position next to a force also suggest EAPs, as many feature catch states.

2.3. *Experimental Investigation Of Aerodynamic Characteristics Of NACA 23015 Under Different Angle of attack*

Rasheed et al conducted tests in which various aerodynamic characteristics were examined and analyzed in subsonic wind tunnel. At different angles of attack variation among lift, drag, moment, co-efficient of pressure and co-efficient of lift can be observed. Furthermore experimental and theoretical results state that variation of pressure along the chord of the airfoil at effective angles of 9-15 degree depicts unusual changes in Cp and Cl value. the experimental results were done on the features of incompressible air flow and subsonic aerodynamics at certain Reynolds's number.

2.4. *Continuous Skin Variable Camber Air foil Edge Actuating Mechanism*

Statkus et al describes the unique method of varying the camber of an airfoil section with maintain the continuous skin provides enhance flow and other aerodynamic characteristics. The actuating mechanism helps the bar linkage to provide the horizontal and vertical displacement to the airfoil which in turn improves aerodynamic performance, payload and manoeuvrability. furthermore the mechanism is subjected towards leading and trailing edges with angle of rotation to produce up and down movements. NACA 4 digit series airfoil is tested under subsonic wind tunnel and various aerodynamic parameters are observed. A pivot bar mechanism for varying the leading and trailing edge is used to change the internal structure of the wing profile. The tail pivots at downward position and skin slides to the nose by Rinnet al (2000)

2.5. *An Optimized Wing Camber By Using Form variable Flap Structures*

Monner et al conducted test on fixed wing geometry which is a concerned area of improvement for better efficiency and smooth working. A flexible flap system is introduced which is capable of chord wise and span wise differential variation. The deformable ribs vary over upper and lower skins with minimal gap whilst maintain the smooth contour over the surface. results show that high L/D ratio is achieved including with reduced weight structure. the following mechanism also proven to be efficient in increased cruise range and C_L value.

2.6. *Morphing Winglets For Aircraft Multi Phase Improvement*

This paper mainly deals with morphing of winglet section using MORPHET application. With the help of DSP adaptive materials, structure, actuating mechanisms and design constraints are decided best according to the phases. with the application of MORPHLET application various multiphase mission performance is evaluated after putting it under different weight loadings and design constraints. Test results on non planar wing over initial, final and descent end depicts increased cant angle and wing cant angle. the wing cant angle is not exceeded more than 360 degrees by Ursache et al.

2.7. *Variable Camber Continuous Trailing Edge Flap*

Upender et al. investigated the effect of various VCCTEF(variable camber continuous trailing edge flap) setting on the lift and drag of a generic transport model wing cross section at a particular span wise position (break station). Three flap segment were extended at the rear of the trailing edge, with a range of deflection angles adding together 6 deg. Design cruise situation at 36,000 feet at free stream Mach number of 0.797 and Reynolds number of 30.734×10^6 was replicated for an angle of attack sweep from -3 deg to 10 deg. His team also establish that the stream on these configurations separate further downstream on the suction side. The parabolic arc camber (VCCTEF123) configuration may be extra most advantageous than circular arc camber (VCCTEF222) configuration in requisites of transonic performance because it produce smallest amount strong shock than any other VCCTEF configurations and consequently the best L/D performance at the design C_L=0.51 in cruise.

Examination of outcome from linear theory show an outstanding conformity between the computed and the speculative incremental lift

2.8. *Adaptive Wing Design Using Piezoelectric Actuators*

Santhakrishnan et al. did study on the progress of an adaptive wing design using piezoelectric actuators to differ the suction face camber of a adapted NACA 4415. Three profiles as of a NACA 4415 baseline shape contrary in their upper face camber and maximum thickness have been construct and analyze by XFOIL. Wind tunnel analytic dimensions show to at low Reynolds numbers, the adaptive wing control division by exert either unreceptive flow control due to static face curvature variation or lively flow be in charge of due to dynamic oscillation of the camber. It is experimental from the outcome of experiment and computation that at chord base Reynolds numbers less than 100,000, the stall angle of attack is greater than before in the case of static camber disparity, while the oscillating camber case show capable results in calculating stall. An inverse design base shape optimization regular is currently under expansion to decide ideal airfoil geometry for the formerly determined optimum operating points.

2.9. *Estimation Of Drag Reduction With Camber Deflection Profile In Flight Profile*

Eric et al. in this paper he present the idea of Drag decrease studies at a range of flight circumstances be conduct in categorize en route for inspect the show of dissimilar flap configuration with chosen variable camber deflection profile. swift optimization of the design space is achieve by means of Aerodynamic structural modelling based on a vortex lattice technique attached by transonic tiny commotion with Integral Boundary Layer Solution. The begin cruise optimization outcome illustrate that a parabolic flap deflection profile design with three-cambered-segments achieves the major drag reduction of 8.4% as compare to a clean wing configuration. The design is used to run supplementary optimizations measure performance benefits at different flight situation including 20% fuel end cruise, a transform of 30% design lift coefficient, and a Mach over speed situation. The optimization construction and original outcome make insight that can be used to process the optimization of variable-camber incessant trailing-edge flap configurations with higher-fidelity aerodynamic tools.

