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Numerical Investigation of Flow Behavior Around Chordwise Morphing NACA 0012

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ABSTRACT: In the present study, numerical simulation of transonic flow around chordwise morphing airfoil has been accessed. Fluid-Structure interaction for analyzing flow field behavior in conjunction with morphing airfoil is used. In this regard, a two-dimensional finite element model is established and the arbitrary Lagrangian-Eulerian formulation (ALE), in the flow field and structure configuration is applied to accommodate the deforming boundaries and due to the good conformation of flow filed and deforming boundaries in this formulation, the distortion of computational grid is diminished after the deformation. The procedure incorporates the one-equation Spalart-Allmaras turbulence model which is a suitable model for aerodynamics. In this study, the preferable Mach number for the transonic regime is 0.7. Chordwise elastic deformability by uniformly varying extended parabolic load on both leading and trailing edges is considered for morphing purposes. The model is validated against conventional rigid airfoil for various angles of attack, and the comparisons show considerable improvement in the aerodynamic performance and prove the efficiency of elastic morphing airfoil. Moreover, the ultimate results indicate that chordwise morphing contributes to the best flight conditions for cruise flight which contains a wide flight endurance. All the simulations are steady-state and are carried out by COMSOL Multiphysics software.

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1- Introduction

Improvement of an airplane's wing efficiency is one of the recent dominant steps toward the reduction of drag force and optimization of airflow and airborne structures interaction, as it has a function similar to bird's wings. In other words, these wings, in contrary with rigid ones which are currently being used, have the flexibility and consistency in various flight conditions.

Due to the discontinuities in the junction points of high lift devices, the passing air flow turns into a turbulent flow in certain local positions, subsequently, due to the generated vortexes and also the corresponding flow separation, the flow stability lessens and as a result, the drag force increases. By elimination of these discontinuities and unification of dynamic systems on wing surface (high lift devices) in which the mechanical actuation process alters into a fully elastic deformation, one can optimize the aerodynamic efficiency of the airplane in various flight conditions. Reduction in drag force, fuel consumption, and noise pollution, are among the noteworthy advantages of elastic wings. The currently designed airplanes are mostly optimized for cruise flight condition which has the maximum endurance during a typical flight and consequently, other flight conditions such as; landing, take off, banking turn, altitude control etc., are not fully optimized. By applying the elastic deformation systems, the optimized cruise flight condition could be extended over the other flight maneuvers, in such a way that the wing smartly senses the present flight condition and morphs into the desired and sufficient shape.

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In this study, chordwise deformation has been investigated. By elastically deforming leading and trailing edges on the wing structure and comparing with rigidly deformed one, optimized efficiency of these airfoils will be proved.

2- Methodology

The compressible steady state Navier-Stocks equations are expressed as the governing equations for the fluid flow part of the Fluid-Solid-Interaction (FSI) problem. First, these equations are written in the typical form, then the ALE forms are derived to rearrange it as a part of FSI problem. The key point in simulating FSI problems is the choice of kinematic description of flow field as to the fact that the boundary deformation and motion be feasible. The arbitrary Lagrangian-Eulerian (ALE) description is the sufficient and required solution for this problem, as it tackles with the all deficiencies of Eulerian and Lagarangian descriptions in computational domain.

$$\nabla \cdot \boldsymbol{U} - \hat{\boldsymbol{u}} \cdot \nabla \cdot \rho = 0 \tag{1}$$

$$\nabla (\boldsymbol{u} \otimes \boldsymbol{U}) - \hat{\boldsymbol{u}}.\nabla.\boldsymbol{U} = \nabla.\boldsymbol{S} + \rho \boldsymbol{g} \tag{2}$$

$$\boldsymbol{u} - \hat{\boldsymbol{u}}) \cdot T = \frac{1}{\rho c_v}\left[\nabla \cdot \left(k \nabla T\right) + S : \nabla \boldsymbol{u}\right] + \frac{1}{c_v}\boldsymbol{g} \tag{3}$$