2.10. *Fluid-Structure Interaction And Aerodynamic Flow On A Flexible Wing*

Markus et al present loosely coupled Fluid Structure Interaction (FSI) simulation used to estimate the smooth flow to determine the deformation of structure of a flexible wing. NASA provides a universal three dimensional Algorithm to interrupt among different mesh which serves to chart pressure in addition to displacements among the Aerodynamics and Structural code. This technique be useful to develop variable camber compliant wing" VCCW, which is an flexible wing intended for dynamic wing camber adjust with no separate control surface. Outcome was compare with wind tunnel analysis statistics to facilitate integrated digital figure link statistics used for face displacement. Although the Fluid Structure Interaction technique which predict the outcome while compare to the Variable cambered compliant wing experiment statistics, in general detection trend harmonized fine. Advanced Computational Fluid Dynamics plus Finite Element Analysis model be optional to get better calculation outcome. more effort is required on the way to process the reliability inside the interruption among the different mesh designed for all camber designs.

2.11. *Hybrid Laminar Flow Control (HLFC) Technology*

Krishnan et al. The paper explain the hypothetical basis behind the HLFC structure and review the system design and existing issue, significant project, diagnostic study and flight tests which were intentioned to get improved major scientific aspect and difficulty of hybrid laminar flow control (HLFC) technology, for purpose in viable aircraft. At hand mounting apprehension for environmental fortification and the imperative issue to be measured is the fuel consumption. The HLFC technology was found extremely capable and has good potential to improve aircraft fuel efficiency, then with enhanced payload and range capability. The expertise has evolve in many scope over the years, from beginning to end the lessons learned from every development. These improvement have made the technology more and more practicable. The advance of HLFC systems is a complex, multi-disciplinary task, which needs scientific solution from a variety of discipline for appropriate system integration.

2.12. *Variable Camber Impact On Aircraft Mission Planning*

Fabian peter et al did morphing of the wing which benefits to estimate the operations and reliability which ultimately affects drag and fuel consumption. A detailed examination of primary performance and mission analysis is studied. for a fixed airfoil geometry Cl is acute, with VCS system L/D ratio can be maintained right without achieving more altitude. MICADO software provided the conditions the pressure gradient over the airfoil is studied with and without VCS. results depicts that with VCS duration of cruise is increased followed by increased flight time with moderate reduction in fuel consumption by Peter et al.

2.13. *Variable Camber Leading Edge Assembly For An Airfoil*

James B et al Variable camber of an airfoil is achieved through attaching the Krueger panel hinging to forward end of the nose. An actuator is connected which provides motion to the aft suspension links to lower surface of the leading edge at particular cruise position and the forward panel overlaps to upper forward edge and seals the skin providing continuous smooth curvature. at takeoff position it turns into rigid truss type load structure. An accurate cam track is used to vary the camber of an airfoil. this mechanism helps to move the nose section rearward to the upper flexible panel. The whole setup is being made in order to maintain continuous skin over the airfoil. the cam track is driven by gear provides motion to outward rear portion which in turn moves the rear part of the upper skin panel that is connected to the structure. any discontinuity over the airfoil is thus eliminated and flow remains attached. the following mechanism provides restrained angular movement at two spaced locations**.**

2.14. *Analysis Of Hybrid Morphing Wing*

Jodina et al did wind tunnel test and software analysis is done on electro active hybrid wing. Deflection in trailing edge performs the wing morphing. It consists of high frequency vibrating pies actuated trailing edge. SMA is embedded on the surface and the wire is heated with the help of electricity which results in crystallographic change and it generates stress to produce a bending moment to the trailing edge. piezoelectric patches are covered with silicone shell. Moreover camber is varied by shape memory alloys. a detailed study of eddy formation is done when the airfoil is placed near wake turbulence region. results show active variation in AOA and reduction in drag generated when the mechanism is brought into -10 to +10mm deflection positive as well as negative chord wise direction. effective increase in lift up to 27% and 4% only due to T.E vibrations**.**

3. Conclusion

This paper focuses on the camber varying technique implemented by the past researchers carried on fixed wing and variable camber compliant wing, in terms of analysis ,simulation, and experiments which have been performed by researchers for wide range of aerofoil's and cambered wing However varying the lift with VCCW can be studied more thoroughly with different morphing technologies and other camber varying techniques. Many of these problems are discussed in above mentioned article.

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