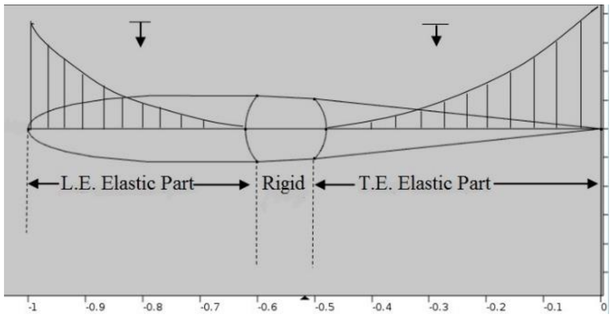

Fig.1. A conceptual design of NACA 0012 airfoil with elastic loading at leading and trailing edges.

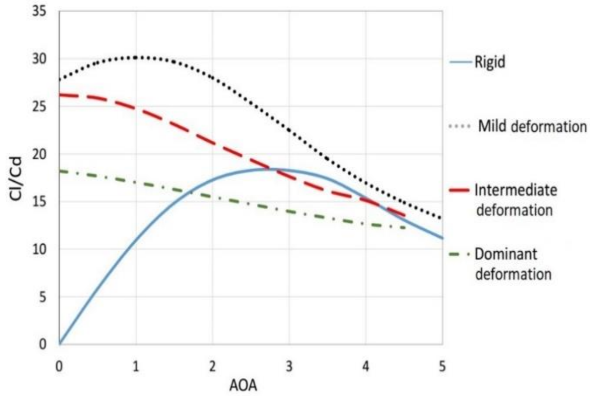

Fig. 2. Lift to drag ratio for different magnitudes of deformation

Eqs. (1), (2), and (3), are the continuity, momentum and energy equations in ALE formulation respectively, where, U=ρu and S represents the Cauchy stress tensor as:

$$\boldsymbol{S} = -p\boldsymbol{I} + \lambda(\nabla.\boldsymbol{u})\boldsymbol{I} + 2\mu\boldsymbol{D} \quad (4)$$

The elastic deformation at leading and trailing edges is simulated by external, extended parabolic loads, varying uniformly along the predefined deformable sections (see e.g. Fig. 1).

The following equations indicate the applied forces at L.E. and T.E.

$$\text{L.E. load} = -\mathbf{F}_{front}\left(\frac{\mathbf{x}-d}{d}\right)^2 load\left(\frac{t}{\mathrm{d}t}\right) \quad (5)$$

$$\text{T.E. load} = -\mathbf{F}_{back}\left(\frac{\mathbf{x}}{l}\right)^2 load\left(\frac{t}{\mathrm{d}t}\right) \quad (6)$$

F_front and F_back are the maximum applied forces at leading and trailing edges respectively.

3- Results and Discussion

The results obtained by numerical simulation are discussed in this section and logically compared with the data for the rigid NACA 0012 airfoil. The simulation is steady state and two- dimensional. The data for rigid NACA0012, obtained from simulation, is validated against the data available in the literature and are compared with the elastic model. Fig. 2 shows the comparison of lift to drag ratio for elastic and rigid airfoils.

4- Conclusion

The aerodynamic performance of elastically deformable airfoils along chordwise direction was examined and the results were compared with the rigid airfoil. This investigation was conducted for three different magnitudes of deformation and also for various angles of attack. The results showed that chordwise elastic deformable airfoil has a desirable efficiency and the aerodynamic performance was improved in comparison to the rigid airfoil. The main advantages of chordwise deformation have been categorized as follow:

1-Generation of additional lift for different maneuvers in cruise flight.

2-Increasing the flight endurance and reducing the fuel consumption by improving aerodynamic efficiency.

3-Delaying the flow separation and restricting the separation zone.

4-Increasing the steadiness of the flow.

5-Reducing the turbulence due to the smooth and seamless deformation.

6-Increasing the safety factor of flaps in various climates.

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